SUSTAINABLE GROWTH AND APPLICATIONS IN RENEWABLE ENERGY SOURCES

Edited by **Majid Nayeripour and Mostafa Kheshti**

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Preface

Worldwide attention to environmental issues combined with the energy crisis force us to reduce greenhouse emissions and increase the usage of renewable energy sources as a solution to providing an efficient environment. This book addresses the current issues of sustainable growth and applications in renewable energy sources. The fifteen chapters of the book have been divided into two sections to organize the information accessible to readers.

The book provides a variety of material, for instance on policies aiming at the promotion of sustainable development and implementation aspects of RES. Authors contributing to the book have tried to prepare the information in an accessible way. We would like to extend our appreciation to all the authors for their cooperation and the attention that they have given to this book.

During this project, it was a pleasure for us to work with InTech – Open Access Publisher. We express our appreciation to all our colleagues in this publication, especially Ms. Ivana Zec, the Publishing Process Manager in charge of this book project.

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Part 1

Sustainable Growth

EU Energy Policies and Sustainable Growth

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1. Introduction

The concentration of greenhouse gases (GHG) in the atmosphere was at 438 parts per million (ppm) of CO_2 equivalent in 2008, that is almost twice the pre-Industrial Revolution level (IEA, 2010). Such an increase is mainly caused by fossil fuel combustion for energy purposes in the power, industry, building and transport sectors (Stern, 2007). In the Reference Scenario, which gives economic and environmental assessments of a world in which the economy continues on its current course without polluting emission reductions policies, fossil fuel use is projected to grow, and the dirtiest fuel, i.e. coal, is expanding its share to face rising energy demand driven by emerging countries such as China and India.

The global response to climate change started with the so called Rio Earth Summit in 1992: governments realized the need to work together for an environmental and sustainable economic development. The Summit was a first move towards an environmental policy at global level, by setting the emission reduction targets for developed countries and establishing a framework of wider reduction for the future from a sustainable development point of view. Its weak point was that the Summit promised a lot at little cost, since it was an agreement without stringent measures (Helm, 2008). The Summit has been followed by several discussions with the purpose of finding optimal shared environmental policy for facing climate change.

Afterwards, the Kyoto Protocol, an international agreement adopted in Kyoto on December 1997, has committed (instead of encouraging) 37 industrialized countries and the European Union (EU) to reduce GHG emissions through national measures. The EU has undoubtedly made a big effort in developing a progressive environmental policy, but many of its own policies are still far from making a difference to climate change. Following the ratification of the Kyoto Protocol in 2002, the EU committed itself to reduce emissions to 8% below 1990 levels by 2008-2012, allowing different national emissions target within the EU accounting for different income level, country size and environmental attitude (Borghesi, 2010).

The current policy action toward green Europe is the so-called 20-20-20 Climate and Energy Package. The EU aims to limit its 2020 greenhouse gas emissions to 20% below 1990 levels and to meet a 20% renewables target of total energy supply by 2020. The Package includes a 20% energy efficiency target and a biofuel target of 10% by 2020 (Hepburn et al., 2006). To meet these targets, governments in EU countries use a large variety of support instruments.

The first part of the chapter is then devoted to a critical review of the main international agreements to reduce climate change and their implementation in the EU environmental policy. The search for a consensus among EU governments is tricky since energy policies advocated by EU members differ. Some of them urge on the implementation of nuclear power, while others advocate the use of renewables instead of nuclear technologies; anyway, all of them are convinced that the economy cannot rely on fossil fuels anymore (Nordhaus, 2006).

The second part of the chapter evaluates the range of strategies implemented in different EU countries to tackle climate change. The primary objective of these strategies is to increase the use of renewable energy in order to enjoy the environmental benefits and for energy security reasons (Held et al., 2006). The analysis reviews the EU climate-change package and the main policy instruments contained in it. We categorize policy instruments through the most frequently used typology, i.e. price-oriented or quantity-oriented (Dinica, 2006). Some of them are claimed to be more market friendly than others, while other schemes are claimed to be more efficient in promoting the development of renewable energy (Meyer, 2003). Currently, there is no general agreement on the effectiveness of each scheme. By analyzing the different schemes that have been used in EU Member States in order to achieve the 20-20-20 targets, the research takes into account the extent of financial support given by each EU member region by considering some exogenous factors, as the availability and distribution of renewable resources, and the institutional context. The strategies planned by governments imply different costs that might be prohibitive if other countries are not making comparable efforts.

Finally, the research highlights the problem of coordination among policy makers that undermines the achievement of the 20-20-20 Climate and Energy Package targets, using a theoretic model of Nordhaus (2009). It is well-known that EU countries should take complementary and coordinated actions to green themselves by implementing their own national plan (Böhringer et al., 2009). Every country would want to spur new activities, new investment, more employment in its own territory, by using an appropriate mix of local taxation and subsidies, in conjunction with other command and control instruments. However, EU countries have the incentive to free-ride, or to impose as few costs as possible on their home economy while enjoying the benefits created at the other countries' cost (Barrett, 1994). So, the research highlight the formidable problems of opportunistic behavior and inefficient outcomes.

2. Energy trends

According to projections of the Reference Scenario (which gives economic and environmental assessments of a world in which the economy continues on its current course without polluting emission reductions policies), energy demand should increase by 1.5% per year between 2007 and 2030 and fossil fuels remain the main sources of energy. They represent three quarters of global energy consumption during the same projection period and the dirtiest fuel, i.e. coal, is expanding its share to face the raising in energy consumption mainly driven by developing countries, such as China and India. Actually, non-OECD countries are the main drivers in the increase of energy demand as a result of their economic and population growth.
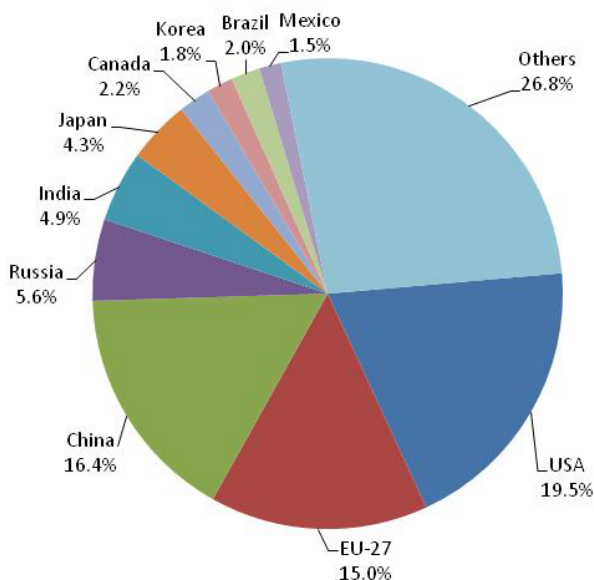
Fig. 1. Gross Inland Consumption in 2007. Source: Eurostat (2009).

Renewable energies, including hydroelectric, geothermal, biomass, solar energy and wind energy, grow at a fast pace relative to electricity production, but their share in energy consumption is still low.

Country	Solids	Oil	Gas	Nuclear	Hydro	Biomass	Other
United States	23.7	38.9	23.0	9.3	0.9	3.5	0.7
EU-27 **	18.3	36.4	23,9	13.4	1.5	5.4	1.1
Japan	22.3	44.8	16.2	13.4	1.2	1.4	0.7
Russia	15.2	19.7	54.4	6.3	2.3	1.0	1.2
China *	65.6	18.2	3.1	0.8	2.1	9.9	0.2
India	40.8	23.7	5.6	0.7	1.8	27.2	0.3
Korea	25.3	42.5	14.0	16.8	0.1	1.2	0.0
Brazil	5.8	39.3	7.5	1.4	13.7	30.7	1.7
Canada	11.2	35.1	29.3	9.0	11.8	4.3	- 0.7
Mexico	4.9	56.9	27.4	1.5	1.3	4.5	3.5
Others	13.5	39.6	25.7	1.6	2.4	16.5	0.8
World	**26.5**	**34.0**	**20.9**	**5.9**	**2.2**	**9.8**	**0.7**

Table 1. Gross income consumption by country in 2007. Source: Eurostat (2009)

Almost 18% of total electricity in 2007 was generated by renewable energy and, according to the Reference Scenario, it is supposed to rise to 22% in 2030. Actually energy production from renewables is more expensive than fossil fuel based technologies, and the reasons for

such disadvantages are several. Methods used by economic engineering to evaluate cost-accounting of energy technology projects are outdated; as a consequence, renewable technology projects seems more expensive (Awerback, 2003). Moreover, it has to be taken into account that production costs of energy from fossil fuels do not internalize both the environmental and human health externalities. A higher penetration of renewable resources in the energy mix would lead to both environmental and economic benefits, as a reduction of polluting emissions and a mitigation of energy import dependency.

The concentration of greenhouse gases (GHG) in the atmosphere was at 438 parts per million (ppm) of CO_2 equivalent in 2008, that is almost twice the pre-Industrial Revolution level (IEA, 2009). Mostly of the world emissions originates from China and United States, which together produce about 12.1 Gt CO2 that is 41% of world CO2 emissions. The relation between GHG emissions and economic growth may be well understood through the Kaya identity, which expresses CO_2 emissions of the energy sector in terms of GDP, energy intensity of output, and carbon intensity of energy consumption (Stern, 2007):

$$\text{Carbon Dioxide Emissions} = \text{population} \cdot \text{per capita GDP} \cdot \text{energy intensity} \cdot \text{carbon intensity}$$

From this identity it is clear that the increase in world GDP tends to increase global emissions, unless increase in income stimulates a reduction in carbon intensity or total energy (Nakicenovic et al., 2006).

Country	CO2 emissions (Gt CO2)	GDP per capita	Carbon intensity	Energy intensity	Population
USA	1.4	1.8	0.0	-1.5	1.2
EU	0.2	1.8	-0.7	-1.2	0.3
UK	- 0.4	2.4	-1.0	-2.3	0.2
Japan	0.7	0.7	-0.5	0.2	0.3
China	3.7	8.5	1.1	-6.4	0.9
India	4.3	3.9	-0.3	-2.5	1.7
World	**1.4**	**1.9**	**-0.1**	**-1.7**	**1.4**

Table 2. Rate of growth of CO_2 emissions **(%)**. Source: Stern (2007)

The contribution to global warming by countries is controversial. The United States represent the second largest CO_2 emitter. On the one hand, the high share of CO_2 emissions is related to the share of GDP that is the largest in the world. On the other hand, the United States generates around 20% of global CO_2 emissions while the population is only 5% of the total world population. China produces 22% of world polluting emissions but it accounts for 20% of the population of the world (Kawase et al., 2006).

The sectors that contribute more to CO_2 emissions are transport and electricity and heat generation, that together account for two-thirds of global emissions in 2008 (IEA, 2010). The former represents 22% of CO_2 emissions in 2008 worldwide, and the World Energy Outlook 2009 projections reveal that the share is estimated to grow to 45% by 2030. Actually, the level of passengers travel is growing according to population growth, and only the EU is encouraging fuel economy (as a response to high fuel price as well) through voluntary

agreement with manufacturers. Electricity and heat generation constitute the largest polluting sectors in 2008, by making a 41% contribution to the world CO_2 emissions in 2008, relying on carbon fuel, especially in developing countries such as China and India.

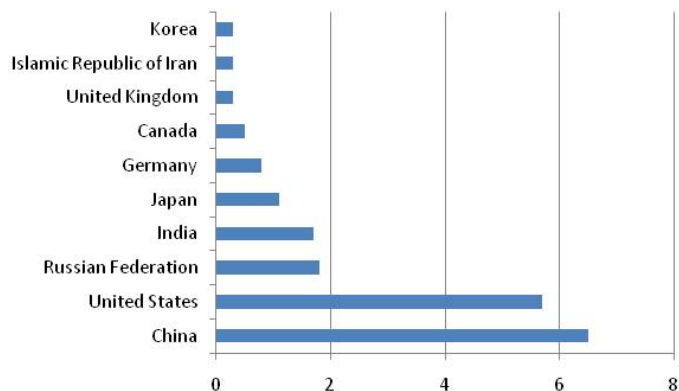Fig. 2. Top 10 emitting countries in 2008 (Gt CO_2). Source: IEA, 2010.
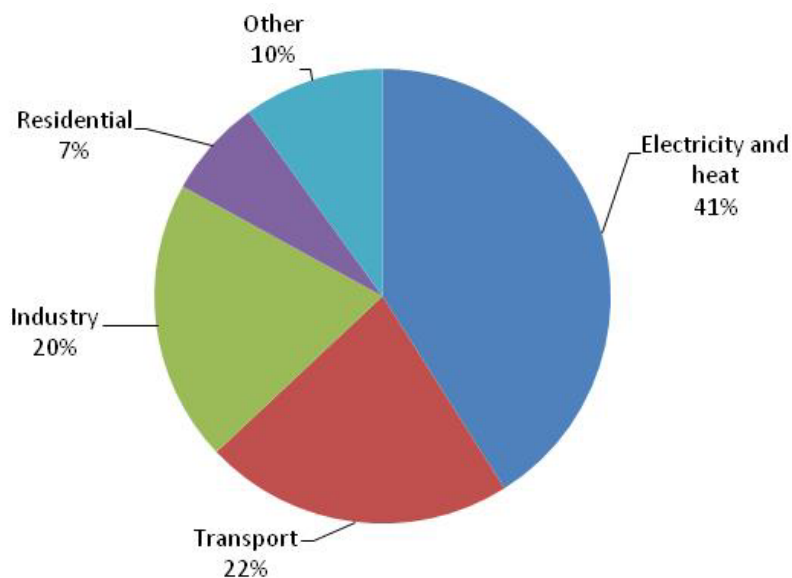

Fig. 3. World CO_2 emissions by sector in 2008. Source: IEA, 2010.

We deem imperative that a global response to face climate change is needed at the European level. The EU energy portfolio relies strongly on fossil fuels, and it has important consequences both in terms of "importing" CO_2 emissions and for energy security reasons.

Origin	2000	2001	2002	2003	2004	2005	2006	2007	Share 2007(%)
Russia	112.4	136.8	154.7	170.8	188.9	188.0	189.6	185.3	33.9
Norway	115.9	108.1	103.1	106.4	108.6	97.5	89.1	84.3	15.5
Libya	45.5	43.8	39.1	45.9	49.9	50.6	53.1	55.5	10.2
Saudi Arabia	65.1	57.5	53.1	61.5	64.5	60.7	51.1	39.4	7.2
Other, Middle East	54.7	48.2	43.2	27.8	28.5	29.9	32.5	34.4	6.3
Iran	33.5	31.4	25.9	34.7	35.9	35.3	36.3	34.1	6.3
Kazahkhstan	9.9	9.1	13.4	15.9	22.2	26.4	26.8	18.3	3.4
Nigeria	22.4	25.7	18.4	23.2	14.9	18.6	20.2	15.5	2.8
Other Origin	58.2	62.3	64.2	56.6	56.6	66.2	65.9	78.1	14.4
Total Imports	519.8	522.9	515.3	542.9	570.2	573.4	564.7	545.1	100

Table 3. Crude oil imports in the EU27 (in Mt) in 2007. Source: Eurostat (2009)

Origin	2000	2001	2002	2003	2004	2005	2006	2007	Share 2007(%)
Russia	4539709	4421515	4554744	4895252	4951044	4952879	4937711	4685365	40.8
Norway	1985231	2136379	2601569	2699473	2801723	2671779	2844237	3061751	16.7
Algeria	2203075	1957181	2132477	2158803	2042137	2256826	2132236	1943976	16.9
Nigeria	172020	216120	217882	335929	410260	436319	563905	588317	5.1
Libya	33442	33216	25536	30390	47809	209499	321150	383615	3.3
Qatar	12443	27463	87952	80414	160170	195713	232721	275496	2.4
Egypt						202419	327394	221305	1.9
Trinidad and Tobago	36334	24498	19120	1365		29673	163233	104917	0.9
Other Origin	112810	199256	125425	100023	313245	409387	227147	213995	12.0
Total Imports	9095064	9015628	9764705	10301649	10726388	11364494	11749734	11478737	100

Table 4. Gas imports in the EU27 (in TJ) in 2007. Source: Eurostat (2009)

	2000	2001	2002	2003	2004	2005	2006	2007	Share 2007 (%)
Total EU-27	151575	173041	171629	180360	196062	197043	213809	214358	100
Russia	14976	20875	23033	26545	40382	48304	55544	56117	26.2
South Africa	40177	49273	53961	56932	54190	51698	53080	46121	21.5
Australia	28600	29450	29337	31004	30838	27013	27147	29069	13.6
Colombia	23132	22633	21398	22908	24224	24147	26068	29018	13.5
United States	20447	20119	14082	12619	15416	15673	17370	20833	9.7
Indonesia	9097	10254	11540	13004	13980	14704	21092	17594	8.2
Other	15146	20437	18278	17348	17032	15504	13508	15606	7.3

Table 5. Coal imports in the EU27 (in kT) in 2007. Sources: Eurostat (2009)

3. Policy

The global response to climate change started with the so called Rio Earth Summit in 1992: governments realized the need to work together for an environmental and sustainable economic development. The Summit was a first move towards an environmental policy at global level, by setting emission reduction targets for developed countries and establishing a framework of wider reduction for the future from a sustainable development point of view. Its weak point was that the Summit promised a lot at little costs, since it was an agreement without stringent measures (Helm, 2008). The Summit has been followed by several discussions with the purpose of finding optimal shared environmental policy for facing climate change.

Afterwards, the Kyoto Protocol, an international agreement adopted in Kyoto on December 1997, has committed (instead of encouraging) 37 industrialized countries and the European Union (EU) to reduce a basket of six greenhouse gases. The Kyoto Protocol entered into force in February by committing contracting parties as a group to achieve an overall reduction in polluting emissions of 5% in the period 2008-12 with respect to 1990 levels(IEA, 2010). The Protocol has helped sensitive public awareness of problems related to climate change. Despite the Protocol has detailed commitment for each country member in terms of GHG reductions, it is limited in its potential to climate change mitigation since not all major emitters as United States were included in reduction commitments. In March 2001, the United States explicitly declared their non-participation in the Kyoto Protocol, because of the too high potential compliance costs and the domestic voters' low willingness to pay (Böhringer and Vogt, 2004).

The European Community has taken part in the Kyoto Protocol through positive measures. Between 2008 and 2012, countries that were already EU members, have to cut 8% off GHG emissions. Countries that have joined EU later undertake to cut emissions for the same amount, apart from Poland and Hungary (6%). Kyoto Protocol suggests tools of action:

- strengthening of national policies to reduce emissions, as improvement of energy efficiency, promotion of sustainable forms of agriculture, development of renewable energies etc.,
- cooperation with other contracting parties, as exchange of experience and information, coordination of national policies through the right to emit.

During the period 1990-2007 the European Commission has recorded emission reductions as follows:

- 7% in the energy sector;
- 11% in the industrial process;
- 11% in agriculture (reduced use of mineral fertilizers);
- 39% in the waste sector.

The EU results should be interpreted not only in the light of Kyoto and all following agreements. The emission reductions are likely to be attributed to two factors as well: the global economic and financial crisis that has reduced industrial production, and the new member States entered in the European Union that have decreased on average the EU level of emissions because of their less productive economies.

3.1 The European climate and energy package

Actually, the European environmental and energy policy is represented by the so-called "20-20-20 Climate and Energy Package", through which the EU is showing to be ready to assume the global leadership to face climate change, tackle the challenges of energy security, making Europe a model of sustainable development for the 21st Century. The EU aims to achieve by 2020:

- a commitment to reduce by at least 20% greenhouse gas emissions compared to 1990 levels by 2020, and the goal of reducing emissions by 30% by 2020 if other developed countries make comparable efforts;
- a binding target for the EU of 20% of energy from renewable sources by 2020, including a target for biofuels.

	1990	2008	% change 90-08	Kyoto Target
Kyoto Parties with targets	**8 858.3**	**7 980.1**	**-9.2%**	**-4.7%**
North America	432.3	550.9	27.4%	
Canada	432.3	550.9	27.4%	-6%
Europe	3 153.6	3 222.9	2.2%	
Austria	56.5	69.3	22.7%	-13%
Belgium	107.9	111.0	2.8%	-7.5%
Denmark	50.4	48.4	-4.0%	-21%
Finland	54.4	56.6	4.0%	0%
France	352.3	368.2	4.5%	0%
Germany	950.4	803.9	-15.4%	-21%
Greece	70.1	93.4	33.2%	+25%
Iceland	1.9	2.2	17.0%	+10%
Ireland	29.8	43.8	46.7%	+13%
Italy	397.4	430.1	8.2%	-6.5%
Luxembourg	10.5	10.4	-0.6%	-28%
Netherlands	155.8	177.9	14.1%	-6%
Norway	28.3	37.6	33.0%	+1%
Portugal	39.3	52.4	33.5%	+27%
Spain	205.8	317.6	54.3%	+15%
Sweden	52.8	45.9	-13.0%	+4%
Switzerland	40.7	43.7	7.4%	-8%
United Kingdom	549.3	510.6	-7.0%	-12.5%
Pacific	1 346.6	1 582.0	17.5%	
Australia	260.1	397.5	52.9%	+8%
Japan	1 064.4	1 151.1	8.2%	-6%
New Zealand	22.0	33.3	51.5%	0%
Economic in Transition	3 852.9	2 624.3	-31.9%	-6%
Other Countries (non-participating)	**11 566.6**	**20 368.2**	**76.1%**	
United States	4 868.7	5 595.9	14.9%	-7%
China	2 244.4	6 550.5	191.9%	
Latin America	869.5	1 476.5	69.8%	none
Africa	545.6	889.9	63.1%	none
Middle East	592.5	1 492.3	151.8%	none
Non-OECD Europe	106.1	92.2	-13.1%	none
Asia (excl. China)	1 510.1	3 521.1	133.4%	none
WORLD	**20 964.8**	**29 381.4**	**40.1%**	

Table 6. World CO_2 emissions from fuel combustion **(in Mt)** and Kyoto targets. Source: IEA, 2010

The 20-20-20 Package, introduced in 2008 through the Communication (COM(2008)30), answers to the call made by the European Parliament about real measures for the transition toward a sustainable development. The Package includes a number of important policy proposals closely interlinked:

- a revised directive on the EU Emission Trading System (EU ETS);
- a proposal on the allocation of efforts by member states in order to reduce GHG emissions in sectors not covered by the EU ETS (as transport, building, services, small industrial plants, agriculture and food sectors);
- a directive on the promotion of renewable energy to achieve the goals of GHG emission reductions.

The EU ETS scheme has been a pioneering instrument prior to the 20-20-20 Climate and Energy Package. It is a market instrument that has been already implanted in the US quite successfully, and it has been introduced in Europe in 2003 in order to find market solutions to encourage firms cutting GHG emissions. The Cap and Trade system sets a maximum amount of emissions per period (2005-07 and 2008-12) per country. Then, each country establishes a national emission scheme and it allocates to firms the emission allowances which could be traded between the companies covered by the scheme. Once the emission permits are allocated, firms can trade them within the EU according to their criteria of economic efficiency. In the first and second ETS trading periods (2005-2012), mostly of the EU permits are allocated for free.

The importance of the EU ETS scheme is that is has been able to create a market and an artificial price for a public good as clean air. Thus, firms covered by the EU ETS have to face costs when emitting CO_2 emissions: on the one hand, a firm that needs for its activity more permits than those at its disposal faces the cost of purchasing them. On the other hand, opportunity costs arise because permits could be sold in case of non-production. The 20-20-20 Climate and Energy Package has modified the Emission Trading Scheme through the Directive 2009/29/EC and it will enter into force from 2013 to 2020, in order to overcome the application problems that rose during the first few years of its application. The first problem is related to the EU allocation mechanisms that have been used so far. Emission permits have been allocated for free, the allocation could be done on the basis of historic emissions, that is grandfathering. This mechanism may create vicious circle since it does not spur adoption of new technologies with a low environmental impact. Moreover, it favors large firms that at the first stage receive many permits to preserve their activity level over the small firms.

Another problem is related to the inconsistencies between the emission permits and the National Allocation Plan: governments have created too many emission permits to protect the welfare of the firms operating in the country who wanted to receive as more permits as possible.

Finally, the large and persistent fluctuations of market price have created havoc in the market and uncertainty on the goodness of the environmental policy.

In this direction, a research carried out by Hesmondhalgh et al. (2009) shows how different factors may influence CO2 prices, as it is shown in the following table 7.

The main elements of the reformed Emission trading Scheme are:

- a new emission cap set at 20% below with respect to the 2005 levels by 2020;
- the use of credits from the Clean Development Mechanisms and Joint Implementation is limited to 50% of the overall EU emission reductions in the period 2008-2020;
- inclusion of new sector as aviation and aluminium sector;

Factor	Effect on CO_2 prices
Higher than expected economic growth	*Upward* - increased demand for allowances
Coal prices fall relative to gas prices	*Upward* - increased demand for allowances
International agreement on abatement post-2012	*Upward* — EU will tighten cap on emissions
Failure to meet renewables and/or energy efficiency targets	*Upward* — increased demand for allowances
Overall fuel prices	*Uncertain* — lower prices may increase energy demand but will mitigate effect of fuel price differentials and vice versa for higher prices
Economic downturn	*Downward* — reduced demand for allowances
Coal prices rise relative to gas prices	*Downward* — reduced demand for allowances

Table 7. Potential influences on CO_2 prices. Source: Hesmondhalgh et al., (2009)

- firms operating in the electricity sector are obliged to acquire 88% of emissions allocated to each installation through the auction mechanism; 10% of permits is redistributed from countries with higher per capita income to the one with lower per capita income and the remaining 2% is given to member States that successfully reached the 20% GHG reduction target in 2005 (i.e. the East European Countries).

The adoption of the auction mechanism in the EU ETS means a better distributional effect compared to grandfathering, because government entries generated by auctioning may be used both to reduce distortionary taxes and to promote research and development (R&D) activities in clean technologies.

The Directive on renewable energies to reach the target of 20% on energy consumption by 2020 shares the burden between Member States. In particular, 50% of this effort has to be shared equally between Member States, while the other 50% is modulated according to GDP per capita. Moreover, the objectives are modified to take into account a proportion of the efforts already made by Member States which have increased the share of renewable energy fuels in recent years.

The promotion in the European Union of electricity production based on renewable energy sources takes place in an energy market that is more and more competitive, since 1996 when the Council of Ministers reached an agreement on the Directive specifying rules for electricity liberalization in EU.
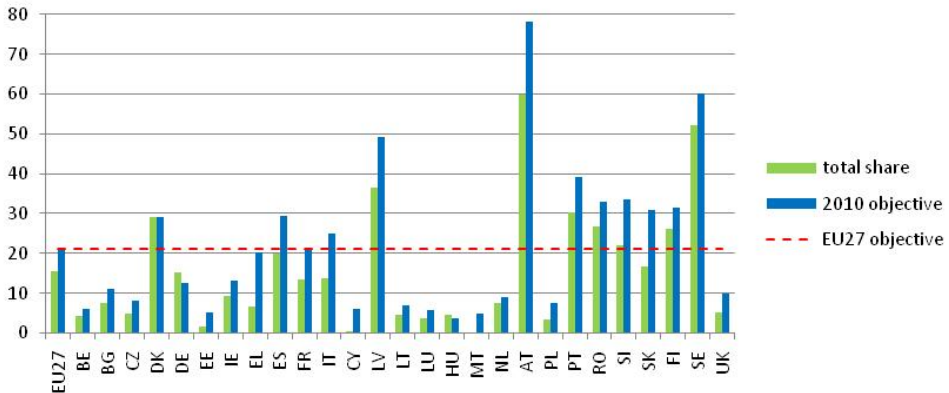
Fig. 4. Share of electricity from renewable energy sources in total electricity consumption (%) – EU27 in 2007. Source: Eurostat (2009)

On the basis of the experience from electricity liberalization around the world, the goal of the European Union is to achieve higher efficiency and lower consumption prices by introducing conditions of intensified commercial competition, but it is quite hard for firms that produce energy from renewable resources to compete within the energy industry that produce energy mainly from fossil fuel.

Governments in EU countries use a large variety of instruments to stimulate the adoption of renewable energies; there are different schemes implemented by the European Union in order to use renewable energies and make them competitive on the energy market (Espey, 2001). The fundamental distinction that can be made among the European support mechanisms is between direct and indirect policy instruments. Basically, direct instruments stimulate the installation of energy from renewable resources immediately, while indirect policy measures focus on improving long-term framework conditions. There exist also voluntary approaches; this type of strategy is based on the consumers' willingness to pay premium rates for renewable energy, like donation projects and share-holder programs.

The important classification criteria are whether policy instruments are price-oriented or quantity-oriented.

With the regulatory price-driven strategies, financial support is given by investment subsidies, soft loans or tax credits. Economic support is also given as a fixed regulated feed-in tariff (FIT) or a fixed premium that governments or utilities are legally obliged to pay for renewable energy produced by eligible firms. Among the price-oriented policy, the most used within the European members is the Feed-in Tariff. The Feed-in Tariff is a price-driven incentive in which the supplier or grid operators are obliged to buy electricity produced from renewable sources at a higher price compared to the price they pay for energy from fossil fuel. The criticisms made to the feed-in tariff scheme underline that a system of fixed price level is not compatible with a free market. Moreover, these favorable tariffs generally do not decrease with the improvements of the efficiency of the technologies that produce green energy (Fouquet and Johannson, 2008). A particular kind of feed-in tariff model used in Spain consist in a fixed premium, in addition to the market price for electricity, given to the producers relying on renewable energy sources. Also in this case, premiums should be adjusted in accordance with the performance of different technologies.

With regard to the regulatory quantity-driven strategies, the desired level of energy generated from renewable resources or market penetration is defined by governments. The most important are tender system and tradable certificate system. In the tender system, calls for tender for defined amounts of capacity are made at regular interval, and the contract is given to the provider that offer the lowest price. The winners of tenders are getting a fixed price per kWh for the period of the contract and the contract offers winner several favorable investment conditions; this system is in a sense quite close to the feed-in tariff model. In the tradable certificate system, firms that produce energy are obliged to supply or purchase a certain percentage of electricity from renewable resources. Then, at the date of settlement, they have to submit the required number of certificates to demonstrate compliance. The firms involved in the tradable certificate system can obtain certificate from their own renewable electricity generation; they may as well purchase renewable electricity and associated certificates from another generator, or they can purchase certificates that have been traded independently of the power itself.

		Direct		Indirect
		Price-driven	Quantity-driven	
Regulatory	Investment focussed	- Investment incentives	Tendering system	Environmental taxes
		- Tax incentives		
	Generation based	- Feed-in tariffs	Tendering system and Quota obligation based on TGCs	
		-Rate-based incentives		
Voluntary	Investment focussed	- Shareholder programmes		Voluntary agreements
		- Contribution programmes		
	Generation based	- Green tariffs		

Table 8. Classification of promotion strategies. Source: Held et al., 2006.

The economic incentives for renewable resources differ among the EU members. In Germany, the main electricity support scheme is represented by a price-driven incentive, the feed-in tariff. The main features of the German support mechanism are stated in the Renewable Energy Source Act of 2000. The Act establishes that the feed-in tariffs are not dependent on the market price of energy but are defined in the law and that feed-in tariffs are different for wind, biomass, photovoltaic etc. Moreover, the feed-in tariffs are decreased over the years in order to take into account the technological learning curves (Petrakis et al., 1997).

The United Kingdom was the first European country to pursue liberalization in the electricity market by the end of 1998. In UK, energy from renewable resources is supported by quantitative-driven strategies. Over the last decades, the scheme adopted by UK was the tender system, but, since 1999, the system in use is a quota obligation system with Tradable Green Certificates. The obligation (based in tradable green certificate) target increases during years, and electricity companies that do not comply with the obligation have to pay-out penalties.

In Denmark the support schemes are mainly related to the wind power sector. To implement renewable resources, the strategy adopted is price-driven, that is a premium feed-in tariff for on-shore wind, and fixed feed-in tariffs for the other renewable resources.

In France, the strategy adopted is mainly price-oriented; the electricity support schemes are feed-in tariffs plus tenders for large projects.

Italy has not a significant experience in producing energy from renewable resources with the exception of large hydro. Several factors obstruct the development of renewables in Italy, as administrative constraints and high connection costs. During the 1990s, the energy sector in Italy was entirely restructured in order to introduce competition, as set by the EU Directive 96/02/EC (Lorenzoni, 2003). The promotion of electricity produced from renewables has taken place through support schemes as the quota obligation system and feed-in tariff. Concerning wind energy, in 2002 the Italian government abandoned the feed-in-tariff, introducing the quota obligation system with tradable green certificates. Under this certificate system, electricity producers and importers are obliged to source an increasing proportion of their energy from renewable resources. Green certificates are used to fulfill this obligation. Italy has adopted a ministerial measure that balances supply and demand in order to tame speculative fluctuations on the value of green certificates.

The recent literature argues that EU ETS mechanism and the promotion of renewable energies may lead to different results (Carraro et al., 2006). While the EU ETS could be interpreted in the light of the "polluter pays principle", which requires the cost of pollution to be borne by those who cause it, the implementation of renewable energies aims at eliminating GHG emissions (Borghesi, 2010). Keeping constant the supply of emission permits, the implementation of renewables may lead to a decrease in emission permits' demand and thus their price without generating a significant GHG emissions reduction. Assuming that to be true, the two instruments should be substitutes instead of complements, unless government reduce the supply of permits on the long run.

Government involvement is essential to spur use of renewable energies. The EU energy consumption is still heavily based on fossil fuels, as it is shown in figure 5.
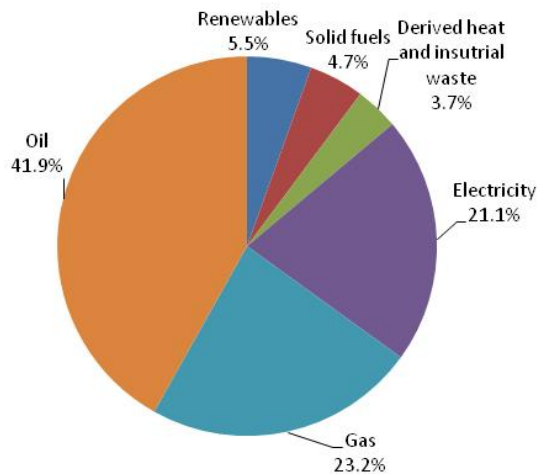

Fig. 5. Final energy consumption by fuel in 2007. Source: Eurostat, 2009

The main advantage of renewable sources with respect to fossil fuels is that they contribute to mitigate climate change. The liberalization of the electricity market may appear as a partial response to climate change since it allows consumers to purchase cleaner electricity directly from suppliers. Anyway, most consumers are not willing to pay higher prices for green electricity since they are burdened with higher prices to preserve a public good (i.e. clean air) which everyone benefits from. Consequently, the proportion of renewable sources in the energy portfolio is low, unless there are governments subsidies (Carraro and Siniscalco, 2003).

Actually, subsidies are needed because fossil fuel prices do not internalize environmental damages to society. In fact, polluting emissions create a damage to society; without a price system, firms face a suboptimal opportunity cost for pollution and this leads to a wrong amount of pollution (Grimaud and Rougé, 2008). Since the right level of pollution will not emerge in a spontaneous way, government must increase pollution cost by raising a tax, in order to reduce pollution generation. If the tax is set at the optimal level, it is called a Pigouvian tax. The optimal amount of pollution is the amount that minimizes total costs from producing one more unit of pollution and total damages from pollution. Thus, the condition that marginal cost (or marginal saving) equals to marginal damage leads to the generation of the right amount of emissions. This is the main idea of the Pigouvian tax: "A Pigouvian fee is a fee paid by the polluter per unit of pollution exactly equal to the aggregate marginal damage caused by the pollution when evaluated at the efficient level of pollution. The fee is generally paid to the government" (Kolstad, 2000). Note that the Pigouvian tax is also equal to the marginal cost from pollution generation at the optimal level of pollution. The difficulty for the government to levy a Pigouvian fee is that there are reasons why it is not feasible. First of all, it is not easy to quantify marginal damage. The number of activities and the number of people affected by pollution are so great that it is quite hard to came up with monetary estimation of damage from pollution. Moreover, the optimal tax level on polluting emissions is not equal to the marginal net damage that the polluting activity generates initially, but to the damage it would cause if the level of the activity had been adjusted to its optimal level (Baumol and Oates, 1971). If we are not at the optimum, the Pigouvian tax will be neither the marginal cost of pollution nor the marginal damage from pollution.

Basically we can say that in a perfect environment, like an economy in which there is perfect information and no constraints on government tax policy, the Pigouvian tax is only necessary to achieve efficiency. If there are other distortions in the economy or limitation for the social planner, then other taxes and subsidies are needed to achieve efficiency (Sandmo, 1976).

Incentive systems are needed to stimulate technical change so that renewable energies lower future production costs. The reasons often put forward are the learning by doing effects from the production of energy from renewable resources on the cost of future production. The main idea is that a critical mass of production has to be reached first, and then costs will be reduced thanks to research and development activities (Fundenberg and Tirole, 1983).

The reasons related to the implementation of renewable energy does not lie only in the mitigation of climate change. There are also political reasons related to energy security issue. Nowadays, energy security does not mean anymore protecting existing energy supplies. The political instability of the Organization of the Petroleum Exporting Countries (OPEC) countries has a strong impact on the global energy markets by leading to supply shortage in importing countries, as the recent conflict in Libya has shown.

The implication of energy policy measures are thoughtful: economic efficiency and political interests may conflict in climate change policies, especially when there are costs imposed in the future (Helm, 2008).

3.2 Coordination between the EU member states

Within the bounds of the 20-20-20 Climate and Energy Package, each Member State should work to support competition in energy markets and harmonize shared rules at European level. From the Package it is clear that Member States could take different mechanisms to reduce GHG emissions and implement renewable energies in the portfolio energy mix. Most countries have chosen the feed-in tariff scheme, while the minority has implemented green certificates. Assessment that results both on the effectiveness and costs of different mechanisms are quite controversial (Dinica, 2006). The availability and quality of renewable energies differ among countries: two countries may offer the same support scheme but they face heterogeneous quality of the energy resource. It translates in different production costs incurred by renewable energies that lead to misleading evaluations of the support instruments. Moreover, support mechanisms are implemented in different economic context which can then bring dissimilar results.

During the last three years the estimated costs to reach the 20/20/20 target have been reduced: in 2007, before the economic and financial crisis started, costs to reach the Climate and Energy Package goals were estimated at around 70 billion euro; nowadays, by taking into account the economic recession, costs come to 48 billion euro (i.e. 0.32% of EU GDP in 2020). The lower costs are due to several factors, including the reduction of world energy consumption due to economic and financial crisis and the rising in oil prices.

In the future, forecast costs of climate change will probably change upward according to the economic recovery, which should also serve as a stimulus to the global energy investment, essential to develop technologies with low environmental impact and increase energy efficiency.

The implementation of less high carbon technologies, such as wind and solar energies furthers the time horizon of the target to 2020. The costs related to the 20-20-20 Climate and Energy Package have to be mainly supported by customers and taxpayers, and such costs are higher if not all Member States make comparable efforts (Böhringer et al. 2009). There exists the incentive to free-ride by EU regions, or to impose as few costs as possible on their home economy while enjoying the benefits created at the other countries' cost, as demonstrated by a fair chunk of literature (Helm, 2008; Kemfert, 2003; Haas et al., 2004).

An interesting research made by Nordhaus (2009) analyzes the impact of non participation on the costs of slowing global warming. The Kyoto Protocol assigns different commitments to developed countries and developing countries. The 20-20-20 Climate and Energy Package involves coordination among all Member States; the implication for policy makers if not all countries participate to the Package are profound in term of costs. Nordhaus assesses the economic impact that arise when some countries do not participate in the agreement to mitigate climate change through a functional form for the cost function that allows to estimate the costs of nonparticipation.

It is quite straightforward that limiting participation produce inefficiencies by rising the costs for the participating countries. His research allows to calculate the cost penalty from nonparticipation (that is equal to the inverse of the square of the participation rate). Intuitively, if many countries do not participate in a treaty, the cost penalty is high, because

the emission reduction target hardly could be achieved. As Nordhaus says: "..there are low-hanging fruits all around the world, but a regimen that limits participation to the high-income countries passes up the low-hanging fruit in the developing world".

We think that European Member States must then take coordinated actions to reach the 20-20-20 goals by implementing national policies at national level.

4. Conclusion

The European Union (EU) has undoubtedly made a big effort in developing a progressive environmental policy, but many of its own policies are still far from making a difference to climate change. The policy into action to "green" Europe is the so-called 20-20-20 climate and energy package. The 20-20-20 Package, introduced in 2008 through the Communication (COM(2008)30), answers to the call made by the European Parliament about real measures for the transition toward a sustainable development. The Package includes a number of important policy proposals closely interlinked, that are: a revised directive on the EU Emission Trading System (EU ETS); a proposal on the allocation of efforts by member states in order to reduce GHG emissions in sectors not covered by the EU ETS (as transport, building, services, small industrial plants, agriculture and food sectors); a directive on the promotion of renewable energy to achieve the goals of GHG emission reductions.

So far, a large strand of literature on climate change states that we need several economic policy instruments to correct for existing types of market failures, for instance, an environmental tax on the carbon emissions and a research subsidy for research and development (R&D) spillovers in the renewable energy sector (Cremer and Gahvari, 2002). Policy instruments implemented to these aims are generally classified as price-oriented or quantity-oriented. Some of them are claimed to be more market friendly than others, while other schemes are claimed to be more efficient in promoting the development of renewable energy (Meyer, 2003). Currently, there is no general agreement on the effectiveness of each scheme. Evidently, every region would want to spur new activities, new investment, more employment in its own territory, by using an appropriate mix of local taxation and subsidies, in conjunction with other command and control instruments. However, EU regions have the incentive to free-ride, or to impose as few costs as possible on their home economy while enjoying the benefits created at the other countries' cost. So, there are formidable problems of opportunistic behavior and inefficient outcomes.

To conclude, the 20-20-20 Climate and Energy Package requires simultaneous and coordinated action. Both politically and institutionally the EU Member States are quite heterogeneous. Unless cooperation is sustained by institutions which can punish free-riding, every region will earn even higher profits by free-riding on the virtuous behavior of the remaining cooperators.

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Sustained Renewability: Approached by Systems Theory and Human Ecology

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1. Introduction

With the growth of the world population and the ever-new technologies emerging from R&D – both creating ever higher needs and expectations – also the energy amount to be acquired, stored, transformed, and finally used is exponentially growing and thus believed to be always at the limit. Actually this capability to use energy, has since the origin of our universe been the central drive of nature: first in its physical evolution, then in the evolution of biological life and finally in the emergence of human societies and cultures. In our modern industrialized life from primary food to industrial good production, via transport and information processing, to every form of cultural activity, everything is depending on this agent allowing the change of the physical state of matter or organisms. This is underlined by the fact that mass and energy are two sides of the same medal as shown by $E=mc^2$ (Einstein, 1905) and always conserved (Noether, 1918a, 1918b). Without energy no work, no process, no change, and no time would exist and consequently the thirst for energy, surpasses the currently accessible resources by far. Interestingly, there is only one other basic resource, which might be equally important as matter and energy: information – the way of how energy is used for change. Also the information amount to be stored and processed is growing exponentially and believed to be always at the limit. Without doubt information technologies have become the key to success in nearly all sectors of modern live: R&D is meanwhile mostly based on the storage and analysis of huge data amounts. In health care, diagnosis and treatment rely on imaging facilities, their sophisticated analysis and treatment planning. In logistics, the shipment of goods, water, electricity and fuels is driven by distribution management systems. The financial and insurance sectors are unthinkable without modelling. Finally, the IT sector itself is inevitably carried by the creation and manipulation of data streams. Thus, also here the demands outweigh the useable resources and especially the public sector struggles to increase their capabilities.

Limits showing e.g. syntropic/entropic materialistic, energetic or other barriers as those of the energy or IT sectors, are well known (Egger, 1975; Faber & Manstetten, 2003). They have constrained first nature and later life since their beginnings and are one of the evolutionary drivers by the "survival of the fittest". Exponential demand growth until reaching a limit seems

to be an inherent property of life and evolution in general (Faber, 1987). The other side of demand growth – waste and pollution – complies with this, although it is not using a resource but destroying the purity of another one. Obviously, this sustainability challenge beyond the materialistic regime can be found on all evolutionary levels up to the psychological, societal, and cultural level. All these levels act as a possible cause for exponential growth. Especially, the abilities of man in his modern societies have accelerated the use of common resources tremendously reaching the planetary carrying capacity (IPCC). Climate change and the sustainability challenge, thus is a complex combination of various effects, which in their holistic consequences have reached an unsustainable level threatening survival. The *(Classic) Tragedy of the Commons* (Hardin, 1968, 1994, 1998; Ostrom, 1990; Commons) describes this dilemma, in which (multiple) independently acting individuals due to their own self-interest can ultimately destroy a shared limited resource despite it is clear that it is not in the long-term interest of the local community or for the whole society. On universal time scales syntropy/entropy laws obviously predict that mankind will reach fundamental limits. Nevertheless, on short time scales huge resources are available: Already the sun delivers ~$3.9 \cdot 10^6$ Exajoules to earth per year, i.e. ~10,000 times the current human energy consumption (~$5.0 \cdot 10^2$ Exajoules/a). The natural geogene radioactive decay is also considerable and has kept the earth core molten now for 4.5 billion years. Both the energy inflow and outflow is balanced. Thus, with the little usage efficiency of our human societies of ~10% the current renewable energy capacity surpasses the human consumption still ~1 million fold! Not only are those resources renewable on a human scale but also free of primary resource costs. Thus, more efficient usage of renewables here is undoubtedly the key to the further success of our societies.

Again there are striking similarities to the IT sector: Due to the pervasiveness of PCs, their number has grown beyond 1.5 billion, outweighing the capacity of computing centres >100 times. Since the capacity is peak performance oriented, less than 5% are used, i.e. >95% of the capacity would be available 99% of the time. In a generic IT sense the term, a resource is any capability that may be shared and exploited by a network – normally termed "grid". These resources have been already paid for including their external follow-up costs (environmental etc.). The same holds to less extent for cluster infrastructures due to virtualization strategies. The Erasmus Computing Grid (de Zeeuw et al., 2007) with ~20,000 PCs (~50,000 cores, ~50 Teraflops), corresponds to a ~30 M€ investment. Especially in the notoriously under-funded public domain more efficient resource usage by means of grid would satisfy a big demand challenge. Thus, both in the energy, IT, as in any resource sector more efficient usage is of major importance for advancements. Thus, at least locally the disaster of reaching the (physical) limit can be delayed largely. A prime example from the production of fundamental raw materials is e.g. the integrated production in the chemical industry (Faber et al., 1987): Here byproduct usage, i.e. the waste of one process, is reused in another one as basic resource or often even as main process component (Jentzsch, 1995). Integrated production can reach the level of an extremely fine-tuned ecological organism (as in the highly sophisticated chlorine chemistry) that little changes have severe "survival" consequences for the whole system (Egger & Rudolph, 1992; Faber & Schiller, 2006). In real biological systems, however, there is more flexibility as in the highly integrated and sophisticated agro-forestry systems e.g. in Indonesia, which have been developed over centuries reaching extremely high efficiencies and are one of the biggest cultural achievements ever. In both cases the efficiency, i.e. the relation between system input and output, are maximized and beat every other process or management (Faber et al., 1998).

Here, the internalization challenge of underused energy resources in general and especially of the vastly underused renewable energies is analysed by the new concept of *Sustained Renewability* combining systems theory with *Human Ecology* and describing adequately the integrated holistic ecology like system parameters and strategies necessary. Therefore, fossil, renewable energy as well as grid and cloud IT resources (Foster & Kesselmann, 2004), their exploitation networks and organizational exploitation structures are analysed generically in relation to their technical systemic challenge. To approach the internalization challenge of underused renewable resources, the novel generic notion of the *Inverse Tragedy of the Commons*, i.e. that resources are underused in contrast to their overexploitation, is introduced. It is combined with the challenges on the micro level of the individual with its security/risk/profit psychology (Egger, 2008) as well as on the macro level of autopoietic social subsystems (Egger, 1996; Luhmann, 2004, 2008; Maturana & Varela, 1992). To derive points of action, the classical *Human Ecology* framework (Bruckmeier & Serbser, 2008; Egger, 1996) will be extended to describe the interactions between invironment-individual-society-environment completely and then is combined with the systemic complexity challenge. This leads inevitably to the new concept of *Sustained Renewability* and defined point of actions. Thus, sustained systemic renewability of resources in general can be really reached and thus leaves at least on the human scale much room for advancement for a big part of our future.

2. Fossil and renewable energy resources and their means of exploitation

Energy is always bound to and thus stored in a state of matter and has to be extracted thereof and transformed into the corresponding form for a certain usage. Primarily the energy we have access to comes either from nuclear fusion as in our sun (heating and driving the atmosphere), from nuclear decay within earth (keeping a molten core, volcanism, plate tectonics), and from the gravitational fields of our planetary system (tidal changes). This primary access is far from endless or renewable: e.g. hydrogen fusion has been done 2/3 already, i.e. only ~2 billion years are left for hydrogen fusion and thus already in ~300 million years the earth atmosphere will start to be heated up so much that life as one knows cannot exist anymore. Radioactive decay and the gravitational energy are also slowly used up. Consequently, the term renewable in that sense is only a relative terminology in respect to human time scales: Considering sun energy present for another 100 million years means ~30 million human generations or ~30 times the evolutionary development to homo sapiens. Nevertheless, on a human scale the term renewable thus really makes sense. In contrast, fossil energy resources (despite geogene gas and radioactives) consist mainly of organic substances produced through biogene conversion of sun energy by photosynthesis and their further transformation by geological process to coal, gas and oil. I.e. they are in principle a tertiary energy resource already. Due to the slow geogene processes and geological exploitation degree, the accessible size of these resources is fairly limited and especially concerning the human energy consumption very limited compared to the size of primary energy resources, their lasting and also not changeable natural production. Also the forms of energy which are termed renewables are in that sense secondary resources: i) sun energy is stored in photons, i.e. light, ii) wind energy is due to the sun energy transformed to heat creating atmospheric pressure imbalances, iii) hydro energy is due to water evaporation and gravitational lifting to higher altitudes and rain, iv) tidal energy is based on the earth-moon gravitational energy and stored in ocean movement,

v) geothermal energy is heat from radioactive decay stored in the geosphere itself, and vi) biomass is sun energy transformed by photosynthesis into biological matter as e.g. wood.

2.1 Renewable energy resources and their distributed exploitation

Renewable energy resources are due to their primary and secondary origins in principle homogenously distributed in an extensive and variant mixture compared to the very localized fossil resources: i) sun energy depends mostly on the geographic altitude, ii) wind energy is strong at coasts, great plains or mountains, iii) hydro electric energy needs rain, mountains, or rivers, iv) tidal energy needs tidal differences, v) geothermal energy is best at geological active sites, and vi) biomass counts on a vivid agro- and forestry capability, i.e. thus fertile soils and water. Actually in biological terms the presence of ample energy resources at each location, which are available in principle everywhere and in principle exploitable similarly, are the deeper basis for the thriving of life, i.e. the success of evolution (neglecting now extreme life forms). Three different exploitation means of these renewables can be distinguished e.g. in electricity production: i) direct conversion of e.g. sun energy by photovoltaics or heat by thermotaics, ii) conversion of kinetic energy via a generator as for hydro, tidal, or wind power, and iii) chemical conversion into heat as for biomass or directly for geothermal power, then into kinetic energy before electricity generation. Consequently, to reach the highest exploitation and conversion efficiency it is obvious to use the local resource mixture according to the usage profile, and only transport the overproduction to where it currently might be needed or stored for local demand rich times, i.e. to secure supply for the peak demand. Thus, here also the most systemic integration, that means the best adaption to the local usage scenarios can be reached, since the conversion plants, i.e. photovoltaic modules, wind turbines, small hydroelectric plants etc. are relatively small in size and can be aggregated in the most modular and thus sensible way. Also the exploiters and/or producers are either the same as the users or at least very near to them, thus ownership and participation in the exploitation-transformation-usage cycle can be maximal.

2.2 Fossil energy resources and their central exploitation

In contrast, the fossil resources are highly localized due to their origin: coal, gas, oil and uranium deposits are regional and need with their decline increased exploitation efforts. Despite being a local resource in a globalized world they are transported to the power plants. Thus, local economic thriving depends on an efficient transport system. Fossil energy conversion is based on chemical (in the case of nuclear decay, physical) transformation into heat, which is then transformed into kinetic energy driving turbines connected to generators for electric energy. Whereas renewable conversion is high-tech, the latter is still based on the steam engine and the electric generator. The best efficiencies are reached for big plants or a systemic combination of electricity and heat. Thus, due to the size the transformed energy transport itself becomes a major challenge and cost factor due to the large losses involved. From evolutionary optimized biological systems it is known that their scaling and success is based on: i) the distribution system is fractal, ii) the transport loss is minimized, and iii) the smallest part of the transport system has the same minimum size. Unfortunately, for the modern distribution networks this is mostly due to redundancy issues not the case anymore. Due to the plant size and the transport issues, the investments are high and only doable by international private companies, with relatively low integration with the local usage structures or participation of the local users. Thus, the production and usage can hardly be

integrated in a systemic manner anymore with high efficiency. Beyond, fossil resources have one big drawback: they produce waste, i.e. CO_2 is the leftover, whereas renewables only convert the energy form but not a resource additionally to the energy form. Thus, in a limited world this unavoidable leads to pollution and thus e.g. climate challenge.

3. Generic organization of the fossil and renewable energy sectors

As described briefly before, there are huge renewable energy resources available, which are based on the earth own geological nuclear decay, the suns nuclear fusion energy reaching us as light, and planetary gravitation. Simultaneously, there is a great shortage of exploitable resources as constantly claimed by users and providers – similar to the IT sector. Consequently, this paradoxical situation must have a reason, despite even the relative slow turnover rates of technical solutions in the energy sector, which are ~30-50 years for a production facility and perhaps the double for a complete new technology generation, compared to the 3-5 year fast turnover rates for a full technology replacement cycle in the IT sector. Thus, comparing the production solutions and organization of fossil and renewable energy resources is important. Both are based on dedicated organizations which handle the technical as well as management challenges and posses the same fundamental organization principles similar to the IT sector: i) ownership and control, ii) size of plant, iii) diversity and distribution, iv) technological broadness, and v) spatial distribution. To understand further the challenges, which still exist despite the crucial longing for energy and IT, the main three different electricity production approaches in Germany are analysed:

The renewable energy sector has grown tremendously in Germany in the last 10-15 years mainly by guarantying a fixed price for the produced energy allowing return of investment of ~6% per year over 20 years: Today ~25,000 wind turbines with ~30 GW peak performance and ~800,000 photovoltaic plants with ~18 GW peak performance of electricity deliver ~7% and ~3.5% of the German electricity consumption. Together with biogas and biofuel production, combined heat and electricity production (KWK) and hydroelectric plants from lakes and rivers – each from some kW to some MW peak capacity – in total ~17% of the German electricity are now renewable and emission free. Whereas wind mills have a peak performance of 300 kW to 7.5 MW and are usually aggregated in parks of up to 50-100 mills, photovoltaic plants range from 1-2 kW to ~30-50 MW peak performance. Wind parks naturally reside in wind rich regions but are meanwhile spreading to the southern continental regions. Photovoltaic plants are installed throughout the country on the roofs of private households, government, or industry buildings. Bigger ones are also placed on farmland and conversion zones e.g. unused industrial estates. Investment costs range from some thousand Euros for a photovoltaic plant on a family home, some million for a medium sized windmill, to some hundred million for a big photovoltaic plant or wind park. Consequently, the production plants fit different business models and investor groups from the individual up to institutionalized funds. The electricity is mainly introduced into the grid and has priority by law over conventional electricity production. The electricity grid providers measure the production and the producers are monthly refunded by the local grid or electricity company. The grid belonged to the four big German electricity companies ENBW, EON, RWE, and Vattenfall until recently, but is now in other private hands. The free energy flow to the consumer – so called grid-neutrality – is guaranteed by law. The price guaranty to the producer is shared by an addition to the bill of all electricity consumers in a social manner and often also sold as special green electricity product – then by green energy sellers. Besides the knowledge gain in Germany and being the world

leader in renewable energy facility production with ~350,000 employed people meanwhile, the resource, i.e. sun or wind, has not to be paid for, which leads to a big economic advantage. Due to the range of business models in principle everybody can be an electricity producer, which means a democratization of electricity or renewable energy production within society.

The public city producers, which often have been owned by the cities or regions especially in the past have a very conventional portfolio consisting of coal or gas power plants, which are sized to serve the local or regional electricity and sometimes thermal, i.e. heating, energy needs. Historically they developed when electricity and heat was starting to be needed by major parts of society, i.e. between 1850 and 1950. The electricity is put into the electricity grid, which has often belonged also to the public city producers. The distribution network for the heat, which is a byproduct of the conventional electricity production, has also been build up by them, since this was relatively easy to implement concerning the technical and organizational efforts for a well thermally isolated pipeline system underground from production to consumers throughout a city. Electricity, nevertheless, is mainly traded at the European Energy Exchange and production depends on the national demand price, which depends again on the coal, oil, and gas trading prices, i.e. depends on a European/worldwide market price and thus is a major part of the production costs. The local city producers are also the major seller for their electricity. Meanwhile, many of them possess also renewable energy production capabilities (photovoltaic plants or wind parks, usually regional), besides the classic hydroelectric production facilities at lakes and rivers, which again has regulatory reasons. Since they are connected to the regional government and thus are controlled by the local inhabitants they are relatively much bound into the regional development process as well and also impact the regional industry.

In contrast, the four large-scale producers of electricity in Germany – ENBW, EON, RWE, and Vattenfall, who are often termed the big "German Four" – are meanwhile world wide acting producers of mainly conventional coal, gas, oil, and also atomic electric power. Their plants have investment costs of billions and their regional placement depends besides the energy production process and consumption needs mostly on business and regulatory reasons. Thermal energy is only in some cases used locally for heating since the amount surpasses by far the local demand, thus the electricity, which is put to the electricity grid, is often internationally transported through the network to the consumer. The network for a long time mainly belonged also to them until recently, and had been bought from regional city producers over the years, thus the "German Four" controlled production and transport in a very monopolistic manner. Naturally, they also have to buy the energy resource and thus depend critically on the resource price of energy resources, although due to their size they are in the position to influence that by their large demand. In selling terms they are the big sellers of electricity and due to their market position (and especially while being owners of the distribution network) can influence the price to some extent to their gusto. That this is not excessively abused, the German government has implemented a regulation agency controlling their market and price models. Due to the unavoidable switch to renewables due to the climate challenge they also invest meanwhile into very large photovoltaic plants, wind parks especially offshore, and hydroelectrics – again based on their business model of large-scale with a monotechnic approach. According to their financial power they act such that their market position, i.e. their monopolistic centrality is hardly touchable and thus that they can control the heart of the electricity sector in Germany. The dependencies this creates and the risk for society is retrospectively also one reason for the huge success of renewables with their decentral relative small-scale and thus democratic production.
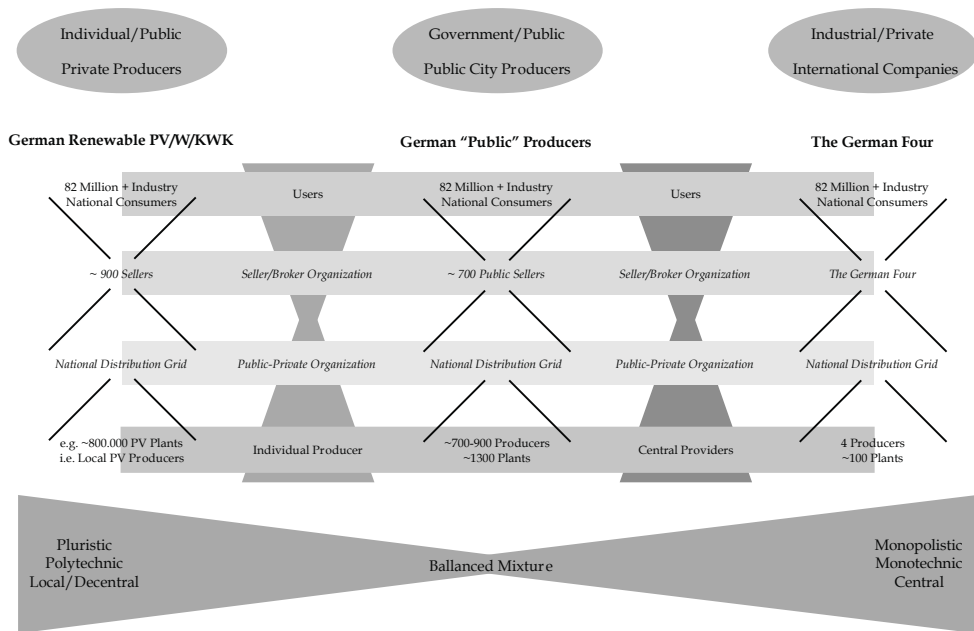
Fig. 1. Abstraction and detailed structure of the German electricity sector, showing three pillars and the four levels of infrastructures involved from production to usage. The three pillars are characterized by: i) individual/public "private" producers, ii) government/public city/regional producers, and the very few industrial privately owned international companies. All share four levels of infrastructure from production to usage: i) users, ii) seller organizations, iii) the semi-private, i.e. public-private network organizations, and iv) individual producers. The three pillars are already characterized by their means of energy production: i) renewable and small scale, ii) regional and medium sized, and iii) classic large scale fossil and atomic. Whereas the first can be characterized by pluristic, polytechnic local/decentral means, the last is characterized by monopolistic, monotechnic, and central terms. Although, the details may vary, the structure leads to similar challenges on the micro and macro level, which can be understood by the *Human Ecology* rectangle

Generalizing, the renewables obviously belong to the class of individual/public distributed producers with a pluristic, polytechnic and local/decentral approach, whereas the "German Four" large scale producers are clearly industrial/private with a monopolistic, monotechnic, and central attitude. The German government/public city producers are a mixture of both: government and public, not too pluristic, polytechnic, and local/decentral and neither industrial/private, nor monopolistic, monotechnic, and central. Consequently, this shows already the similar property and power structures in the energy and IT sectors. Especially the "German Four" show the similarity to the newest development concerning IT resources, i.e. clouds, with the same monopolistic structures etc. and blocking effects on development. The analysis of these and other such many an infrastructure shows that four levels of organization are involved also in energy producing and distributing organizations: i) users,

ii) organizing broker organizations, iii) provider organizations, and iv) individual providers. In a more abstract form this shows that actually there are i) individuals and ii) societies of individuals, which are both involved on each of the four levels of organization, with a different degree of influence. Consequently, there is a micro level from which a macro level emerges, having again an influence on the micro level, i.e. that both levels are connected in a complex and cyclical manner as in any evolutionary evolving system. Thus, the micro level is constituted by an invironment and the macro level creates an environment. This will later constitute already the *Human Ecology* rectangle.

4. Generic organization of grid and cloud IT infrastructures

Obviously, there are also huge resources available in the IT sector – similar as in the renewable energy sector, although there is – at the same time – a shortage of resources as constantly claimed by users and providers. Consequently, this paradoxical situation must have again a reason and especially for the IT sector where the opportunities for technical solutions with fast turnover rates of 3-5 years for full technology replacement cycles are large compared to the ~30-50 years in the energy sector. Grid and cloud infrastructures are one solution to ease the resource shortage by more efficient usage of available resources and are based on dedicated organizations, which handle the technical as well as management challenges involved. They also posses the same fundamental organization principles and can be classified by the same characterization as already the energy sector: i) ownership and control, ii) size of grid/cloud, iii) diversity and distribution, iv) technological broadness, and v) spatial distribution. Thus, it is very interesting to see that despite the much higher turnover rates and the innovative potential of the IT sector in principle the same challenges exist as in the energy sector. Therefore, now two grid and one cloud infrastructure will be investigated in greater detail to show the similarities:

The Erasmus Computing Grid (ECG) is one of the largest desktop grids for the biomedical research and care sectors worldwide (de Zeeuw et al., 2007; Fig. 2). The computing cycles of the desktop computers of the Erasmus Medical Centre and the Hogeschool Rotterdam (the local University for Applied Sciences) are donated to the ECG. Technically, these cycles are exploited by the middleware CONDOR and a newly developed management system, which administrates on the one side all the computers in the grid as well as the users and on the other hand posses an easy accessible back-end/front-end system for usage. The latter is especially important for efficient use and security: The users only need to deliver their application, which then is implemented in a work flow scenario, thus the users for production only need to upload via a portal their new data and parameters for the analysis. The users are informed about status and final plausibility result checks. The rest is shielded for security reasons. Currently, the ECG has a capacity of ~15 Tera FLOPS already available for user applications (total existing capacity: ~20,000 desktop PCs, ~30,000 computing cores, ~50 Tera FLOPS). This corresponds to a ~30 M€ investment. In absolute terms this is also one of the largest dedicated computer resources world wide available to users via a central entry port managed by the Erasmus Computing Grid Office (ECGO). The ECGO is the secretariat in front of the technical infrastructure, supporting users, technical maintainers of the desktops, and serves as the development hub for grid as well as special user wishes. The aim of the ECG is to serve the areas of research, education, and diagnostics according to the mission of the donating public organizations. Beyond, the aim is to develop the ECG as a general broker organization for computing resources also for industry and other sectors.

Therefore, the ECG is also connected to other grid and cloud infrastructures and respective European initiatives as e.g. the German MediGRID/D-Grid initiative, the European EGEE and EDGES infrastructures and several other local resources.

MediGRID (Krefting, 2008; Sax, 2007, 2008) and its services branch Services@MediGRID operate the national German biomedical research and care grid and is one of ~20 community grids of the German nation wide D-Grid initiative. The resources are cluster computers, which are located and maintained at local universities. Their size varies from ~16 CPUs with 2 or 4 computing cores each (i.e. 32-64 cores) to 2048 CPUs with 4 cores (i.e. 8192 cores). These resources run different middlewares and can be accessed by the users via a central access portal or a central access to the resources directly (Fig. 2). Here again the userfriendliness is of major importance to gain a broad group of especially non-computing experts. Special security protocols allow data transfer between the clusters under high-security medical conditions. Thus, the German MediGRID is said to be one of the most advanced health grids in the world combining data storage, computing power and sharing of applications in an entire nation. To serve the aims of research, education, and diagnostics in the biomedical research and care sectors MediGRID is organized in different modules, which are distributed via different institutions throughout Germany and thus form a more or less decentral organization. Nevertheless, special services, business modules and strategies were developed within the Services@MediGRID project allowing the grouping into different service classes and thus to apply different business and accounting models to distribute and organize appropriate the usage of the grid most efficiently. This also includes the possibility for billing and thus in principle commercial usage. Since MediGRID is located in the national research arena the latter is currently mostly valuable for accounting within the research community to balance and monitor the money flow within German research.

The Amazon EC2 cloud favours now an even more concentrated production facility since it exists of a few data centres around the world with massive cluster computing capacity of hundred thousands of computing cores at one centre. The centres are localized according to environmental and business aspects, i.e. that cheap energy supply for cooling, operation, and local subsidies are the main location factor despite a high capacity connection to the rest of the internet. The administration is done centrally in each facility, with different operating systems available and generic portals for user access. The centres are shielded entities and guaranty maximum security despite the country and legal setting they are in. Due to the size, users have access to a free scaling system, for which they are billed per computing hour on different accounting and business models. Amazon also helps to develop together with users their solution of interest, however, focuses mostly on providing pure hardware, the operating system and the access to the resource.

Obviously, the ECG belongs to the class of individual/public desktop grids with a pluristic, polytechnic and local/decentral approach, whereas the Amazon EC2 cloud is clearly industrial/private with a monopolistic, monotechnic, and central attitude. The German MediGRID and thus D-GRID is a mixture of both: government and public, not too pluristic, polytechnic, and local/decentral and neither industrial/private, nor monopolistic, monotechnic, and central. Consequently, this shows similar property and power structures as in the energy sectors including the current phenomenon to set up overcome giant monopolistic structures in the new cloud infrastructures, which are blocking fast development towards new more efficient opportunities. Thus, generically
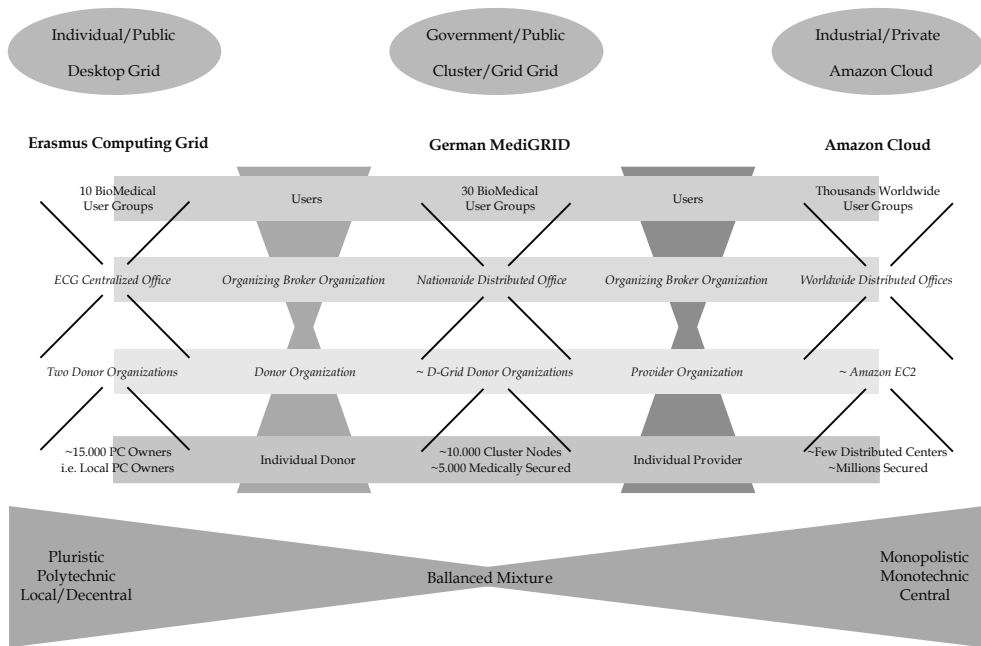
Fig. 2. Abstraction and detailed structure of the Erasmus Computing Grid, the German MediGRID, and the well known Amazon EC2 cloud. The three pillars are characterized by i) individual/public "private" grids, ii) government/public grids and iii) the very few industrial privately owned international clouds. Again all show the four levels involved in grid infrastructures: i) users, ii) organizing broker organizations, iii) donor organizations, and iv) individual donors. Again the three pillars are characterized by their means of capacity: i) small scale desktop and small mainframes, ii) regional and medium sized clusters, and iii) classic large scale cloud centres. And again whereas the first can be characterized by pluristic, polytechnic local/decentral means, the last is characterized by monopolistic, monotechnic and central terms. Although, the details may vary the structure leads to similar changes on the micro and macro level, which can be understood by the *Human Ecology* rectangle.

again four levels of organization are involved also in grid organizations: i) users, ii) organizing broker organizations, iii) donor organizations, and iv) individual donors. In a more abstract form this shows again that actually there are i) individuals and ii) societies of individuals, which are both involved on each of the organization levels, with a different degree of influence. Consequently, there is again a micro level from which a macro level emerges, with influence on the micro level, i.e. that both levels are connected in a complex and cyclical manner as in any evolutionary evolving system. Thus, the micro level is constituted by an invironment and the macro level creates an environment. This we will later see constitutes already again the *Human Ecology* rectangle as in the case of the energy sector.

5. Tragedy of the systemic complexity and the solution for a systemic sustained resource exploitation

Primary energy or IT resource exploitation in reality involves a complex chain of events already on a technical level from the resource to usage, and involves e.g. resource i) acquisition, ii) basic exploitation, iii) storage and provision, iv) transformation to usable form, and v) transport to or access from users. Consequently, for a highly efficient exploitation of this chain, i.e. reaching a high efficiency from the primary resource to the end usage and thereby minimizing both the recyclable and unrecyclable losses, these five steps have to be optimized in a systemic manner to guaranty a careful exploitation of the primary resource. Optimization means here that not only the different steps are optimized within themselves but beyond, that the overall efficiency of the chain is optimized, since the optimum in on step of the chain might as a side effect reduce even the level of efficiency in another step or the rest of the chain far below the optima of these single steps and thus reduce the overall efficiency of the entire exploitation chain. Thus, the exploitation chain is already a complex system, where different parts influence all other parts.

It is obvious that usually the chain is seen mostly from each end, i.e. that the perception of the exploitation chain is either i) resource oriented or ii) usage oriented: i) it is easy to look only on the energy or IT resource and then think about its exploitation without looking at the usage, and ii) it is equally easy to take only the perspective of the usage and user and neglect the meaning for the primary resource exploitation. The first perspective is often taken e.g. in fossil energy business models where power plants have at the beginning been built near the coalmines. Equally, big hydroelectric dams can only been built locally whether there is a usage at hand or not. Often then potential users take the opportunity to move to that location. The second perspective, however, is often taken due to the low transport costs of fossil resources, i.e. coal is just transported around the world to the user. In contrast, renewable energy or grid IT approaches try to combine both perspectives: here first the two questions are asked at the same time: i) what demand exist locally, and ii) what resources are available locally? If availability and demand cannot be brought in agreement locally then the radius can be broadened from local to regional and so forth. In either case then the details of the different steps have to be questioned and the best mix of resources – if there are different ones – has to be considered, thus the whole exploitation chain can be optimized. This is, of course, a dynamic process, i.e. the optimized exploitation chain will most likely vary over time, i.e. that the time factor of a technology replacement or entire new introduction has also to be considered. In the case of renewables this involves less the primary resource, which is one of the biggest advantages of renewables and leads already to a sustained availability of the primary resource, which nevertheless is only one chain part.

The complex exploitation chain is, however, still a too simple rationalization, since the chain from the resource to usage involves on each of the five described technical levels again other chains of events, which need again various resources i) energy, ii) information, and iii) materials. Thus, respectively, the exploitation chain itself needs to exploit energy, information and material resources to exploit the resource of interest, as e.g. energy or IT resources. Consequently, this means that the exploitation chain is in reality a complex network of exploitation chains based on the availability of the same and other resources. And on these secondary levels again exploitation sub-chains exist and so forth and so forth… Thus, an exploitation network makes naturally the situation tremendously more complex then just a complex exploitation chain, not only because there are even more

components to be considered, but mostly because the number of non-linear interactions of these components are even higher, more complex, and more dependent on each other. Especially the recursive dependence on the primary exploitation chain by the secondary, i.e. that also the secondary exploitation chains nested on each of the primary exploitation chain levels, need e.g. energy or IT resources to be able to function, is here of major importance in terms of complexity increase. The influence is now not only non-linear but also adds many an exponential interaction, which can in- or decrease the importance of a small tiny factor somewhere in the exploitation network enormously.

Beyond, an exploitation network connected to a specific e.g. energy or IT resource now involves many other resources, which have as well their limits and renewability aspects. Especially, material resources play here a fundamental role as – additional to energy and information resources – e.g. steel for the primary resource exploitation within machines and transport systems, rare metals for the transformation as e.g. metal catalysts or the dotation of the silicium in photovoltaic cells as well as copper for energy or information transmission or lithium for high capacity storage energy, to name only a few. Consequently, the whole resource and exploitation sector already on the technical level is a multi-recursive network of resources and their exploitations, where finally the single small component, its resources status, and renewability, might be as important as the major resource to be exploited. Nevertheless, there is a caveat in this on first sight depressing and seemingly unsolvable complexity. There is a natural hierarchy of the importance of and the amount of resources: If a resource is renewable or at least highly recyclable then these limits are tameable as well as in the case of resource replacement. Whereas for a fundamental resource like energy or information this can be tremendously difficult, for the materialistic part in exploitation networks that might in most cases be possible due to the fact that with the building box nature provides us in the many physical elements and thus the chemical products one can make thereof. So it is possible nowadays to replace steel by carbon fibre, i.e. heavy industry products by light chemical materials. The same holds for many components, although all follow again the resource limit, exploitation network, and renewable or recycling generic challenges as already discussed.

Consequently, for a highly efficient exploitation of such a complex systemic network, i.e. reaching a high efficiency from the primary resource to usage, all single steps have to be optimized in a systemic manner to guaranty a careful exploitation of the primary and all other involved resources. Actually the exploitation network becomes now also a general resource network. Thus, optimization means here that not only the different steps are optimized within themselves but beyond, that the overall efficiency of the entire network is optimized, since the optimum in one step might as a side effect reduce even the level of efficiency in another step or the rest of the network far below optima of these single steps and thus reduce the overall efficiency of the entire resource and exploitation network. Thus, the resource and exploitation network is already a hyper complex system, where different parts influence all other parts, which creates in principle what can be termed the *Tragedy of Systemic Complexity*:

The Tragedy of the Systemic Complexity:

Resource exploitation is a complex systemic network with a huge number of technical components
and beyond huge exponential non-linear interactions between these components,
thus highest efficiency can only be achieved by a systemic optimization
with contradictions appearing on the level of single components
leading to huge individual and social paradoxical challenges of perceptions and understandings.

This now has huge consequences for the implementation of a highly systemic exploitation network by individuals and society, since now all individual components have to be optimized themselves with respect to all other components and the complete complex hyper systemic exploitation network. Therefore, the classic reductionistic approach is unavoidable as long as it finally ends in a holistically reintegrated systemic result. Consequently, for a highly efficient energy and IT resource exploitation this is the vital core to *Sustained Renewability*, since only then also primary renewable resources are not compromised by the limits in the complex resource and exploitation network and since only then enough resources will on human time scales always be available to exploit this primary resource and thus sustain its exploitation and usage for again on human time scales indefinite time. Thus, the technical level requires a holistic systemic approach for *Sustained Renewability*.

6. The inverse tragedy of the commons in the renewable energy and grid IT sectors

Analysing both the energy and IT resources, their means of exploitation and usage scenarios in a systemic manner, clearly shows beyond a pure estimate of scale, that obviously there are affluent resources and also solutions for their efficient exploitation available. The *Tragedy of the Systemic Complexity* thereby shows that already the pure technical means in the entire chain from the resource to usage has to be taken special care of, since otherwise the loses are far too big, i.e. the efficiency is far too low. E.g. considering overall efficiencies below 1% would mean that a system of resources would be 100 times faster depleted than in the, of course, impossible case of 100% efficiency. Again it should be stressed that this must include beyond the basic energy or IT resource themselves, their entire exploitation chain and thus the resources needed for this exploitation as well. Renewables and grid are means of doing that in a very sophisticated manner at least to a larger extent then the classic large-scale power plants, computing centres, or cloud infrastructures. Thus, the fundamental basis for *Sustained Renewability* means solving the technical systemic complexity in a productive manner, i.e. the technical chain from the resource to usage must be exploited in a systemic manner already on the pure technical level. Without such a systemic approach for resource exploitation, no *Sustained Renewability* can be reached. Thus also all the limits have to be considered in the entire exploitation network, since even if there is a huge resource their might be a tiny but nevertheless bottleneck within a resource network as e.g. a rare metal or substance which is crucially needed somewhere in a corner of the exploitation network. Nevertheless, exploiting the renewable energy or IT resources in a systemic approach purely technical, i.e. by integrated holistic ecology like systems e.g. by using the renewable resource or sharing the available IT infrastructure, seems hard since both renewable energy and grid infrastructures slowly emerge, which is due to their importance and especially in the IT sector with its great opportunities and fast turnover rates, paradoxical.

The analysis of energy and grid organizations showed already generically that there is a micro level from which a macro level emerges. Actually, the organizational chain suggests that this is true for every resource exploitation network and thus is its fundamental cultural root, especially if the resources, which are to be exploited, are part of the commons as the renewable energy (i.e. in the climate change dilemma) or IT resources (i.e. the dilemma of e.g. to little information transforming capacities) in principle are. Both this micro and macro level now wraps the technical exploitation into the dialectics from invironment to environment. In the case of over-exploitation of common resources, the exactly same

complex interplay between the individual and the society as well as the invironment and the environment appears. This his is well known as the so called *Classic Tragedy of the Commons* (Hardin, 1968, 1994, 1998; Ostrom, 1990; IASC; Commons), in which (multiple) independently acting individuals due to their own self-interest can ultimately destroy a shared limited resource even though it is clear that it is not in the long term interest of the local community and society as a whole. The phenomenon in principle is nothing new and appears already in ancient myth and religions, since it concerns the basis of life, i.e. the usage of resources in general and in particular that of energy and food. The violation of the carrying capacity, the theft of resources connected with the decline or death of those who lose their resource basis, and the squandering of resources are deeply integrated in all cultures reaching the level of archetypical traits. E.g. the Irish measure for the size of a piece of land in *callop*'s describes the size in terms of the carrying capacity for different animals: the same sized piece of land, i.e. e.g. one callop might be 10 cows, 12 horses, or 40 sheep. In the case of under exploited resources there seems to be the same phenomenology of the *Classic Tragedy of the Commons* challenge put forward. This phenomenon is now theoretically defined – as a logical consequence – as the *Inverse Tragedy of the Commons* (Fig. 3):

The (Classic) Tragedy of the Commons:
A resource belonging to all and being on limited demand is
OVEREXPLOITED by the user due to responsibility diffusion!

<center>*<=> TRANSFORMATION <=>*</center>

<div align="right">

:The INVERSE Tragedy of the Commons
A resource belonging to all and being in affluent availability
on limited demand is UNDEREXPLOITEDby potential users due to responsibility diffusion!

</div>

Interestingly, not only is responsibility diffusion the most likely and general reason for the appearance of both tragedies, but also the psychological description for both the micro and the macro level hits the same archetypical traits (Fig. 3) as mentioned above. Whereas the *Classic Tragedy of the Commons* corresponds to i) indifferent hedonists, ii) careless players, and iii) the chronic overstrained, the *Inverse Tragedy of the Commons* corresponds to i) hedonists, ii) the cool calculating, and iii) the tragic hopeless. The under-used potentials, i.e. the general basis (matter, energy, information, biological, psychological, and societal level) and over-used resources (materials, reservoirs, memes, organisms, behaviours, cultures), clearly show how from a virgin resource opportunity, concrete objects emerge with their attached limitation burden (Fig. 3). Nevertheless, they all cluster around a systemic technical development. Thus, the complex field created, describes exactly the tension found in resource limitation phenomena and evolutionary emergence.

Consequently, it becomes now also clear what constitutes the micro and macro levels: on the micro-social level the systemic and the open sharing attitude of the individual play the key roles, whereas on the macro-social level the organization culture of the embedding institutions and in the end society as a whole as well as its cultures are the central points. I.e. that beyond the technical implementation of an exploitation network in a systemic technical manner, but nevertheless still technically focused approach, the individual and society with their invironment and environment they consist of and create respectively, need to be considered as the crucial to be investigated fields to understand why still with even a systemic technical exploitation scheme with highest efficiencies existing, even the best solved *Tragedy of Systemic Complexity* is not implemented (not to speak of the development
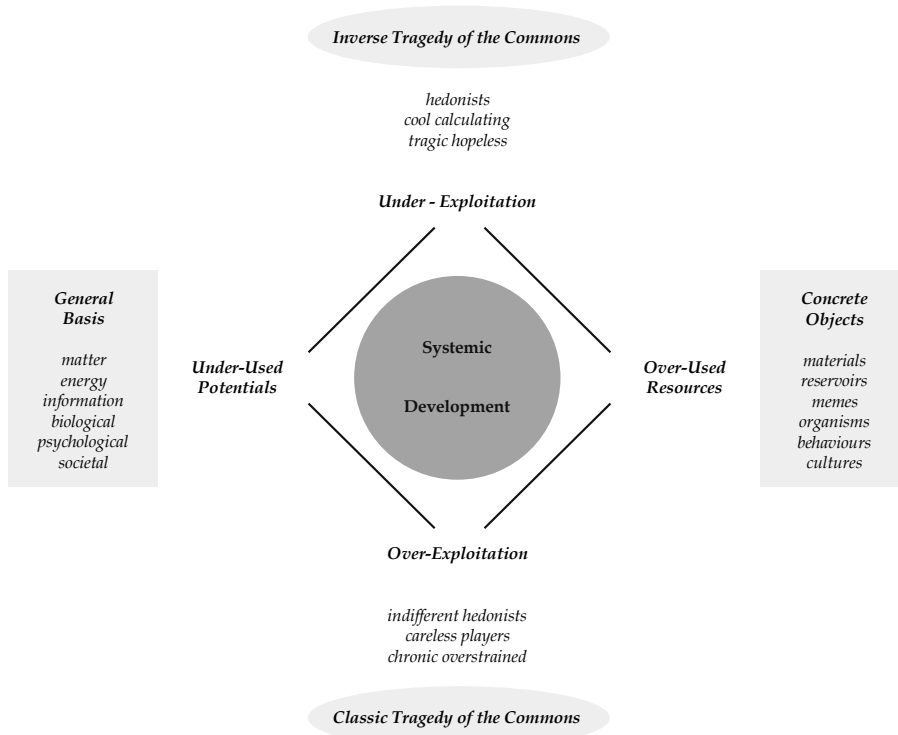
Fig. 3. Generalization of the *Inverse Tragedy of the Commons*: the *Classic* and *Inverse Tragedy of the Commons* are directly complementary to each other and can on the deep psychology level be associated with complementary pears of archetypical behavioural traits. This is in line with the complementary under-used potentials and over-used resources, which emerge from the potentials by freezing of potentials into concrete objects with corresponding limits. Both correspond to the general basis and concrete objects. Whereas the *Classic Tragedy of the Commons* corresponds to i) indifferent hedonists, ii) careless players, and iii) the chronic overstrained, the *Inverse Tragedy of the Commons* corresponds to i) hedonists, ii) the cool calculating, and iii) the tragic hopeless. All cluster around a systemic technical development as the technical core.

of a solution for the *Tragedy of Systemic Complexity*). Thus, the system of i) technical system, ii) micro level, and iii) macro level has now to be investigated as a system in a holistic systemic manner itself. Therefore, pinpointing the phenomenon of under exploited potentials to the same phenomenological root as the well known phenomenon of over exploited resources opens now the complete opportunities and tool set to examine the challenge of introducing a *Sustained Renewability* approach into practice (as e.g. in the renewable energy or grid IT sectors) as well as its principle day-to-day management. Thus, practical implications can be derived from an analysis of the micro and macro levels, which then have to be embedded in a systemic manner and approached on a theoretic level. Appliance of this concept with practical guidelines, the implementation of *Sustained Renewability* practically, can be realized in principle for every resource management sector.

7. The tragedy of autopoietic social subsystems

The challenge to integrate exploitation measures of energy or IT resources, which follow technically a systemic approach and thus beat the *Tragedy of Systemic Complexity,* into society involves naturally all stakeholders of society (Fig. 1, 2). The existence of a *Tragedy of Systemic Complexity* and an *Inverse Tragedy of the Commons* and its macro social aspects, point to the major importance of the interaction complexity of the social subsystems theory by Niklas Luhmann (Luhmann, 2004, 2008), i.e. a systemic approach analysing and describing the social system and the subsystems it consists of: It is based on the autopoietic concept of Humberto Maturana and Francisco Varela (Maturana & Varela, 1992), and is the most advanced social systems theory, describing the huge complexity of the macro sociality of the renewable energy as well as grid IT phenomenon. An autopoietic system is a network of processes consisting of: i) interactions and transformations continuously regenerating and realizing its networks of existence, and ii) the constitution of the system as a unity in space in which the component exist by specifying the topological domain of its realization. Central to this description of evolutionary emergence, i.e. self-reproducing systems, is the material and information exchange between the components. Social systems are obviously communication systems, with society being the most encompassing one. Immediately that makes clear what challenge that suggests: what are the social systems, is there more than one, if so how do they interact, and most importantly who can they act together in a systemic manner to achieve a goal which is either emerging from one system internally or introduced from the outside. Consequently, many of the conundrums appearing during the society internalization become evident and are in agreement with the *Tragedy of Systemic Complexity* and the *Inverse Tragedy of the Renewable and Grid Commons*:

Around seven social subsystems can be defined and reflect the evolutionary emergence from deep psychology to society (Luhmann, 2008): i) religion, ii) education, iii) science, iv) art, v) economy, vi) jurisdiction, and vii) policy. All of these systems have their internal code of communication and their own connectivity interface to the other subsystems. Thus, the *Tragedy of Systemic Complexity* struck now in principle again, although this time on a social level, which results in huge barriers: e.g. the religious code of believe or not-believe is incompatible with the have or not have money code of the economic sector. This is even truer for science (true vs. non-true), jurisdiction (just vs. un-just) and politics (power vs. no-power), which have nothing to do with education (knowledge vs. no-knowledge). Renewable energy exploitation belongs to several subsystems, mainly those of science and economy in contrast to grid IT infrastructures, which belong currently mostly to the academic sector (de Zeeuw et al., 2007; Krefting et al. 2008; Sax et al., 2007, 2008). Despite the success of both renewable energy exploitation approaches as well as the widespread usage of grid IT infrastructures within society, the broad rollout, i.e. the internalization of systemic approaches into society, is decelerated by the lack of interoperability between these subsystems. Consequently, the *Inverse Tragedy of the Commons* results in

The Tragedy of Autopoietic Social Subsystems:

Subsystems have their own code of communication and are separated from each other in a way blocking in principle a consistent integration although they form a society, with all their contradictions, which thus leads to blockage of the system.

This macro level tragedy clarifies that renewable energy and grid IT organizations are just another example for complex infrastructures whose efficiency increase depends beyond more or less complex technical solutions on the participation of all subsystems concerning their societal internalization. In detail this means that each of those social subsystems must be analysed according to their internal constituents in respect towards the implementation of a systemic approach in respect to the status quo as well as to the ability to react to an until then not used or entire novel systemic approach. Thus, it might be, that such a systemic approach might not at all be implementable within such a subsystem at first, that major transformation need to be made, or that in the best case already existing structures can be used. The same holds for the communication between the subsystems, since here different internal preparedness levels might either ease or worse the communication in respect to such an implementation. Consequently, the challenge of implementation of *Sustained Renewability* approaches into society involves again two levels: On the micro level of individual subsystems the move towards implementation depends on the subsystem "stickiness" of individuals. On the macro subsystem level the integration of institutionalized subsystems via soft interfaces, which allow the communication barriers to be lowered, is central. Both has to be taken care of since this is given beyond the systemic pathways within the subsystem and the setting how subsystems can be moved or interact with others.

The acceptance of this is an important knowledge opening huge opportunities to examine and approach the challenge of introducing renewables or grids and their management. Beyond, this clarifies the challenges in all other exploitation sectors (probably residing in other subsystems) since all subsystems should always be involved. Thus, the *Tragedy of the Systemic Complexity* in terms of systemic integration into society can be understood and has to be taken into account. Beyond, the *Classic* and *Inverse Tragedy of the Commons* are a societal challenge with the opportunity to be resolved, if as well the technical systemic approach is combined on the social system level in a sustainable systemic manner.

8. The tragedy of security/risk/profit psychology

Since the macro level of social subsystems emerges evolutionarily from the micro level (Egger, 2008), one needs to consider the individual for whom each implementation and internalization of a new technology is based on a positive relation between the risk and the profit involved from the perspective of the individual. This is the core of any action a human individual takes and defines the degree of motivation a person commits to an action, i.e. the change of something in contrast to doing nothing. Thus, the level of altruism leading to successful implementation as in the renewable energy case or the sharing in the grid IT case on the individual level and its commitment beyond its own job/agenda, as well as that of its own institution without incentive structure to take responsibilities, is essential and leads to responsibility diffusion: Even the obvious win-win situation renewables like photovoltaic on the roof, or small hydroelectrics on the grounds of an individual, are hard to communicate and even the clear effects of producing with no energy resource costs the own energy result in slow implementation of renewables compared to the benefits and the climate issue at face. Even more so, the clear win-win situations for individual grid users are under these circumstances hard to communicate and even the additional networking effects result hardly in the set-up or usage of grids. It is also unlikely that people take the risk to exceed their own budget and corresponding responsibilities, when future results and its benefits are unclear to them.

As long as exploiting the renewable energy resources or sharing in the grid IT sector is voluntary and in hand with uncertainty and risks, it is less likely that individuals will behave altruistically on behalf the societal benefit. Consequently, on the micro level the situation is that of a perverse *Inverse Tragedy of the Commons*: the commons is not abused or overexploited, but in contrast the tremendous resources are not used at all despite the needs and obvious benefits, due to secondary (mostly "irrational") interests.

Thus, the integration challenge involves the individual of the different institutionalized society stakeholders in a very deep way since these individuals shape the individual actions according to their function in a social subsystem. How an individual perceives the security/risk/profit ratio depends on its personal security/risk/profit psychology matrix:

Deep Psychology Security/Risk/Profit Cascade:	*:Autopoietic Subsystem Correspondence*
emotional individual s/r/p perception	*genetics and deep psychology*
rational s/r/p knowledge acceptance	*education and science*
internalized incidental s/r/p behaviour	*economics*
accepted legal and political s/r/p scenarios	*jurisdiction and politics*
lived religious and cultural s/r/p archetypi	*religion, art and culture*

Thus, this matrix describes a similar challenge on the micro level similar to the macro level with conflicting personal positions and internal balancing the invironment with the environment. This creates on the micro level again a tragedy:

The Tragedy of Security/Risk/Profit Psychology:

Individuals balance constantly a complex combination of invironmental and environmental security/risk/profit deep psychology factors, whose contradictions lead to responsibility diffusion.

In detail this means that each of those levels need to be considered especially from key individuals, i.e. of those, who hold important positions within social subsystems, to just the collective invironment of an entire population. And again this poses two obvious challenges in a systematic concept: on the micro level, the risk perception and the emotional well-being of the individual has to be considered, whereas on the macro level, the risk perception in the procedural and institutionalization in organizations have to be considered, i.e. the interaction of the individual with the organization it is working in. Thus, it might be that such a systemic approach might not at all be implementable with certain individuals or collective emotions in place at first, that major transformations need to be made, or that in the best case already existing structures can be used. Unfortunately, the identification and analysis of this tragedy is by far more challenging in every respect and especially concerning management guidelines, due to the hardly changeable basis, due to its genetic and evolutionary basis and the time scales involved to change archetypical societal concepts, in contrast to the macro level, where bypassing measures and changes can in principle be implemented *at will*, i.e. major screws can be relatively easy adjusted by order with or without societal participation and/or agreement. Consequently, this tragedy has to be tackled with big care and shows that the *Tragedy of Systemic Complexity* as well as that of the *Inverse Tragedy of the Commons* can really be addressed by a *Human Ecology* rectangle approach integrating the different tragedies in a systemic manner and thus to reach systemic renewability by such super-systemic approach, as will be shown in the following.

9. Human ecology for a sustained renewable energy and grid IT resource network exploitation

To overcome the *Tragedy of Systems Complexity* and the *Inverse Tragedy of the Commons* together with the base tragedies of the latter, the *Tragedy of Autopoietic Social Subsystems* as well as the *Tragedy of Security/Risk/Profit Psychology* in the renewable energy and grid IT sectors a systemic approach on the technical level combined with an approach to tackle the micro and macro social levels is crucial to reach *Sustained Renewability* in these and in principle generically any exploitation sector. The basis of all these is the level of complexity in the corresponding areas leading to the heart of the matter – responsibility diffusion. For this the inter- and transdisciplinary field of *Human Ecology* (Egger, 1992, 1996, 2004; Bruckmeier & Serbser, 2008) gives a framework for their combination, followed by understanding and approaching direct guidelines for the management of renewable energy and grid IT resources. I.e. *Human Ecology* embeds the technical systemic solutions with a systemic approach on the micro and macro level of societies. *Human Ecology* was developed originally by Robert Park (1864-1944) and Ernest Burgess (1886-1966) and evolved in Chicago in the 1920's in close connection to the field of city development. Here complex questions and challenges arose, ranging from e.g. i) fundamental technical questions of how to structure a city in terms of spatial use, transport of the basic supplies as energy and water, and the removal of waste, ii) of how to structure and organize social needs from governmental services and schools to commercial shopping malls to economic entities for production, as well as iii) cultural issues as how to plan a modern human city which allows everybody to achieve a fair share of the pursuit of happiness, whether one belonged to the poor or the wealthy part of society. By analysing the different stakeholders playing the fundamental roles there, the complex system challenges appearing were abstracted on the social level, since this was seen as the main issue of the – at that time – not yet in detail defined and worked out *Tragedy of the Commons*. Thus, *Human Ecology* classically deals with the complex interplay between i) the individual, ii) the society, and iii) the environment, which usually is symbolized in the so called *Human Ecology* triangle. This triangle is the paper tool representation and believed to be the core of the complex interplay factors in society. The framework has been used to investigate many a complex mankind related challenges as e.g. the exponential demand growth until reaching a limit, its inherent property of life and evolution, as well as waste and pollution related issues, i.e. in principle all the above mentioned tragedies. Obviously, these sustainability questions beyond the materialistic world are found on all evolutionary levels up to the psychological, societal and cultural one and involve also every cause for exponential growth, which is the major reason for reaching the natural unchangeable and thus unavoidable limits extremely fast.

Already, the *Tragedy of the Systemic Complexity* on the technical level shows that this rationalization and projection to three major constituents needs at least to be extended by a systemic approach on the technical level or better, the technical systemic approach must be embedded within the triangle. Beyond, the detailed analysis of the generic organization of the fossil and renewable energy as well as grid and cloud IT infrastructures proposed a micro and a macro level. Thus additionally, the detailed dissection of the *Inverse Tragedy of the Commons* by investigating the *Tragedy of Autopoietic Social Subsystems* and the *Tragedy of Security/Risk/Profit Psychology*, proposes the extension of the classical *Human Ecology* triangle to a rectangle consisting of: i) invironment, ii) individual, iii) society, and iv) environment

(Fig. 4). Consequently, here the invironment is added, since it is the core on which the individual is based or in other terms, due to the presence of the irrational part of the individual in respect to its security/risk/profit psychology, the latter can also be accounted for. Thus, the *Human Ecology* rectangle describes the relation between the invironment (Innenwelt), the individual, the society and the environment (Umwelt). The invironment and the environment as well as the individual and the society are complementary pairs and create a field. The invironment thereby constitutes the Innenwelt, the individual forms society, the individual society creates an environment as the invironment constitutes much of the society. And consequently, the rectangle reflects the micro level (invironment and individual) and the macro level (society and environment) correctly, or in retrospect the micro and macro level constitute each half of the *Human Ecology* rectangle. This fits the field of the *Classic* and *Inverse Tragedy of the Commons*, with its under-used potentials and over-used resources, i.e. means that both can be correspondingly overlaid and connections can be made accordingly. Consequently, the invironment is the missing link to reach systemic completeness of *Human Ecology*, and thus round it up to its full power in terms of usability concerning the management of systemic challenges as put forward by the renewable and grid IT challenges on a practical level. That means that the *Tragedy of Autopoietic Social Subsystems* as well as the *Tragedy of Security/Risk/Profit Psychology* which are the heart of the *Classic* and *Inverse Tragedy of the Commons* can not only be wrapped in a systemic framework which is complete in its constituents, but moreover, that this framework now can be really applied to the solution of the *Classic* and *Inverse Tragedy of the Commons* much better then with the *Human Ecology* triangle alone. This is important since without such a systemic framework and the internalized knowledge always perceived paradoxes will appear, which cannot be understood and thus cannot be resolved adequately on the level required. To reach its full power also in respect to the *Tragedy of the Systemic Complexity* on the technical level, additionally, now this needs to be extended again by a systemic approach on the technical level or better, the systemic approach must be embedded within the rectangle again, since without this technical level the complete system of technology, micro and macro level would again be not complete. Now this means nothing else than that the complete system of technical development and implementation has to be considered as well as the security/risk/profit psychology of the individual with its invironment and the autopoietic subsystem organization of society with its environment. On first sight this insight to take a holistic viewpoint and make that the basis for solving the issues involved with the renewable energy, grid IT or any other complex exploitation network seems natural and in principle is completely obvious – actually not even be worth thinking about. However, the fundamental issues and challenges faced in exploitation networks to be implemented to reach *Sustained Renewability*, i.e. to solve the problems of resource network limitations and thus to overcome the fundamental limits of energetic and material consumption growth reaching carrying capacity limits by the classic approach, are obviously there and demand urgent solutions in respect to the urge of the problems involved if nothing substantial is changed. Thus, the pure existence of the climate challenge shows the importance of a *Sustained Renewability* approach which overcomes the technical *Tragedy of Systemic Complexity* and the *Inverse Tragedy of the Commons*, in which resources are not unsustainably overexploited but in contrast used in a *Sustained Renewability* way holistically integrating the i) technical resource exploitation networks and ii) all the autopoietic social subsystems on a macro level as well as the psychology of individuals on the micro level, in an holistically
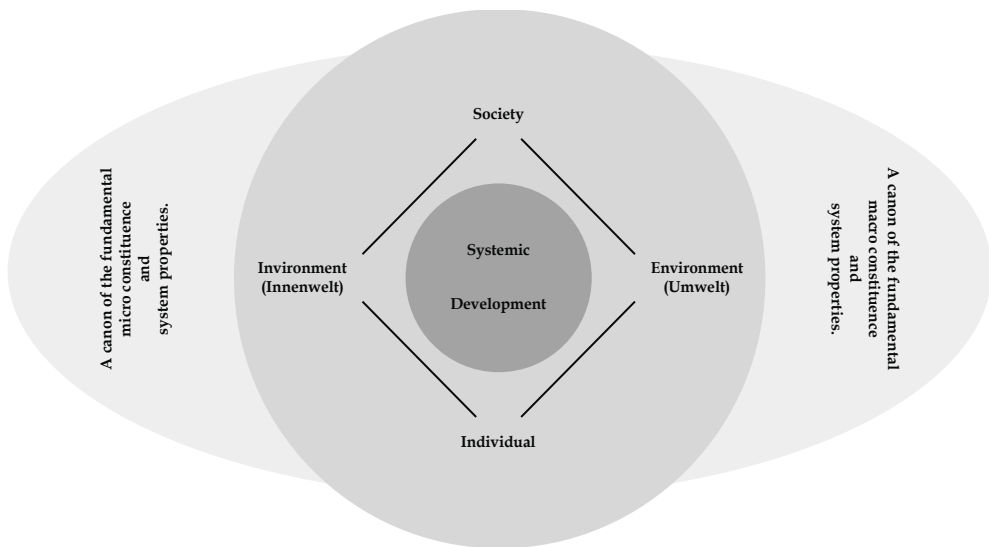
Fig. 4. The *Human Ecology* rectangle describes the relation between the invironment (Innenwelt), the individual, the society, and the environment (Umwelt). It is the extension of the incomplete classical *Human Ecology* triangle, which consists only of the individual, the society, and the environment but not the invironment. The invironment and the environment as well as the individual and the society are complementary pairs spanning a field between them. The invironment thereby constitutes the Innenwelt, the individual forms society, to the individual society gets a general environment as the invironment constitutes much of the society. Within the rectangle on each level the systemic aspects of each system and development thereof need to be encountered. To handle the invironment and the environment a canon of their micro and macro constituents and system properties is necessary.

systemic ecology like manner. Consequently, *Sustained Renewability* can be fundamentally defined according to the most fundamental and classic definition of the classic (biogene) ecology (Haeckel, 1866, 1898; Knoch, 2009, 2010):

*The Definition of Sustained Renewability and thus the Combination of
Technical Systemic Theory with Human Ecology:*

*"Under Sustained Renewability, i.e. Technical Systemic Human Ecology, we understand the
complete science of the relationships of Sustained Renewability to the surrounding environment to
which we can count all conditions of existence in the widest sense."*

*(Sustained Renewability is)... the relationship between the technical system complexity and all
micro/macro constituents of Human Ecology."*

10. Sustained renewability by systemic theory and human ecology means

Without doubt both the growth of the world population and the ever-new technologies
emerging from R&D – both creating ever higher needs as well as expectations – also the
energy and information amount to be acquired, stored, transformed, and finally used is
exponentially growing and due to the classic reductionist approach reaching the
fundamental limits and due to pollution also the carrying capacity of earth. Nevertheless, it
is also obvious that there are huge renewable energy and grid IT resources available as in
most other resource networks, concerning technical production or any social level. This
results in many opportunities of which most, however, are not realized, i.e. introduced and
internalized into society. In contrast, ever more resources are said to be required but
believed to be at their limit and thus already unavailable for further exploitation. Especially
in the energy and IT sector the demand still grows exponentially and is satisfied still with
antiquated solutions. Although exponential growth inevitably will lead to limits sooner or
later, there seems to be also many an opportunity to sustainably manage resources on very
long time scales. Thus, clever resource management can increase the efficiency
tremendously and in consequence avoid limiting barriers as e.g. integrated chemical
production or sophisticated agro-forestry systems show. Renewable energy and grid IT
infrastructures are believed to be such solutions which exploit under-used and available
resources by a *Systemic Renewability* approach, which in principle is based on a simple
holistic systemic analysis of the technical systemic complexity combined with a *Human
Ecology* approach. Both have in common that their technological turnover rates are faster
than in classic dinosaur approaches, although especially the grid IT sector with its fast
technological turnover rates, however, allows to bring innovation opportunities very fast to
the market and thereby increase the efficiency from the resource to usage tremendously.
This could results on the one hand in lower investments into infrastructure, which
obviously would provoke large resistance by the producing industry, or on the other hand
results in a much higher output and thus return of investment made by society in these
infrastructures, which would give a big "present" with only minor further investment to
society as a whole. Nevertheless, it remains a big issue despite all the efforts of the
renewable, the grid IT, and any other resource exploitation sector, why the obvious huge
benefits of much higher resource exploitation network efficiencies is so hard to internalize
into societies despite its crystal clear benefits concerning the fundamental limits of resource
exploitation, carrying capacities as well as economic, social and cultural benefits already in
the short but even much more so in the long term.

The *Tragedy of the Systemic Complexity* shows already what complex exploitation networks
mean, since in reality a complex network of resources and exploitation based on the
availability of the same and other resources exist instead of a nevertheless complex

exploitation chain. Thus, an exploitation network makes naturally the situation tremendously more complex than just a complex exploitation chain due to the number of i) non-linear, ii) nested, and thus in the end iii) exponentially recursively linked interactions of these components since they are even higher, more complex, and more dependent on each other. Especially the recursive dependence on the primary exploitation chain by the secondary, i.e. that also the secondary exploitation chains nested on each of the primary exploitation chain levels need e.g. energy or IT resources to be able to function, is here the main driver of complexity increase. The influence is now not only non-linear but also adds many an exponential interaction, which can in- or decrease the importance of a small tiny factor somewhere in the exploitation network enormously. Consequently, for a highly efficient exploitation of such networks, all single steps have to be optimized in a systemic manner to guaranty a careful exploitation of the primary and all other involved resources. Actually the exploitation network becomes now also a general resource network. This has huge consequences for the implementation of a highly systemic exploitation network by individuals and society, since all individual components have to be optimized themselves with respect to all other components as well as the complete complex hyper systemic exploitation network. Therefore, the classic reductionistic approach is unavoidable as long as it finally ends in a holistically reintegrated systemic result. Consequently, for a highly efficient energy and IT resource exploitation this is the vital core of *Sustained Renewability*, since only then also primary renewable resources are not compromised by the limits and since only then enough resources will be – on human time scales – always be available to exploit this primary resource and thus sustain its exploitation. Thus, the technical level requires a holistic systemic approach for *Sustained Renewability*.

Beyond, the organizational architecture analysis of renewable energy and grid IT infrastructures as well as their management shows that there are four levels of stake-holders involved: i) users, ii) organizing broker organizations, iii) producer or provider organizations, and iv) individual producers or providers. That is a much more complicated than the integrated production in chemical industry, since here one has a large spatial and cultural coverage in contrast to the "internal" situation of one single company. There is also a big difference to sophisticated agro-forestry systems as e.g. those in Indonesia, since these systems had a huge temporal time span for development. Although they involve in principle the entire society, the decisions are still taken by the single farmer and community despite their a posteriori internalization in tradition and cultural rules. Abstraction of the four levels involved in grid infrastructures leads to a micro level from which a macro level emerges, having again an influence on the micro level and vice versa. The micro level is constituted by an invironment and the macro level creates an environment, which already constitutes the *Human Ecology* rectangle as was shown. Consequently, here from the pure theoretical viewpoint not only complete consistency was reached proving the validity of the arguments, but also access to a "tool box" was gained to be used successfully for complex internalization issues. This is important for generalization and for justification of the thereof derived management measures. Beyond, the fact that renewable and grid IT resources are completely underused attributes to the phenomenon of the *Inverse Tragedy of the Commons*, i.e. that the resources are not overexploited unsustainably until their destruction. Together with the finding of the micro and macro level in the organization of grid organizations which plays the important role in both the *Classic* and *Inverse Tragedy of the Commons* lead to

responsibility diffusion and thus inefficient resource management. This, consequently, makes clear that the grid challenge concerning implementation and integration of grids lies in the social embedding of the micro and macro level phenomena: i) the attitude/socialisation based on the security/risk/profit psychology of the individual, and ii) the culture of the embedding institution and society based on the interaction of the autopoietic social subsystems. This is similar for the renewables as well as the grid IT sector and also has huge implications for any other complex resource exploitation network sector. Considering the macro level more in detail reveals that the autopoietic subsystems theory describes the social environment best. Unfortunately, the social subsystems i) religion, ii) education, iii) science, iv) art, v) economy, vi) jurisdiction, and vii) policy, have a more or less incompatible code of communication which leads to the *Tragedy of the Autopoietic Social Subsystems* and thus to large inconsistencies and blockings. Consequently, the challenge lies in the integration of autopoietic subsystems towards a working society on the micro and macro level by i) approaching the subsystem stickiness of individuals, and ii) the soft bridging of subsystems. In the daily work individuals have first to realize their own working and borders of their and other social subsystems. In a second step the possible bridges between social subsystems need to be realized and concrete ways to circumvent inherent blockings have to be explored to reach the level of a joined effort realization. On the micro level the security/risk/profit psychology matrix plays the major role since for the individual each internalization of a new technology is based on a positive relation between the security/risk/profit involved. Even for clear win-win situations the phenomenon of responsibility diffusion can appear. Since individuals have to balance constantly between the invironment and the environment, i.e. between psychology and social subsystems, there appears also a hard to tackle *Tragedy of the Security/Risk/Profit Psychology*. Consequently, the challenge on the micro and macro level are given by i) the individual perception and the individual well being, and ii) the procedural and institutionalized careful management. I.e. for the daily work that the individual need to rationalize its own behavioural background and invironmental constituency, and that institutions need to accept and develop the invironment of their employees as well as the psychological status of the environment they create. Thus, the creation of awareness might not change the individual but by team formation with different characters and corresponding procedures, the openness in an institutionalized form can increase the internalization of new technologies.

Consequently, to overcome the challenges put forward by the *Tragedy of the Systems Complexity*, and the *Classic* and *Inverse Tragedy of the Commons* with its base tragedies, the Tragedy of Autopoietic Social Subsystems and the *Tragedy of Security/Risk/Profit Psychology* in the renewable energy and grid IT sector, a *Sustained Renewability* approach in a holistic ecology-like manner combining the micro and macro level is crucial for in principle every resource and exploitation network. The interdisciplinary field of *Human Ecology* gives a framework also for the understanding and approaching of the *Classic* and *Inverse Tragedy of the Commons* for direct guidelines in the day-to-day management of grids as well as other areas and combine the above into a unified framework. Theoretically, the analysis carried out here showed that it is necessary to extent the classical *Human Ecology* triangle to a rectangle with i) the invironment ii) the individual, iii) the society, and iv) the environment. Thus, from the pure theoretical viewpoint, not only complete consistency was reached proving the validity of the arguments, but also access to a "tool box" – which has been used already successfully – was gained. This is important for generalization and justification of

thereof derived management measures. To reach its full power also in respect to the *Tragedy of the Systemic Complexity* this needs to also embed a systemic approach on the technical level, since without this technical level the complete system of technology, micro and macro level would again be not complete. Now this means nothing else than that the complete system of technical development and implementation has to be considered as well as the security/risk/profit psychology of the individual with its invironment and the autopoietic subsystem organization of society with its environment. On first sight this insight to take a holistic viewpoint and make that the basis for solving the issues involved with the renewable energy, grid IT, or any other complex exploitation network seems natural and in principle completely obvious – actually not even to be worth thinking about. However, the fundamental issues and challenges faced in exploitation networks to be implemented to reach *Sustained Renewability*, i.e. to solve the problems of resource network limitations and thus to overcome the fundamental limits of energetic and material consumption growth reaching carrying capacity limits by the classic approach, are obviously there and demand urgent solutions in respect due to the urge of the problems involved if nothing substantial is changed. Thus, the pure existence of the climate challenge shows the importance of a *Sustained Renewability* approach, which is characterized by investigating all detailed factors involved for a certain resource and the challenges of an exploitation super-network can be overcome. Thus, then the technical Tragedy of Systemic Complexity and the *Inverse Tragedy of the Commons* can be overcome since resources are not unsustainably overexploited but used in a *Sustained Renewability* way by holistically integrating the i) technical resource exploitation networks and ii) all autopoietic social subsystems on a macro level as well as the psychology of individuals on the micro level, in an holistically systemic ecology like manner – or in short in a *Sustained Renewability* approach.

11. Conclusion

The worldwide amount of energy and IT resources to sustain human life is – with the classic exploitation and usage strategies – fast reaching the limits and carrying capacity. Nevertheless, huge underused energy and IT resources are obviously available and often even renewable on a human scale. Therefore, the *Tragedy of Systemic Complexity* already on the technical level and the *Inverse Tragedy of the Commons* have to be overcome for the renewable energy as well as the grid IT sectors by combining solutions of the systemic resource and exploitation networks with solutions of all autopoietic social subsystems on a macro level as well as the psychology of individuals on the micro level, i.e. a technical systemic solution is combined with an extended *Human Ecology* paradigm. Thus, not only advanced underused resources can be implemented and internalized, but also *Sustained Renewability*, i.e. a long lasting resource exploitation and renewable cycles can be managed – for on human scales – large time spans with paradisiacal opportunities for the life on earth.

12. Acknowledgements

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Renewable Energy Use and Energy Efficiency – A Critical Tool for Sustainable Development

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1. Introduction

Energy efficiency and renewable energy are the "twin pillars" of a sustainable energy policy. Both strategies must be developed concurrently in order to stabilize and reduce carbon dioxide emission (American Council for an Energy-Efficient Economy, 2007). Efficient energy use is essential to slowing the energy demand growth so that rising clean energy supplies can make deep cuts in fossil fuel use. If energy use grows too rapidly, renewable energy development will chase a receding target. Likewise, unless clean energy supplies come online rapidly, slowing demand growth will only begin to reduce total carbon emissions; a reduction in the carbon content of energy sources is also needed. A sustainable energy economy thus requires major commitments to both efficiency and renewable (American Council for an Energy-Efficient Economy, 2007).
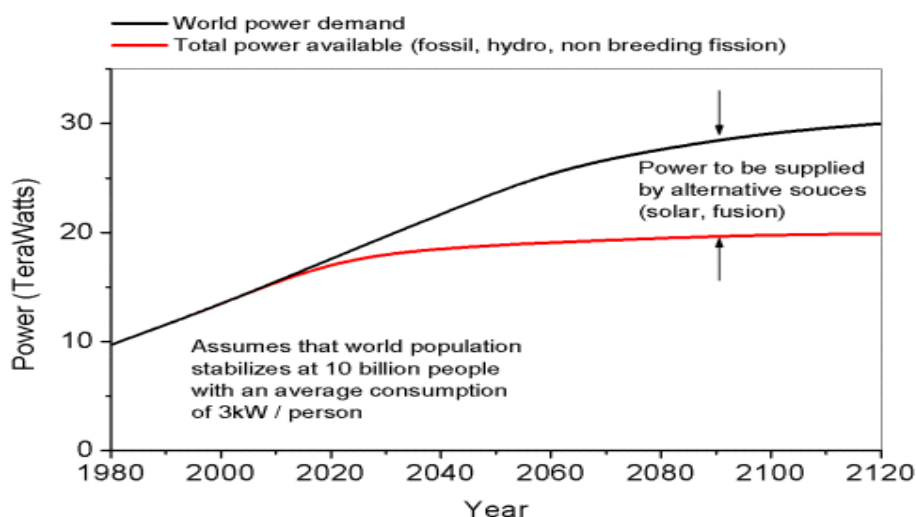
Estimates of the world energy use indicate that the demand for energy, by the middle of the 21st Century, may significantly exceed the energy supplied by conventional sources. The shortfall in energy becomes larger after the depletion of fossil fuels, about 100 years in the future. Source: http://www.plasma.inpe.br

Renewable energy is energy which comes from natural resource such as sunlight, winds, plants growth, rain, tides and geothermal heat which are naturally replenished.

The first law of thermodynamic says that the total amount of energy on our planet remains constant. The second law states that as forms of energy are expended they become less easily available. That is entropy: the slow winding down of available energy (Jacobson, 2009).

- First law of thermodynamics: *A change in the internal energy of a closed thermodynamic system is equal to the difference between the heat supplied to the system and the amount of work done by the system on its surroundings.*

The first law of thermodynamics asserts the existence of a state variable for a system, the internal energy, and tells how it changes in thermodynamic processes. The law allows a given internal energy of a system to be reached by any combination of heat and work. It is important that internal energy is a variable of state of the system whereas heat and work change the state of the system.

The first law observes that the internal energy obeys the principle of conservation of energy, which states that energy can be transformed (changed from one form to another), but cannot be created or destroyed.

- Second law of thermodynamics: *Heat cannot spontaneously flow from a colder location to a hotter location.*

The second law of thermodynamics is an expression of the universal principle of decay observable in nature. The second law is an observation of the fact that over time, differences in temperature, pressure, and chemical potential tend to even out in a physical system that is isolated from the outside world. Entropy is a measure of how much this process has progressed. The entropy of an isolated system which is not in equilibrium will tend to increase over time, approaching a maximum value at equilibrium.

When coal, gas or oil is burnt, it rapidly converts a relatively easily available and concentrated source of energy into a much less available form: dispersed exhaust gases.

A high concentrated energy source, built up over millions of years quickly gone up in smoke. So, burning fossil fuels is high-entropy way of using energy.

Using renewable energy however merely taps into a natural flow of energy, sunlight, moving water, wind, biological or geothermal process. These are part of natural cycles of highs and lows. Their energy is truly renewable as it remains available to the same degree and is not depleted any more than it otherwise would be by using it.

Renewable energies include wind, ocean, wave and tides, solar, biomass, rivers, geothermal (heat of the earth) etc. They are renewable because they are regularly replenished by natural processes and are therefore in endless supply (Fatona, 2009; Jacobson, 2009). They also can operate without polluting the environment. Technologies have been developed to harness these energies and such technologies are called renewable energy technologies (RET) or sometime also called "Clean technologies" or "Green energy" (Pearce et al, 1989). Because renewable energy are constantly being replenished from natural sources, they have security of supply, unlike fossil fuels, which are negotiated on the international market and subject to international competition, sometimes may even resulting in wars and shortages. They have important advantages which could be stated as follows:-

1. Their rate of use does not affect their availability in future, thus they are inexhaustible.
2. The resources are generally well distributed all over the world, even though wide spatial and temporal variations occur. Thus all regions of the world have reasonable access to one or more forms of renewable energy supply.

3. They are clean and pollution-free and therefore are sustainable natural form of energy.
4. They can be cheaply and continuously harvested and therefore sustainable source of energy.

Unlike the nuclear and fossil fuel plants which belong to big companies, governments, or state around enterprises, renewable energy can be set up in small units and is therefore suitable for community management and ownership. In this way, value from renewable energy projects can be kept in the community.

Transition from fossil fuels to renewable energy will not result in net job losses or cause harm to the economy. Renewal energy technologies (RETs) are labour intensive, and can produce more jobs than fossil fuel or nuclear industries. When RETs are properly integrated into national development plans and implemented, they can substantially reduce greenhouse gas emissions and simultaneously increase employment (Pearce et al, 1989). Moreover, it will also enhance energy security by reducing reliance on oil, preserve the competitiveness of energy, lead to savings for consumers and provide transitional assistance to workers in negatively affected industries and communities. With the right approach the interest of working families and the environment can come together (Pearce et al, 1989).

2. What is energy efficiency?

Energy efficiency means improvement in practice and products that reduce the energy necessary to provide services like lightning, cooling, heating, manufacturing, cooking, transport, entertainment etc. Energy efficiency products essentially help to do more work with less energy. Thus, the efficiency of an appliance or technology is determined by the amount of energy needed to provide the energy service. For instance, to light a room with an incandescent light bulb of 60w for one hour requires 60w/h. A compact florescent light bulb would provide the same or better lighting at 11w and only use 11w/h. This means that 49w (82% of energy) is saved for each hour the light is turned on.

Making homes, vehicles, and businesses more energy efficient is seen as a largely untapped solution to addressing the problems of pollution, global warming, energy security, and fossil fuel depletion. Many of these ideas have been discussed for years, since the 1973 oil crisis brought energy issues to the forefront. In the late 1970s, physicist Amory Lovins popularized the notion of a "soft energy path", with a strong focus on energy efficiency. Among other things, Lovins popularized the notion of negawatts—the idea of meeting energy needs by increasing efficiency instead of increasing energy production (Krech, 2004).

Lovins viewed the energy problem not one of an insufficient supply of oil and other conventional energy sources, but rather as one of inefficient energy use, coupled with lack of development of renewable energy sources. Lovins argued that conventional energy production was both energy intensive and a source of substantial pollution. With his reformulation of the energy problem, "environmentalists criticized plans for large-scale energy developments, especially those relying heavily on nuclear power".

The "soft energy path" assumes that energy is but a means to social ends, and is not an end in itself. Soft energy paths involve efficient use of energy, diversity of energy production methods (matched in scale and quality to end uses), and special reliance on co-generation and "soft energy technologies" such as solar energy, wind energy, bio-fuels, geothermal energy, wave power, tidal power, etc (Nash, 1979).

Soft energy technologies (appropriate renewables) have five defining characteristics. They (1) rely on renewable energy resources, (2) are diverse and designed for maximum effectiveness in particular circumstances, (3) are flexible and relatively simple to understand, (4) are matched to end-use needs in terms of scale, and (5) are matched to end-use needs in terms of quality (Nash, 1979).

Residential solar energy technologies are prime examples of soft energy technologies and rapid deployment of simple, energy conserving residential solar energy technologies is fundamental to a soft energy strategy. Active residential solar technologies use special devices to collect and convert the sun's rays to useful energy and are located near the users they supply. Passive residential solar technologies involve the natural transfer (by radiation, convection and conduction) of solar energy without the use of mechanical devices.

Lovins argued that besides environmental benefits, global political stresses might be reduced by Western nations committing to the soft energy path. In general, soft path impacts are seen to be more "gentle, pleasant and manageable" than hard path impacts. These impacts range from the individual and household level to those affecting the very fabric of society at the national and international level.

Lovins recognised that major energy decisions are always implemented gradually and incrementally, and that major shifts take decades. A chief element of the soft path strategy is to avoid major commitments to inflexible infrastructure that locks us into particular supply patterns for decades.

Lovins explained that the most profound difference between the soft and hard paths — the difference that ultimately distinguishes them — is their different socio-political impact. Both paths entail social change, "but the kinds of social change for a hard path are apt to be less pleasant, less plausible, less compatible with social diversity and freedom of choice, and less consistent with traditional values than are the social changes which could make a soft path work".

Moving towards energy sustainability will require changes not only in the way energy is supplied, but in the way it is used, and reducing the amount of energy required to deliver various goods or services is essential. Opportunities for improvement on the demand side of the energy equation are as rich and diverse as those on the supply side, and often offer significant economic benefits.

In most places, a lot of energy is wasted because industries, power companies, offices and households use more energy than is actually necessary to fulfill their needs. The reasons is because they use old and inefficient equipment and production processes; buildings are poorly designed; and because of bad practices and habits. With energy efficiency practices and products, nations can save over 50% of the energy being consumed. Using energy more efficiently would:

1. Reduce electricity bills.
2. Leave more energy available to extend energy supply to all parts of the population.
3. Increase the efficiency and resilience of the economy – including reduced reliance on oil and thus improve balance of payments.
4. Improve industries competitiveness internationally.
5. Minimize the building of new power stations and thus free up capital for other investments like health and welfare.

6. Reduce the negative environmental and human health impacts from energy production and use.
7. Increase employment through interactions e.g. in industry, housing, transport.

3. Renewable energy and sustainable development

The World Summit on Sustainable Development (WSSD) in Johannesburg in 2002 recognized the important role of energy for reaching millennium development goals. Access to affordable, reliable and sustainable energy is essential to sustainable development (Hasna, 2007). An adequate solving of energy problems will contribute to achieving progress across all pillars of sustainable development; social, economic and environmental and in meeting the UN millennium goals. Although there are no MDGs on access to energy, WSSD recognized that inadequate access to energy is both a cause and an effect of poverty and recommended the following:

"*Take joint actions and improve efforts to work together at all levels to improve access to reliable and affordable energy service for sustainable development sufficient to facilitate the achievement of the Millennium Development Goals, including the goal of halving the proportion of people in poverty by 2015, and as a means to generate other important services that mitigate   poverty, bearing in mind that access to energy facilitates the eradication of poverty*" .

"Sustainable development" has been defined best by the Brundtland Commission as development that meets the needs of the present without compromising the ability of future generations to meet their own needs (Hasna, 2007). Adequate and affordable energy supplies has been key to economic development and the transition from subsistence agricultural economics to modern industrial and service oriented societies. Energy is central to improved social and economic well being and is indispensable to most industrial and commercial wealth organization. It is the key for relieving poverty, improving human welfare and raising living standards. But however essential it may be for development, energy is only a means to an end. The end is good health, high living standards, a sustainable economy and a clean environment.

Much of the current energy supply and use, based as it is, on limited resources of fossil fuels, is deemed to be environmentally unsustainable. There is no energy production or conversion technology without risk or waste. Somewhere along all energy chains - from resource extractions to the provision of energy service – pollutants are produced, emitted or disposed of, often with severe health and environmental impacts (Dasgupta, 2001; Fatona, 2009). Combustion of fossil fuels is chiefly responsible for urban air pollution, regional acidification and the risk of human – induced climate change (Dasgupta, 2001; Fatona, 2009). Achieving sustainable economic development on a global scale will requires the judicious use of resources, technology, appropriate economic incentives and strategic policy planning at the local and national levels. It will also require regular monitoring of the impacts of selected policies and strategies to see if they are furthering sustainable development or if they should be adjusted (Arrow et al, 2004).

When choosing energy fuels and associated technologies for the production, delivery and use of energy services, it is essential to take into account economic, social and environmental consequences (Ott, 2003; Wallace, 2005). There is need to determine whether current energy use is sustainable and, if not, how to change it so that it is. This is the purpose of energy indicators, which address important issues within three of the major dimensions of sustainable development: economic, social and environmental.

4. Energy indicators for sustainable development

4.1 Social dimension

SOC1: Share of households (or population) without electricity or commercial energy, or heavily dependent on non-commercial energy
- Households (or population) without electricity or commercial energy, or heavily dependent on non-commercial energy
- Total number of households or population

SOC2: Share of household income spent on fuel and electricity
- Household income spent on fuel and electricity
- Household income (total and poorest 20% of population)

SOC3: Household energy use for each income group and corresponding fuel mix
- Energy use per household for each income group (quintiles)
- Household income for each income group (quintiles)
- Corresponding fuel mix for each income group (quintiles)

SOC4: Accident fatalities per energy produced by fuel chain
- Annual fatalities by fuel chain
- Annual energy produced

4.2 Economic dimension

ECO1: Energy use per capita
- Energy use (total primary energy supply, total final consumption and electricity use)
- Total population

ECO2: Energy use per unit of GDP
- Energy use (total primary energy supply, total final consumption and electricity use)
- GDP

ECO3: Efficiency of energy conversion and distribution
- Losses in transformation systems including losses in electricity generation, transmission and distribution

ECO4: Reserves-to-production ratio
- Proven recoverable reserves
- Total energy production

ECO5: Resources-to-production ratio
- Total estimated resources
- Total energy production

ECO6: Industrial energy intensities
- Energy use in industrial sector and by manufacturing branch
- Corresponding value added

ECO7: Agricultural energy intensities
- Energy use in agricultural sector
- Corresponding value added

ECO8: Service and commercial energy intensities
- Energy use in service and commercial sector
- Corresponding value added

ECO9: Household energy intensities
- Energy use in households and by key end use

- Number of households, floor area, persons per household, appliance ownership

ECO10: Transport energy intensities

- Energy use in passenger travel and freight sectors and by mode
- Passenger-km travel and tonne-km freight and by mode

ECO11: Fuel shares in energy and electricity

- Primary energy supply and final consumption, electricity generation and generating capacity by fuel type
- Total primary energy supply, total final consumption, total electricity generation and total generating capacity

ECO12: Non-carbon energy share in energy and electricity

- Primary supply, electricity generation and generating capacity by non-carbon energy
- Total primary energy supply, total electricity generation and total generating capacity

ECO13: Renewable energy share in energy and electricity

- Primary energy supply, final consumption and electricity generation and generating capacity by renewable energy
- Total primary energy supply, total final consumption, total electricity generation and total generating capacity

ECO14: End-use energy prices by fuel and by sector

- Energy prices (with and without taxes or subsidies)

ECO15: Net energy import dependency

- Energy imports
- Total primary energy supply

ECO16: Stocks of critical fuels per corresponding fuel consumption

- Stocks of critical fuel (e.g. oil and gas)
- Critical fuel consumption

4.3 Environmental dimension

ENV1: Greenhouse gas (GHG) emissions from energy production and use, per capita and per unit of GDP

- Population and GDP

ENV2: Ambient concentrations of air pollutants in urban areas

- Concentrations of pollutants in air

ENV3: Air pollutant emissions from energy systems

- Air pollutant emissions

ENV4: Contaminant discharges in liquid effluents from energy systems

- Contaminant discharges in liquid effluents

ENV5: Soil area where acidification exceeds critical load

- Affected soil area
- Critical load

ENV6: Rate of deforestation attributed to energy use

- Forest area at two different times
- Biomass utilization

ENV7: Ratio of solid waste generation to units of energy produced

- Amount of solid waste
- Energy produced

ENV8: Ratio of solid waste properly disposed of to total generated solid waste
- Amount of solid waste properly disposed of
- Total amount of solid waste

ENV9: Ratio of solid radioactive waste to units of energy produced
- Amount of radioactive waste (cumulative for a selected period of time)
- Energy produced

ENV10: Ratio of solid radioactive waste awaiting disposal to total generated solid radioactive waste
- Amount of radioactive waste awaiting disposal
- Total volume of radioactive waste

5. Dimensions of sustainable development

Sustainable development is essentially about improving quality of life in a way that can be sustained, economically and environmentally, over the long term supported by the institutional structure of the country (Adams, 2006; Chambers et al, 2000).
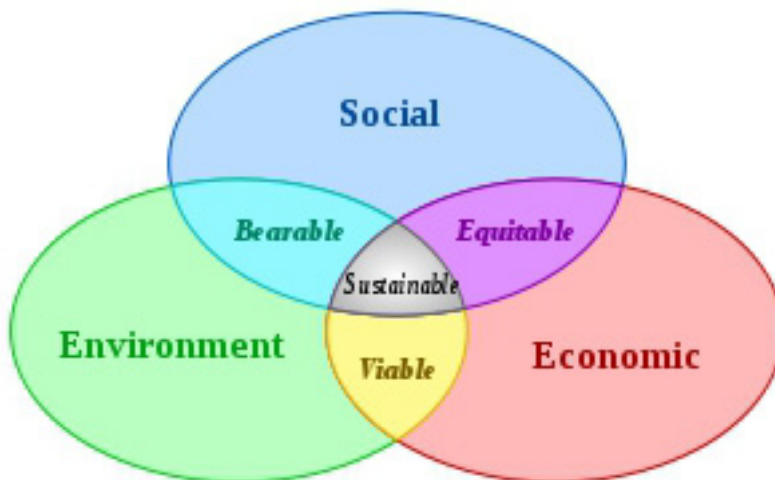
Scheme of sustainable development: at the confluence of three constituent parts

Social dimension:- Availability of energy has a direct impact on poverty, employment opportunities, demographic transition, pollution and health. Social equity is one of the principal values underlying sustainable development, involving the degree of fairness and inclusiveness with which energy resources are distributed, energy systems are made accessible and pricing schemes are formulated to ensure affordability. Energy should be available to all at a fair price.

The use of energy should not damage human health, but rather should improve it by improving conditions. Yet the production of non renewable has the potential to cause injury or disease through pollution generation or accidents. A social goal is to reduce or eliminate these negative impacts. The health indicators have the sub theme of safety, which covers accident fatalities caused by the extraction, conversion, transmission / distribution and use of energy. Oil rigs and particularly coal mines are subjected to accidents that injure, main or kill people. Oil refineries and power stations may release emissions into the air that cause lung or respiratory diseases.

Economic dimension:- Modern economics depend on a reliable and adequate energy supply, and developing countries need to secure this as a prerequisite for industrialization. All sectors of the economy – residential, commercial, transport, service and agriculture demand modern energy services. These services in turn foster economic and social development at the local level by raising productivity and enabling local income generation. Energy supply affects jobs, productivity and development.

The prices of end-use energy by fuel and sector have obvious economic importance. Efficient energy pricing is a key to efficient energy supply and use and socially efficient levels of pollution abatement.

Addressing energy security is one of the major objectives in the sustainable development criteria of many countries. Interruptions of energy supply can cause serious financial and economic issues. To support the goals of sustainable development, energy must be available at all times, in sufficient quantities and at affordable prices. Secure energy supplies are essential to maintain economic activities and providing reliable energy services to society.

Environmental dimension:- The production, distribution and use of energy create pressures on the environment in the household, workplace and city and at the national, regional and global levels. The environmental impacts can depend greatly on how energy is produced and used, the fuel mix, the structure of the energy systems and related energy regulatory actions and pricing structure. Gaseous emissions from the burning of fossil fuels pollute the atmosphere. Large hydropower dams cause silting. Both the coal and nuclear fuel cycles emit some radiation and generate waste. And gathering firewood can lead to deforestation and desertification Daly & Cobb, 1990; Hilgenkamp, 2005).

Water and land quality are important sub-themes of the environmental dimensions. Land is more than just physical space and surface topography; it is in itself an important natural resource, consisting of soil and water essential for growing food and providing habitat for diverse plant and animal communities. Non – renewable energy activities may result in land degradation and acidification that affect the quality of water and agricultural productivity.

Land is also affected by energy transformation processes that often produce solid wastes, including radioactive wastes, which require adequate disposal. Water quality is affected by the discharge of contaminants in liquid effluents from energy systems, particularly from the mining of non renewable energy resources, which is environmentally unsustainable (Daly & Cobb1990; Hilgenkamp, 2005).

Environmental sustainability is the process of making sure current processes of interaction with the environment are pursued with the idea of keeping the environment as pristine as naturally possible based on ideal-seeking behavior.

Consumption of renewable resources	State of environment	Sustainability
More than nature's ability to replenish	Environmental degradation	Not sustainable
Equal to nature's ability to replenish	Environmental equilibrium	Steady state economy
Less than nature's ability to replenish	Environmental renewal	Environmentally sustainable

An "unsustainable situation" occurs when natural capital (the sum total of nature's resources) is used up faster than it can be replenished. Sustainability requires that human activity only uses nature's resources at a rate at which they can be replenished naturally (Barbier, 2007). Inherently the concept of sustainable development is intertwined with the concept of carrying capacity. Theoretically, the long-term result of environmental degradation is the inability to sustain human life. Such degradation on a global scale could imply extinction for humanity.

6. Conclusion

There is an intimate connection between energy, the environment and sustainable development. A society seeking sustainable development ideally must utilize only energy resources which cause no environmental impact. Clearly, a strong relation exists between energy efficiency and environmental impact since, for the same services or products, less resource utilization and pollution is normally associated with increased energy efficiency.

Sustainable energy is the provision of energy that meets the needs of the present without compromising the ability of future generations to meet their needs. Sustainable energy sources are most often regarded as including all renewable energy sources, such as hydroelectricity, solar energy, wind energy, wave power, geothermal energy, bio-energy, and tidal power. It usually also includes technologies that improve energy efficiency.

Renewable energy technologies are essential contributors to sustainable energy as they generally contribute to world energy security, reducing dependence on fossil fuel resources and providing opportunities for mitigating greenhouse gases. As such, sustainable energy promotes sustainability. Sustainability, here, is twofold, as it constitutes self-sustenance and the ability to foster sustainable development.

By being self-sustaining the energy source is in essence limitless. Solar energy, wind energy, geothermal energy, hydropower and biomass are all self-sustaining. They all have sources that cannot be depleted. These energy sources allow for the conservation of other energy sources, like trees that would have been used for charcoal production. Using these "renewable" energies also encourages the protection of the environment which traditional energy sources have helped to destroy. The use of some traditional energy sources, like oil and charcoal, the Natural Resources Conservation Authority (NRCA) reported "carries with

it a number of environmental problems, such as water and air pollution and the contamination of soils." Utilizing sustainable energy would then lead to the conservation of the environment which would eventually lead to a development which meets the needs of the present, without compromising the ability of future generations to meet their own needs. In other words, sustainable energy use leads to sustainable development.

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4

Renewable Energy and Coal Use in Turkey

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1. Introduction

The development level of a country is directly related to its economical and social level. One of the most important factors that takes an active role in achieving such development level is energy. Energy, which is the requirement of sustainable development, can only be an impulsive force in industrialization and overall development of societies if it is supplied on time, with sufficient quantity and under reliable economical conditions and considering the environmental impacts. The demand for energy increases rapidly in parallel with the population increase, industrialization and technological developments in Turkey and the other developing countries in the world.

Turkey has been developing since the foundation of the Republic of Turkey in 1923. Turkish Government played a leading role in energy production and in energy use, as well as in other fields, and implemented several policies to increase electricity production. By 1950s, thermal power plants were used commonly in electricity production. In the following years, hydroelectric power plants were put into operation in order to use the considerable amount of water resources of the country. Coal-fired power plants using national resources accounted for 70–80% of the thermal electricity production. After 1960s, oil, an imported resource, was replaced with national resources due to two petroleum crises. Therefore, the proportion of use of lignite in the energy field increased. By 1980s, energy production lead by the government went on. Afterwards, applications of liberal economy policies resulted in implementation of different energy production methods, and the country had a increasing tendency to meet energy demand by imports as a result of improvement in international economic relations. Natural gas became prevalent in the country as well as all over the world and accounted for 50% of the electricity production in 2009 (Fig 1, Table 1).

On the eve of 21st century, Turkey was unable to meet its energy requirement with its limited sources as a result of the increasing population and industrialization and thus the deficit between the energy production and energy consumption increased rapidly. Under such conditions, utilizing own resources more effectively had become more important increasingly day by day. Turkey became more dependent on imports year to year. It still supplies about 71% of its primary energy consumption from imported energy sources. This percentage is 59% for electricity production. It is now vital for Turkey to attach importance to coal and renewable energy sources, which are the largest domestic energy sources of Turkey, in order to meet this increasing energy deficit. Especially, it is possible to produce electricity using the said domestic sources.

• Population	73.722.988 (2010)
• Gross national product (GNP)	615 billion $
• GNP per capita	8.215 $/person
• Primary energy production	30.328 ktoe (thousand tons of oil equivalent)
• Distribution of primary energy production	Lignite 52%,wood 12%, hydraulic 10%, Petroleum 8%,hard coal 4%, other 14 %
• Primary energy consumption	104.117 Ktoe
• Distribution of primary energy consumption	Petroleum 29 %, natural gas 31 %, lignite 15 %, hard coal 14 %, hydraulic 3 %, other 8 %.
• Distribution of primary energy consumption by sectors	Industry 23 %,residential 27 %, transportation 15%, energy 25%, other 10%
• Rate of primary energy [production/consumption]	29 %
• Primary energy consumption per capita	1435 Koe (Kilogram oil equivalent)
• World primary energy consumption per capita	1710 Koe
• Installed capacity	44.761 MW
• Distribution of installed capacity by primary energy sources	Renewable 35 %, natural gas 26 %, lignite 18 %, petroleum 4 %, imported coal 5 %, hard coal 1%, other 11 %
• Electricity generation	194.813 GWh
• Distribution of electricity generation by primary energy sources	Natural gas 49 %, renewable 19%, lignite 20 %, petroleum 3%, imported coal 6 %, hard coal 2 %, other 1 %.
• Electricity gross consumption	194.079 GWh
• Electricity gross generation per capita	2.685 kWh/person
• Electricity net consumption per capita	2.162 kWh/person
• Word electricity generation	20.202 billion kWh (2008)
• Word electricity consumption	16.880 billion kWh (2008)
• World electricity generation by primary energy sources	Coal 42%,natural gas 21%, nuclear14 %, hydraulic 16%, petroleum 6%, biomass 3%, other 4 %. (2007)
• World electricity production per capita	3012 kWh/person (2008)
• World electricity consumption per capita	2516 kWh/person (2008)

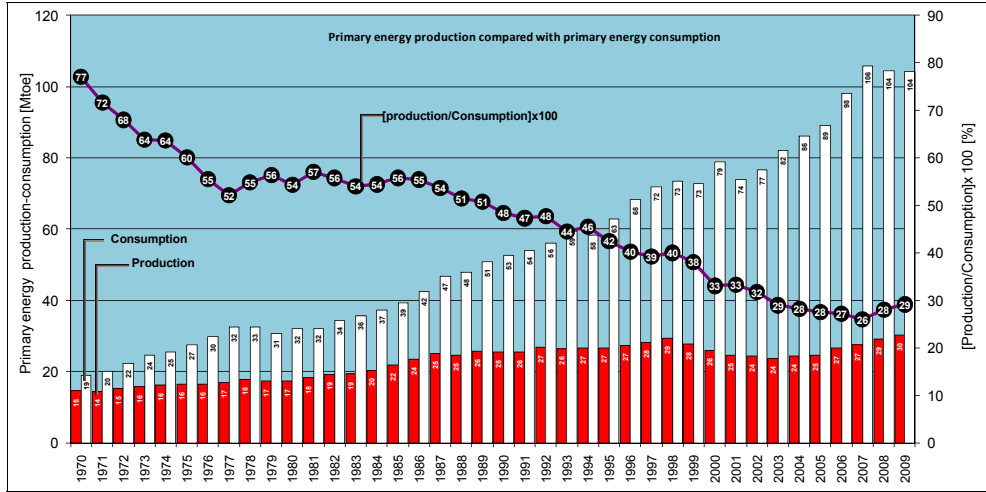Table 1. Energy Profile of Turkey (2009)

Fig. 1. During period of 1970-2009, primary energy production-consumption and rates of production and consumption (data from MENR,1970-2009)

In this chapter, the primary energy production– consumption of renewable energy sources of Turkey and coal as well as the development of their use rates in electricity production are discussed for a definite time period. In addition, some information is given about the projected use rates of such energy sources in energy production and projected consumption in Turkey for the years 2015 and 2020.

2. Energy outlook of Turkey

When the Republic of Turkey was founded in 1923, Turkey's population was 12 million. Installed capacity of electricity production, total electricity production, per capita electricity production and per capita electricity consumption were 33MW, 45 GWh, 3.6kWh and 3.3 kWh, respectively. Initially, almost all electricity demand was met by thermal power plants. The foundation of the Turkish Republic became the start of the development of the country. In 2009 year, the population has reached 73,7 million increasing about by six fold. In 2009 year, installed capacity reached 44.761MW increasing about by 1356-fold, electric production reached to 194.813 GWh increasing by 4329-fold. Per capita electricity production and electricity consumption reached 2685 and 2162 kWh increasing by 745-fold and by 655-fold, respectively. In 2009 year, primary energy production and consumption were 30.328 Ktoe and 104.117 Ktoe respectively. Also, distributions of primary energy production were lignite 52%, wood 12%, hydraulic 10%, hard coal 4%, and petroleum 8%. Distribution of primary energy consumptions were petroleum, natural gas, lignite, hard coal, hydraulic and other 29%, 32 %, 15%, 14 %, 3 % and 8%, respectively (Table 1). The net effect of all these factors is that Turkey's energy demand has grown rapidly almost every year and is expected to continue growing (Arıoğlu and Yılmaz, 1997a; SIS, 2003,2004; Yılmaz, 2003, 2004,2011; TEIAS, 2004, 2009; Yılmaz and Uslu 2007; BP, 2009).

Energy has been the most important investment sector over the world. Turkey's energy needs are increasing quickly. Primary energy production-consumption and rates of production and

consumption are illustrated in Fig.1. Since Turkey is an energy importing country more than about 70% of the country's energy consumption is met by imports, and the share of imports is growing in the following years. While the primary energy consumption in 1970 was 18.84 mtoe, it reached 104 mtoe (million ton oil equivalent) with an increase rate of 552% in 2009. Primary energy production and consumption rates realized 1.39% and 4.29% per year, respectively. In other words, increase in consumption is three times bigger than the increase in production. While the ratio that production meets consumption was 77 % in 1970, this ratio reduced and reacted to 29 % in 2009. In other words, Turkey has been a country that depends on other countries in energy fields, especially in terms of oil and natural gas. (Fig. 1). (Yılmaz, et al, 2005; Yılmaz, 2003; Yılmaz and Arıoğlu 2003; Yılmaz and Uslu, 2007; Yılmaz 2006; Yılmaz 2009; Yılmaz 2011; Arıoğlu 1994; Arıoğlu 1996).

Distribution of total electricity generation by energy resources during the period 1940–2009 is shown in Fig 2. As seen in the figure, renewable, oil-natural gas and coal accounted for 8%, 6%, 86 of electricity production in 1940. The share of the coal reduced continuously in the following years and reached as 55% in 1960, 25% in 1980 and again increased to 29%(imported coal included) in 2009. The increase rate of use of renewable energy sources was accelerated especially from 1960s, as seen in the electricity production capacity, and use rate of renewable energy sources was recorded as 8 % in 1940, 37% in 1960, 52% in 1980 and decreased to 19% in 2009. Because, after the year 2000, a sharply increase in share of imported natural gas in electricity production, lowered the use of domestic lignite and hard coal. Turkey is dependent on foreign countries especially in terms of oil and natural gas. In 1960, imported oil made up 8% of electricity production and this rate abruptly increased in the after years and it's had been reached 30% in 1970. During period 2000s years, imported of the natural gas sharply increased and reacted to 50% in 2009. Natural gas has been fast-growing fuel of energy market in Turkey. The tremendous growth and increased trend in gas demand during the period 1990-2009 showed that Turkey will need much more gas in the following years. Especially the share of the natural gas consumed in electricity generation has sharply increased and is considered to increase also in the future (Yılmaz 2008; Yılmaz 2011).

Turkey became more dependent on imports year to year. It still supplies about 71% of its primary energy consumption from imported energy sources. This percentage is 59% for electricity production. These rates are exactly seen in Fig 3. and Fig. 4 during of the period 1970-2009. In Fig 3 show that Turkey's primary energy consumption was 77% share of the domestic energy sources in 1970. While 54% of the consumed energy in 1980 was by the domestic energy sources, this percentage decreased to 33% and 29% in 2000 and 2009 respectively. On the other hand, share of the imported energy sources was increased from 23% in 1970 to 71% in 2009. In Figure 4 distribution of electricity production by domestic and imported energy sources are given in historical order. As seen in Figure, while domestic energy sources had a share of 68% in electricity production in 1970, imported energy sources had a share of 42% in electricity generation. After the 1970s years, oil crisis started. Turkey gave importance on lignite, coal and own renewable energy potential sources. So the rate of electricity production using Turkey's domestic sources was increased. But in 1990s use of imported natural gas in electricity production has sharply increased to 45% and 59% in 2000 and 2009 respectively. It is now vital for Turkey to attach importance to coal and renewable energy sources, which are the largest domestic energy sources of Turkey, in order to meet this increasing energy deficit. Especially, it is possible to produce electricity using the said domestic sources (Yılmaz 2006; Yılmaz 2011, Yılmaz and Arıoğlu 1997b).
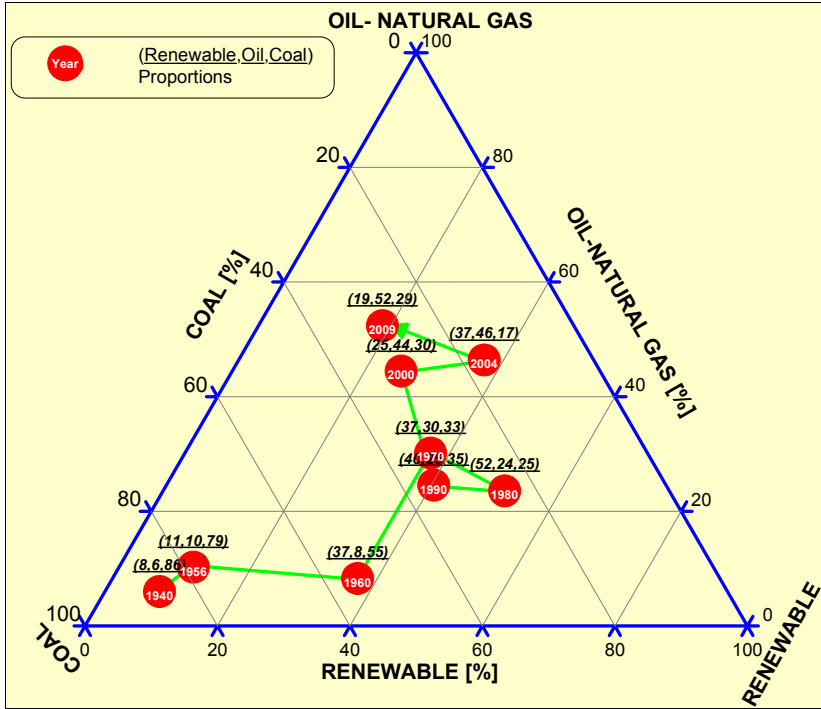
Fig. 2. Distribution of primary energy sources in electricity production by years (data from TEIAS, 2009)
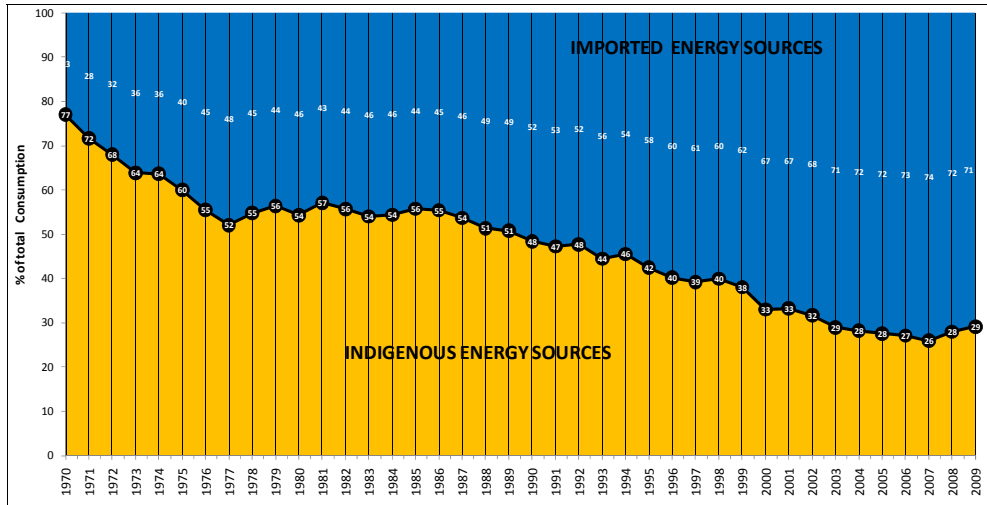

Fig. 3. During the period 1970 and 2009, primary energy consumption with domestic and imported energy sources (data from MENR, 1970-2009)
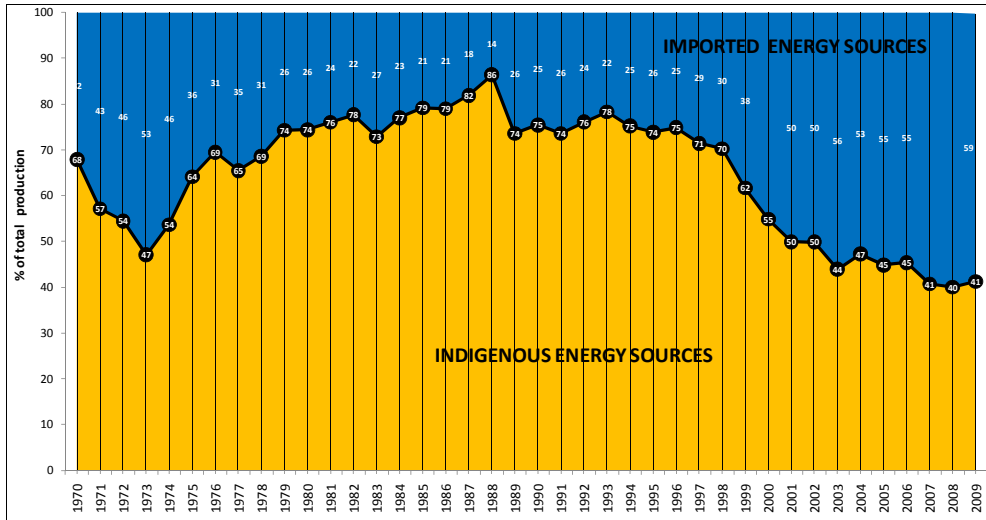
Fig. 4. During the period 1970 and 2009, in electricity generation imported and indigenous energy sources (data from TEIAS, 1970-2009)

3. Renewable energy use in Turkey

Totally energy demand of Turkey was making up about 29% of domestic resources and about 71% import resources. Turkey's primary energy production is 30.3 Mtoe (Table 1, Fig 1.). Turkey got a great share coal which is consisted of 57%. The primary energy that follows the coal and their shares are as follows; oil 8%, natural gas 2% and renewable energy 33%. Distribution of the share on the renewable energy are hydraulic, geothermal, wood, animal and vegetable waste and other 10%, 6%,12%,1% and 1%, respectively in primary energy production (Fig 5.). On the other hand, primary energy consumption of Turkey is 104.1 Mtoe in 2009. The biggest energy consumption resource is natural gas with 32% and followed of this gas; oil 29%, coal 30%, and renewable energy 9% in consumption (Fig5). Distribution of the share on the renewable energy are hydraulic, geothermal, wood, animal and vegetable waste and other 3%, 1%, 3%, 1% and 1%, respectively in primary energy consumption (MENR, 2010; TKI, 2004,2009). Turkey is dependent on the import of foreign primary energy sources especially; oil, natural gas and hard coal. Recently, according to research estimates, this trend is likely to continue in the near future.

Turkey has two main energy resources with large capacities. These are coal and renewable energy resources. Both energy resources constitute 90% of the primary energy production. The total primary energy production was 31% in 1970 and increased to 50% and 57% in 1989 and in 2009 respectively and this rate was met by coal. The share of the renewable energy resources was 43% in 1970 and decreased to 33% in 2009 (Fig. 6) (Yılmaz 2006; Yılmaz 2011).
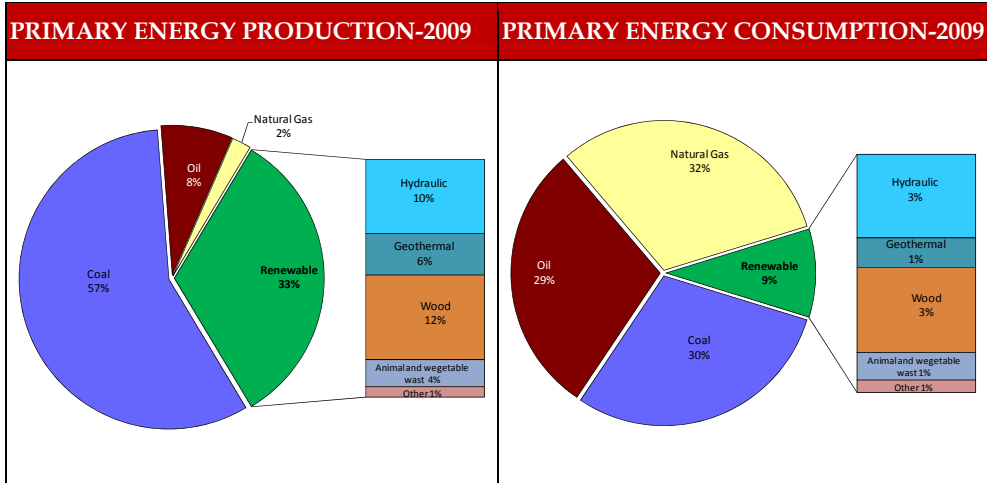
Fig. 5. Total primary energy production and consumption by energy sources in 2009 (data from MENR, 2009)
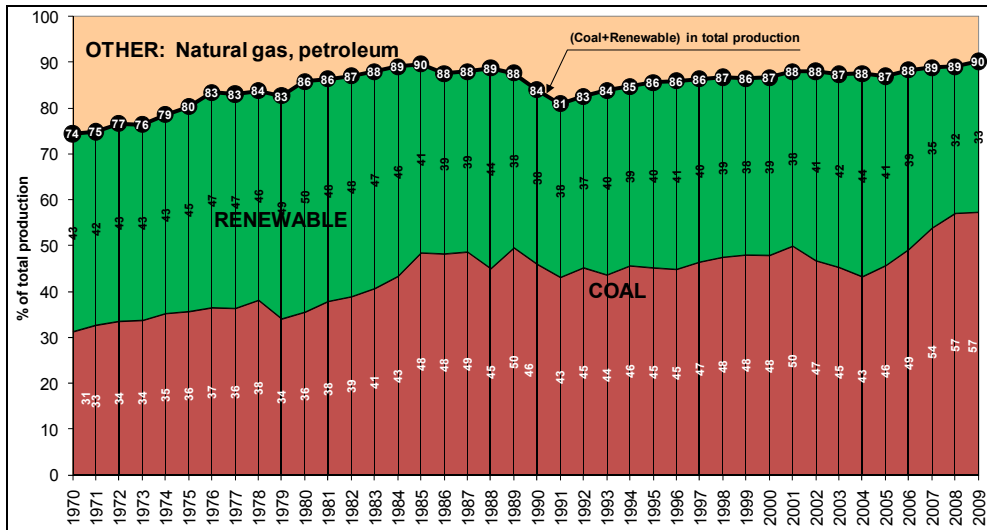
Fig. 6. During of the period 1970-2009, total primary energy production with rates of renewable energy and coal (data from MENR 1970-2009)

The distribution of renewable energy sources in primary energy production in Turkey is illustrated in Fig. 7 for the term 1970 and 2009. The energy sources used for the primary energy production are hydraulic energy, geothermal energy, wood, animal and vegetable waste. On average 43% of the primary energy production was met by the renewable energy in 1970. This percentage increased to 50% in 1980 and due to the imported natural gas, this rate was decreased to 33% in 2009. The shares of the energy sources in this production rate

were as follows: 10% hydraulic, 6% geothermal, 12% wood and 4% animal and vegetable waste in 2009. According to this data, the largest energy source used in primary energy production was wood and hydraulic. While the share of the wood and waste and drung has decreased, the share of the hydraulic, geothermal has increased (Yılmaz 2008; MENR,1970-2009; SIS, 2003–2004; TEIAS, 2004,2009).
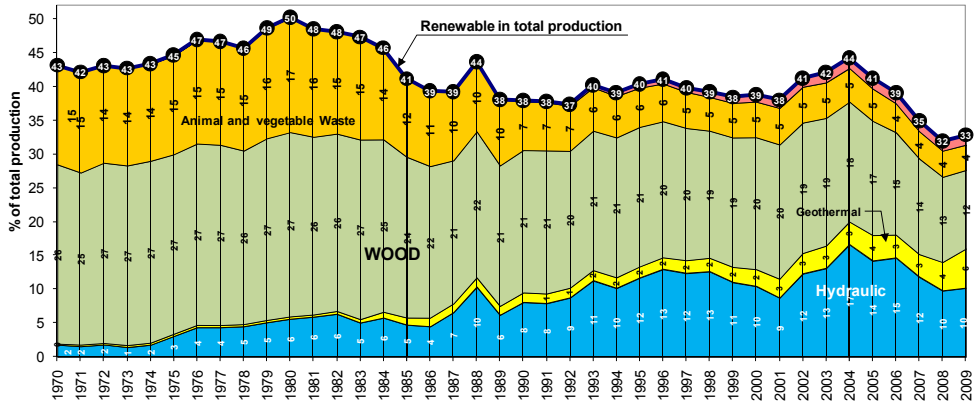
Fig. 7. During of the period 1970-2009, renewable energy sources and rates used in primary energy production (data from MENR 1970-2009)

The development of the total share of renewable energy sources in primary energy consumption in Turkey is illustrated in Fig. 8 for the term 1970 and 2009. Turkey's main energy production resources are hard coal, lignite and renewable energy. The total domestic energy production was 77% (hard coal 15%, lignite 8%, renewable 33% and other oil-gas 21%) in 1970. The share of total domestic energy sources in overall primary energy production was 48%   (hard coal 4%, lignite 18%, renewable 18 and other 8%) in 1990, and it decreased to 29% (hard coal 1%, lignite 15%, renewable 10% and other 4%) in 2009. In other words, the share of the renewable energy resources was 33% in 1970 and decreased to 10% in 2009. As seen in Figure 8, Turkey's total domestic energy sources in overall production has decreased from 1970 and 2009 term. When use of renewable domestic energy sources is considered in terms of primary energy production, it decreased to 10% levels in the recent years.

The primary energy consumption of Turkey has increased day by day and it will follow in the future. The development of the total share of renewable energy sources in primary energy consumption in Turkey is illustrated in Fig. 9 for the term 1970 and 2009. The energy sources used for the primary energy production are hydraulic energy, geothermal energy, wood, animal and vegetable waste. The share of total renewable energy sources in overall consumption was 33% in 1970 (hydraulic 1% wood 20%, waste and drug 11%) and it decreased to 23% (hydraulic 4% wood 11%, waste and drug 5%) in 1990. In 2009, the share of renewable energy sources in total primary energy consumption decreased and reached to 9% (Yılmaz 2008; MENR, 2006-2009; SIS, 2003–2004; TEIAS, 2004-2009).
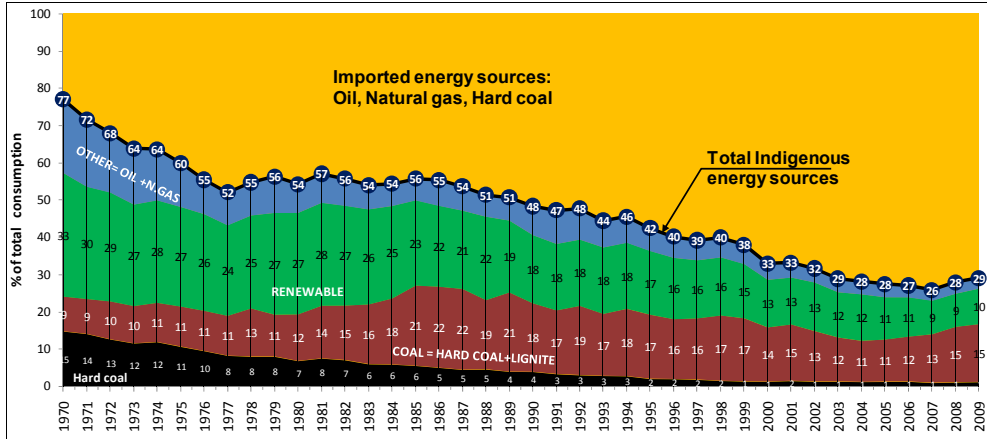
Fig. 8. During of the period 1970 and 2009 development of the total share of renewable energy sources in primary energy production (data from MENR 1970-2009)
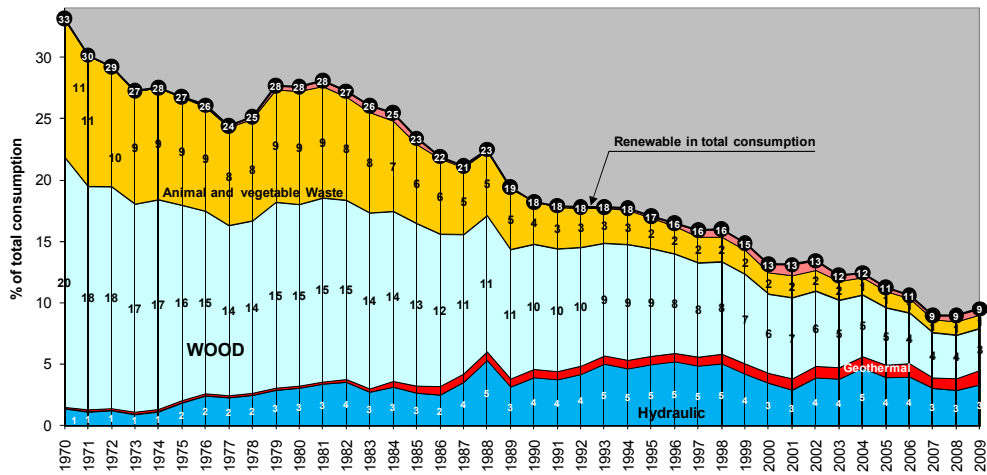
Fig. 9. During of the period 1970 and 2009 development of the total share of renewable energy sources in primary energy consumption (data from MENR 1970-2009)

3.1 Energy production using renewable energy sources

Distribution of installed capacity of Turkey by energy sources during the period 1940 and 2009 is illustrated in Fig. 10. The overall installed capacity was 217 MW in 1940 and the rate of renewable energy source was 3%. The overall installed capacity increased 164 times in 2003 and reached 35587 MW. The renewable source, which was 7.8 MW at the beginning of the term, increased 1614 times and reached 12594 MW (35%). The increase rate of use of renewable energy sources was accelerated especially in the middle of 1950s. This rate increased to 33%, 38%, and 35% in 1973, 1986 and in 2009 respectively. Especially, the electricity production using natural gas caused that this rate decreased. While hard coal

accounted for 50% of total installed capacity and 80% of electricity production in 1950, its share reduced continuously in the following years and realized 1.1% in installed capacity and 1.9% in electricity production. Lignite proved its importance during the petroleum crisis in 1973–1979. After 1973, its importance increased. The share of lignite in electricity production increased to 45% from 20% and its share in installed capacity reached 35% in the 1980s. After the year 2000, an increase in share of natural gas, both installed capacity and in electricity production, lowered the use of lignite. In 2009, the share of installed capacity by resources was 1%, 19%, 35%, 4%, 26% and 11% for hard coal, lignite, renewable, crude oil, natural gas and other, respectively (Yılmaz et al., 2005; Yılmaz, 2004,2011; Yılmaz 2008; Yılmaz and Aydıner, 2009; Yılmaz and Uslu, 2006).

The most important and the largest energy capacities of Turkey's are coal and renewable energy resources. Both energy resources constitute 61% (hard coal 16%, lignite 13% and renewable 32%) of the total installed capacity in 1970. The total installed capacity increased and reached to 78% (hard coal 2%, lignite 29% and renewable 47%) until 1995. In this rate just only hard coal percentage decreased, lignite and renewable increased as domestic energy sources. But, after this time the total installed capacity decreased and reached to 54% (hard coal 1%, lignite 18% and renewable 34%) in 2009 as illustrated in Fig 11.

In Figure 12, distribution of electricity production of Turkey by energy resources is given in a long historical order for 1940 and 2009 term. As seen in the Figure, coal (especially hard coal) had a share of 80% in electricity production in 1940. In the same year, the share of electricity production by resources was 6%, 3%, 6%, 5%, for lignite, renewable, crude oil and other, respectively. The rate of electricity production using renewable energy resources and lignite had begun increasing in time reached to 21% and 14% respectively in 1973. The share of hard coal sharply decreased and reached to 12% in 1973. By the middle of 1960s, use of oil
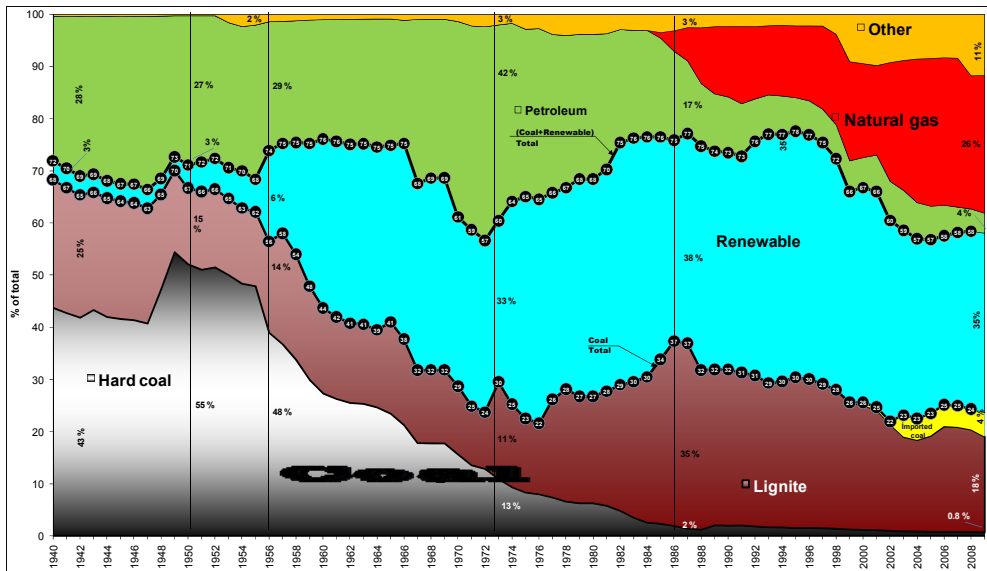
Fig. 10. During period of the 1940- 2009 distribution of installed capacity by energy sources (data from TEIAS 2009)

Fig. 11. During of the period 1970 and 2009 development of the share of renewable energy and coal by the total installed capacity (data from TEIAS, 2009)

in electricity production increased, since it is a cheaper than other resources, and this was quickly renounced after the oil crisis in 1973. After the crisis, Turkey gave importance on lignite, one of its own energy resources, and the share of coal in electricity production began increasing and reached 50%. After 2000s, use of natural gas began using in electricity production as in all other areas and its share in electricity production reached 45% in a very short time until 2003. Also imported hard coal began to use in electricity production with 6% in 2003. The share of natural gas has increased and reached to 49% in electricity generation in 2009. At the same year, distribution by resources was as follows natural gas: coal (hard coal %2 + lignite %20) renewable %19, oil %3, and imported hard coal 7% (Yılmaz 2008; Yılmaz, and Aydıner, 2009).
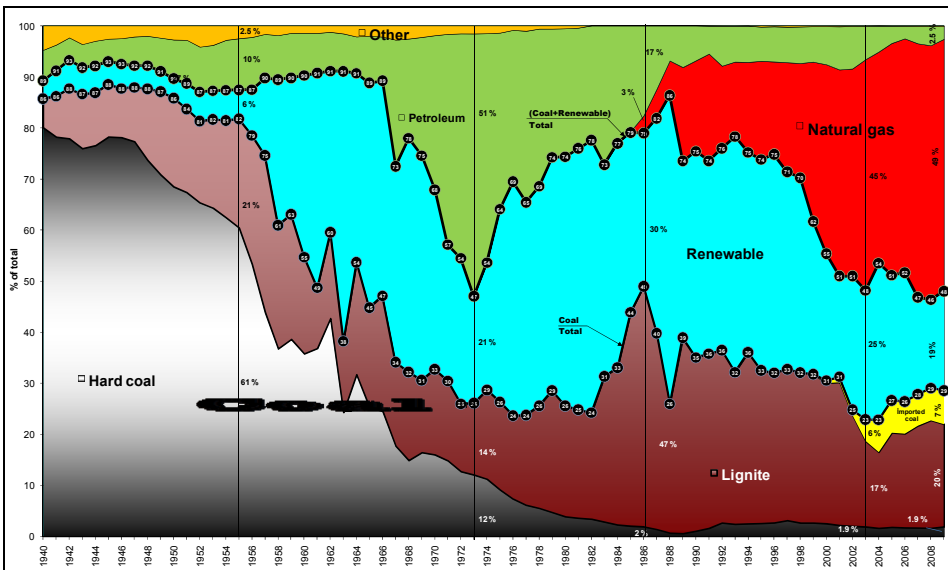
Fig. 12. During period of the 1940- 2009 electricity production by energy sources (data from TEIAS 2009)

The first of the areas where coal and renewable energy can be used most intensively is electricity production. In Figure 13, distribution of the total electricity production by renewable energy and coal sources are given in a historical order. As seen in the Figure, coal (especially hard coal) and renewable energy had a share of 68% (hard coal 16%, lignite 17% and renewable 18%) in electricity production in 1970. The rate of electricity production using renewable energy resources and lignite had begun increasing in time and the share of the hard coal decreased to 1% until beginning of 1988 and the share of renewable energy resources and lignite increased to 42% and 38% respectively. But, after that time the total electricity generation by renewable energy and coal resources decreased and reached to 41 % (hard coal 2%, lignite 20 % and renewable 19%) in 2009. Turkey has become a country, which imports 70% of its energy resources, during this term. Because after the crisis in 1973, Turkey gave importance on lignite, one of its own energy resources, and the share of coal in electricity production began increasing. However, after 2000s, use of natural gas began prevailing in electricity production as in all other areas and its share in electricity production reached 45% in a very short time.
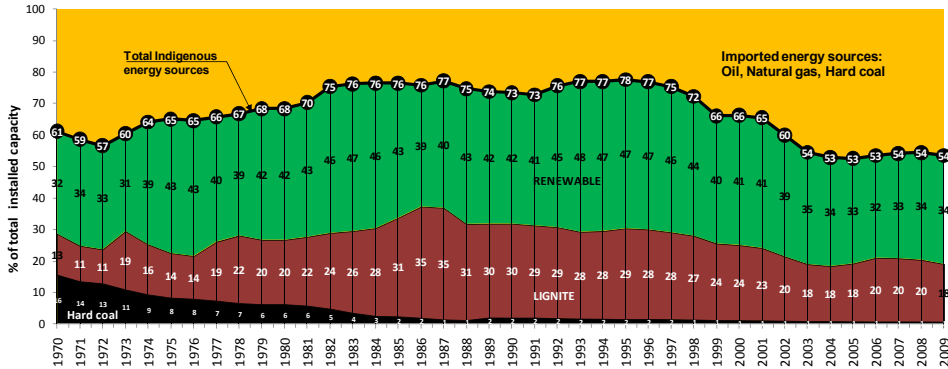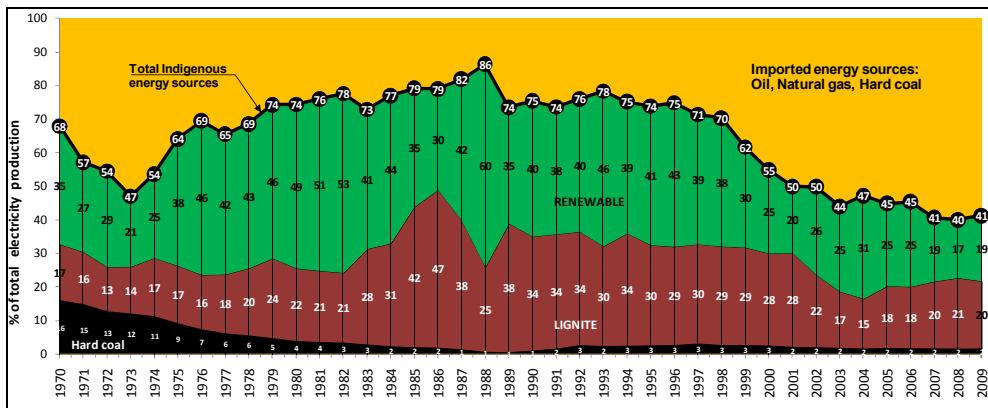

Fig. 13. During of the period 1970 and 2009 development of the share of renewable energy and coal in the total electricity production (data from TEIAS 2009)

3.2 Renewable energy potential of Turkey

The potentials of the main renewable energy sources of Turkey are collectively given in Table 2. The economical potential given in the Table equals the usable potential. The mostly used renewable energy sources in Turkey are biomass energy and hydraulic energy. While geothermal is the third source in the listing, its use is very limited. Use of solar energy is at an emblematic level and use of wind energy is being commenced recently. The overall economical and/or usable potential of the listed renewable energy sources is at a level of 68 Mtoe/year (TUSIAD,1998).

The overall annual electricity production potential of renewable energy sources is 486.3 billon kWh economically. Solar energy, geothermal energy and wind energy potentials are not used or used scarcely. The most used renewable energy source in Turkey is hydraulic energy. Today, the economical hydroelectric potential of Turkey is 129.9 billion kWh and 35% (45.930 GWh) of it is operative, 8% (10.518 GWh) of it is under construction and 57% (73.459 GWh) of it is at project level Table 2.

Renewable Energy Source	Gross	Technical	Economic available

Hydropower
    (MW)
    (billion kWh/year)
	107 500
	430
		53 730
		215
			36652
			129.9

Geothermal
    Heat (MW)
        (Mtoe/year)
    Electricity (MW)
        (billion kWh/year)
	31 500
	-
	4 500
	-
		7 500
		5.4
		500
		-
			2 843
			1.8
			350
			1.4

Solar
    Heat + electricity (MW)
        (billion kWh/year)
        (Mtoe/year)
	111 500 x 10³
	977 000
	80 000
		1 400 000
		6 105
		500
			116 000
			305
			25

Wind
    Electricity (MW)
        (billion kWh/year)
	220 000
	400
		115 000
		290
			20 000
			50

Classic Biomass
    Fuel (Mtoe/year)
Modern Biomass
    Fuel (Mtoe/year)
	30
	
	90
		10
		
		40
			7
			
			25

Table 2. Potential of Renewable Energy Sources (MENR,2009)

4. Coal and energy

4.1 Energy production based on coal

The coal production culture in Turkey was introduced with the exploration of hard coal by Uzun Mehmet in Köseağzı quarter of Kestaneci village in Zonguldak province on 8th November 1829. Up to date, hard coal has been produced in Turkey. There is no definite information about the first use of lignite. It is known that lignite was being produced in many locations in Turkey, especially in Soma -Kütahya (Yılmaz, 2008).

Hard coal is used intensively in industry and heating and especially in electricity production. Lignite coals are used mostly for electricity production since its calorific value is low. The share of coal in overall primary energy production was 31% (lignite 12%, hard coal 19%) in 1970, and it increased to 46% (lignite 38%, hard coal 8%) in 1990 with an increase rate of 48%. In 2009, the share of coal in total primary energy sources has increased and reached to 57% (lignite 53%, hard coal 4%) as shown in Fig 14. The primary energy production of Turkey has been limited and the largest share in this increase belonged to lignite. It is hope that this rate of percentage increase will continue in the following years. On the other hand, the share of coal in overall consumption was 24% (lignite 9%, hard coal 15%) in 1970, and it increased to 31%

(lignite 19%, hard coal 12%) in 1990 with an increase rate of 16%. In 2009, the share of coal in total primary energy sources decreased and reached to 29% (lignite15%, hard coal 14%) (Fig. 15). Turkey's primary energy consumption is higher than energy production. In other words, the increase rate of primary energy consumption is about 6 times of that of the production. And Turkey consumes 6 times of its production. If this rate increased in the following years, Turkey would become an import dependent country in terms of energy in the following years (Arıoğlu, Yılmaz, 2002a, 2002b,2002c; MENR, 2009; Yılmaz 2008).
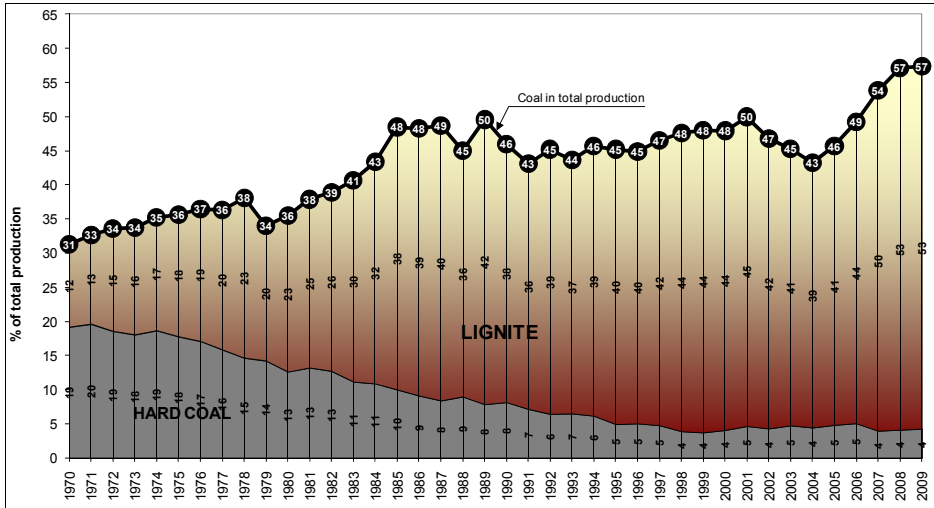
Fig. 14. During of the period 1970 and 2009, development of the share of coal energy sources in primary energy production (data from MENR, 1970-2009)
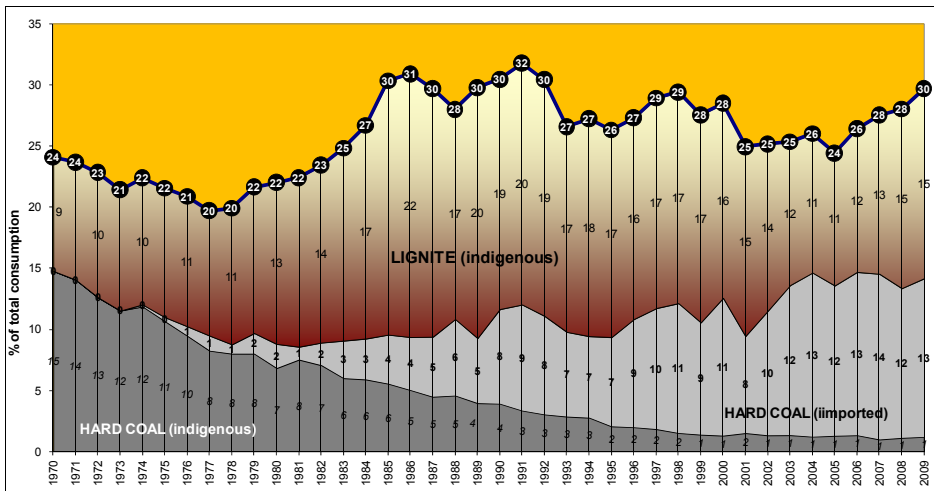
Fig. 15. During the period of 1970 -2009 development of share of coal in primary energy consumption (data from MENR, 1970-2009)

4.2 Coal potential, production and consumption

Turkey has an important potential from the point of view of coal reserves (Fig. 16). Apart from the hard coal and lignite reserves, asphaltite, bituminous shale and peat reserves are also present in the country. Turkey's significant hard coal basin exists in Zonguldak province which is on the Western Back Sea Region. The total reserve (ready + proven + probable + possible) is about 1.3 billion ton (Table 3). Hard coal reserves are distributed into five districts. Distributions of total reserves among these five districts are: Ereğli 34 million tons; Zonguldak 884 million tons; Amasra 408 million tons; Kurucaşile 1 million tons; Azdavay 5 million tons. The calorific value of the hard coal differs from 6.500 to 6.650 kcal/kg (Table 3) (TTK, 2004,2009; TKI, 2004,2009).
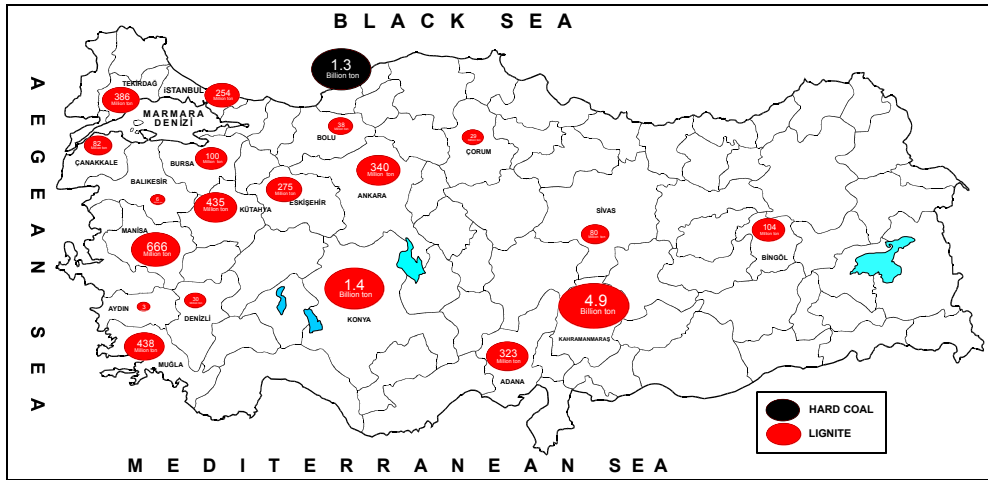
Fig. 16. Distribution of hard coal and lignite reserves of Turkey

Location		RESERVES (1000 TON)				Calorific value, kCal/kg
Province	Dictrict	Proven	Probable	Possible	Total	
Zonguldak	Ereğli	11.241	15.86	7.883	34.984	6650
Zonguldak	Center	351.272	294.043	239.029	884.345	6650
Bartın	Amasra	172.107	115.052	121.535	408.694	6000
Bartın	Kurucaşile		1		1	6500
Kastamonu	Azdavay		5.593		5.593	6500
TOPLAM		534.62	431.548	368.447	1.334.615	-

Table 3. Distribution of hard coal reserves of Turkey (MENR 2010)

Hard coal Production is maintained under very difficult geological conditions. The production depth reached 600-1000 m in some regions. Such difficult working conditions caused that the unit costs increased and this affected the competitive power of the country in world's markets. In addition, the expected increase in production could not be achieved and contrary to expectations the production was decreased to 3 million tons from 9 million tons (Table 4). This

production level can meet only 10%-12% of the overall consumption of Turkey, which are 22-23 million tons. While, especially in the recent years, a significant part of the produced hard coal is used for electricity production, the remaining coal is consumed for other purposes, such as iron and steel industry, household fuel etc as illustrated in Fig.17 and Table 4. In 2009, the share of hard coal consumption by sectoral were 70%, 27% and 4% for industry, power station and house hold, respectively (Yılmaz 2011; TTK 2009; MENR 2010).

Years	Hard coal production/consumption (x1000 ton/year)		[production /consumption] x100], %	Consumption [x1000 ton/year]			Distribution of total consumption, %		
	Production	Consumption		Industry	Power station	House hold	Industry	Power station	House hold
2000	2,392	15,525	15.41	12,777	2,034	714	82.3	13.1	4.6
2001	2,494	11,176	22.32	8,106	2,274	796	72.5	20.3	7.1
2002	2,319	13,830	16.77	10,920	2,051	859	79.0	14.8	6.2
2003	2,059	17,535	11.74	12,845	3,706	984	73.3	21.1	5.6
2004	1,946	18,904	10.29	13,435	4,565	904	71.1	24.1	4.8
2005	2,170	19,421	11.17	13,227	5,259	935	68.1	27.1	4.8
2006	2,319	22,798	10.17	16,315	5,618	865	71.6	24.6	3.8
2007	2,462	25,388	9.70	18,611	5,912	865	73.3	23.3	3.4
2008	2,601	22,720	11.45	15,658	6,197	865	68.9	27.3	3.8
2009	2,863	23,698	12.08	16,472	6,361	865	69.5	26.8	3.7

Table 4. Hardcoal production, consumption and using areas

Fig. 17. Distribution of hard coal consumptions by sectoral (data from MENR 2000-2010)

Lignite reserves constitute the large portion of total coal reserves. Lignite deposits dispersed all over the country (Yılmaz, 2006). The most important known lignite deposits reserves are located in Afşin Elbistan, Muğla Soma, Tunçbilik, Seyitömer, Beypazarı and Sivas regions (Fig. 16). About 40% (4.9 billion tons) lignite reserve is located around Afsin-Elbistan which is in the southeast of the Turkey (Yılmaz and Uslu 2007). Although total lignite 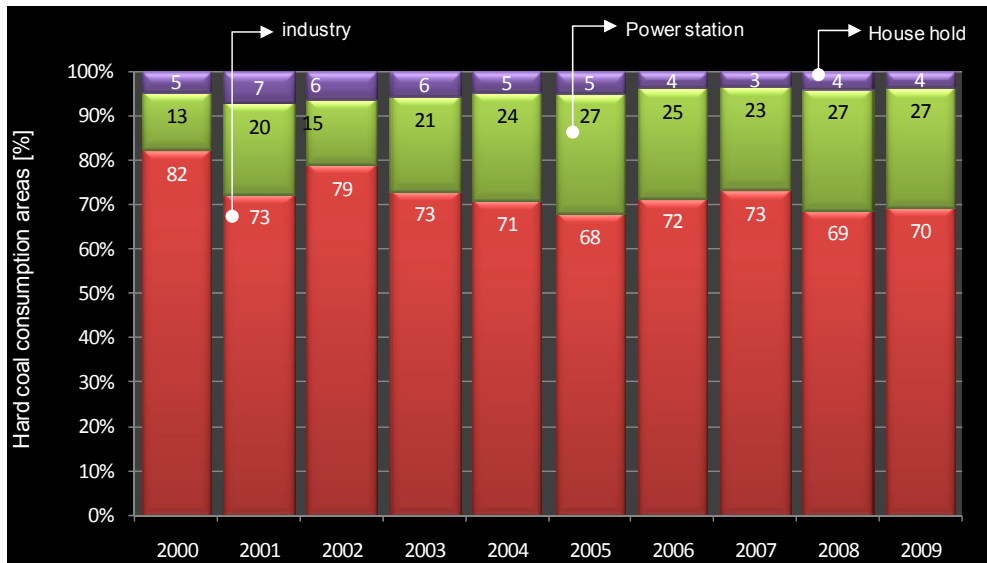reserves were about 8.07 billion tons (TKI 2009; TKI, 2010), Turkey's new total lignite reserves including proven, probable and possible reserves have reached about 11.4 billion tons after recent exploration activities. Turkey has a share of 2.5% in the world reserves and 8.2% in the world production (Yılmaz , 2011). Distribution of the lignite reserves in the Turkey is shown in Table 5 (TKI, 2004; 2010). Turkey's coal deposits are operated by companies which are Turkish Hard Coal Enterprise (TTK), Turkish Coal Enterprises (TKI) and the Electricity Generation Company (EUAS) and Private sectors. TTK is authorized for hard coal production, processing and distribution. More than half of lignite reserves are produced by TKI. Production of remains are belongs to private companies and EUAS for we in power plants. The distribution of reserves is as follows: TKI 21.5 %, EUAŞ 42 %, MTA 23% and Private sector 13.5% (Table 5.) (Yılmaz 2008, EUAS 2004,2009; Anaç 2003).

LIGNITE						
Coal field	Reserves (1000 TON)				Ration in total, %	Calorific value, Kcal/kg
	Proven	Probable	Possible	Total		
EÜAŞ	4.718	104	-	4.822	42.0	1031-4900
TKİ	2.239	218	1	2.458	21.5	
MTA	1.803	685	123	2.611	23.0	
Private sector	1.077	337	138	1.554	13.5	
TOPLAM	9837	1344	262	11.445	100	
ASPHALTITE						
Location		Reserves (1000 TON)				Calorific value, Kcal/kg
Province	Dictrict	Proven	Probable	Possible	Total	
Şırnak	Silopi	31.812	16.21	1	49.022	5310
Şırnak	Merkez	7.724	13.26	6.3	27.284	5330
TOPLAM		39.536	29.47	7.3	76.306	-

Table 5. Distribution of Lignite and Asphaltite Reserves of Turkey (Data from, TTK, 2004; TKI, 2010).

The lignite mined from most lignite deposits is low calorific value lignite and the calorific value of 90% of them is between 1000 and 3000 Kcal/kg (Fig.18). In this context, a significant part of the lignite production is used for electricity production (Fig 19.). Lignite production depends on electricity production. Lignite production reached to 76 million ton/year especially in 1970 and 2009 term, when the lignite production is very effective in electricity production. Its production decreased to 45 million ton/year after 2000, since its use in electricity production repressed after 2000. The overall lignite consumption can be met by the domestic production (Fig.19.)

Lignite production depends on electricity production While 1% of produced lignite in 1970 was used in power stations, 5% was used as house hold and industry. In 2000, the share of lignite consumption by sectoral were 82% and 18% power station and house hold and industry, respectively. In 2009, the share of the power station in lignite consumption increased and reached to 83% (Fig. 19).
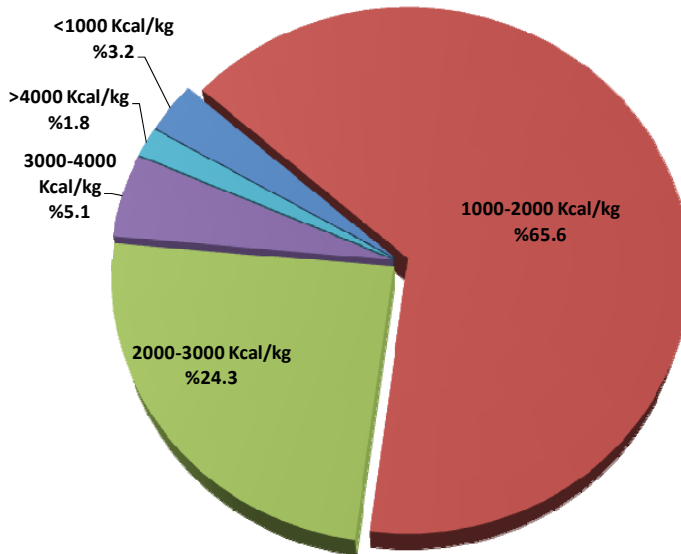
Fig. 18. Lignite by calorific value
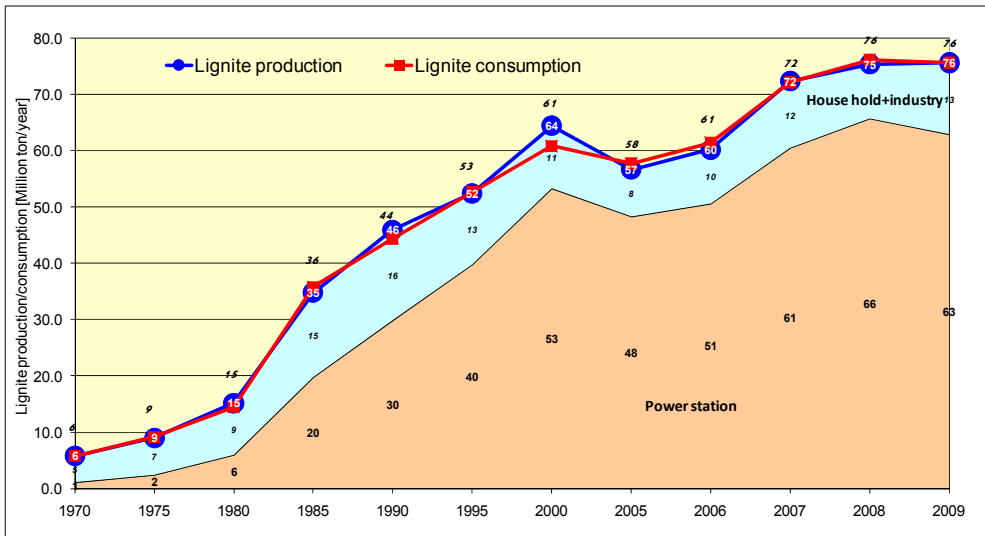
Fig. 19. Lignite production/consumption and consumption areas (data from TKI, 1970-2009)

5. Future projection

The primary energy production–consumption of Turkey and distribution of electricity production of Turkey by sources projected for the years 2015 and 2020 are given in Figs. 20–21. No major change is seen or foreseen in the development of share of domestic energy sources in primary energy production. It is planned that this rate will be 32% in 2015 and 30% in 2020. In other words, 70% of the primary energy production of Turkey will be dependent on imports. On the other hand, renewable energy sources and hard coal constitute 90% of the primary energy consumption; 5–10 points increase is foreseen in the share of coal in primary energy production 2015 and 2020. It is planned that this share will be 54% and 61%, respectively, for the years. The dependence on imported energy sources for electricity production projected for the years 2015 and 2020 are 47% and 50%, respectively (Fig.22). It is projected that the share of coal in electricity production will increase to 28% in 2020 and no significant change is planned in electricity production using renewable sources and it is projected that this share will decrease to 23% in 2020. In other words, Turkey does not plan to introduce any expansion in energy production until 2020 when compared with today's conditions according to its energy projections (Yılmaz,2008; TPAO 2006).
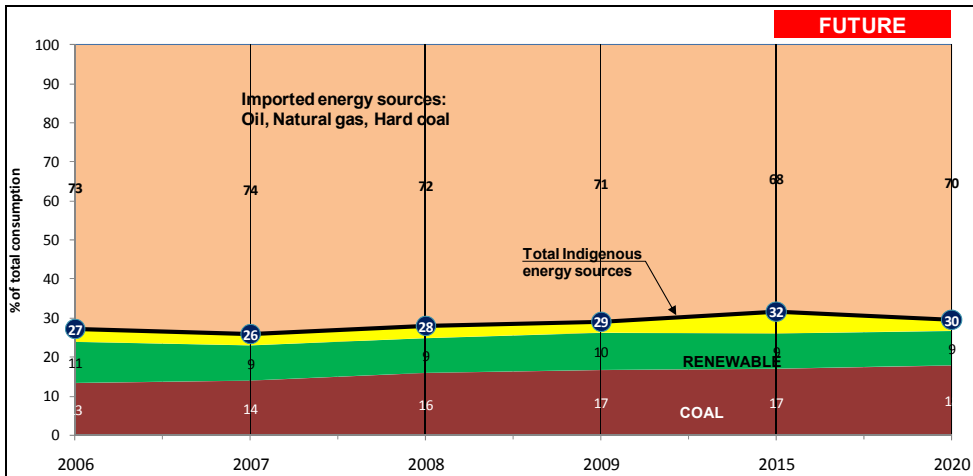
Fig. 20. Projection of development of the share of domestic energy sources in overall primary energy consumption (data from MENR, 2006,2010).
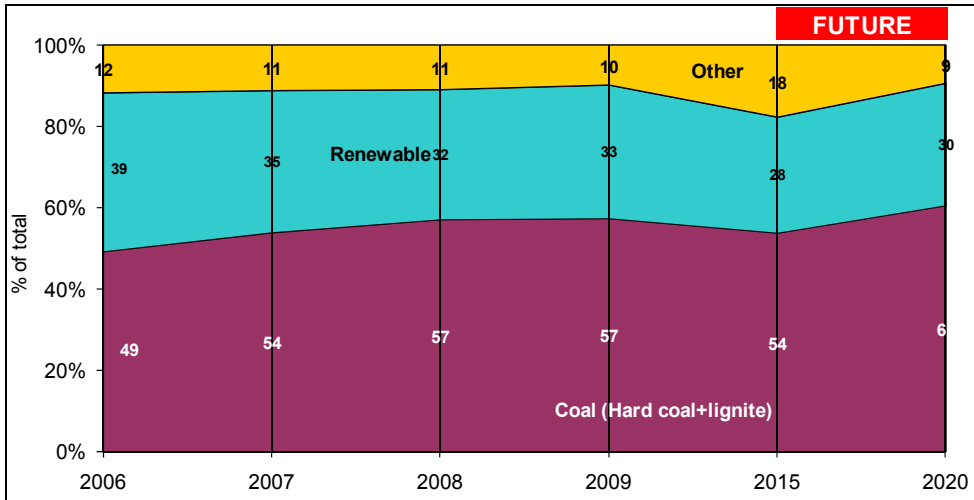
Fig. 21. Projection of distribution of domestic energy sources in overall primary energy production (data from MENR, 2006,2010).
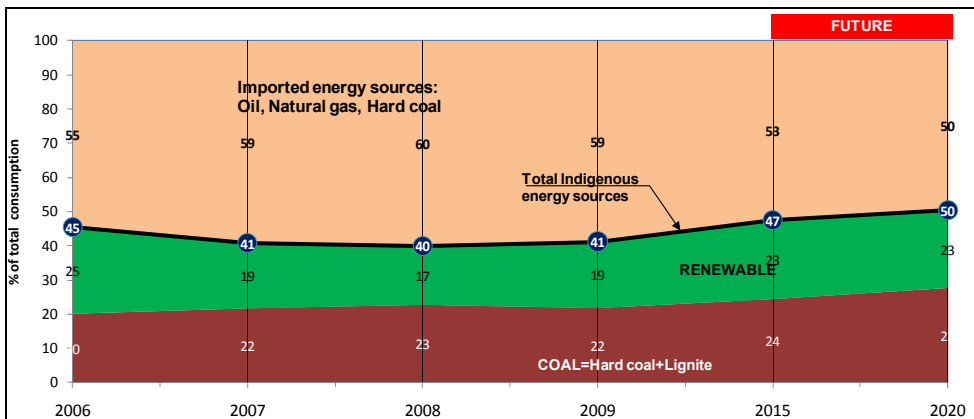
Fig. 22. Projection of development of domestic energy sources in electricity production (data from MENR, 2006,2010).

6. Discussion and conclusion

Turkey imports about 70% of the energy sources it uses in primary energy consumption. This percentage is 59% for electricity production. The imported energy sources are oil, natural gas and hard coal. The load of imports on Turkey's economy as of 2000-2009 is illustrated in Fig. 23. Turkey spent 29 billion dollars overall for energy imports in 2009. This amount constitutes 29% of the overall exports in 2009 and 21% of the overall imports. In other words, Turkey spends approximately one-third of the income it obtains from overall exports for energy imports. Oil and natural gas are the most imported energy sources with a

percentage of 89% (26 billion dollars) of the overall energy source imports and it is followed by hard coal with a percentage of 11% (3 billion dollars). The incredible increase rate of natural gas consumption in the recent years constitutes an important expense item in the imports items of Turkey. More importantly, use of natural gas in industry and electricity production makes Turkey completely dependent on the foreign countries in terms of energy security. Especially Turkey's supplying over 50% of its electricity production from natural gas causes very severe security problems and Turkey should question this issue very seriously. On the other hand, although Turkey has sufficient hard coal reserves, it increasingly imports hard coal in order to consume it in industry and electricity production due to some reasons such as production difficulties and insufficient investments. Turkey should immediately take action in order to meet such requirements from its own sources. It should not be expected that the domestic production covers the consumption within a very short time, but it should be aimed at meeting or minimizing the deficit between the production and import within a long time. On the other hand, although Turkey has sufficient lignite reserves for electricity production, importing hard coal for this purpose is a completely strategic mistake (Yılmaz,2008).

	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Import	55	41	52	69	98	117	140	170	202	141
Export	28	31	36	47	63	73	86	107	132	102
Energy imp/import. [%]	17	20	18	17	15	18	21	20	24	21
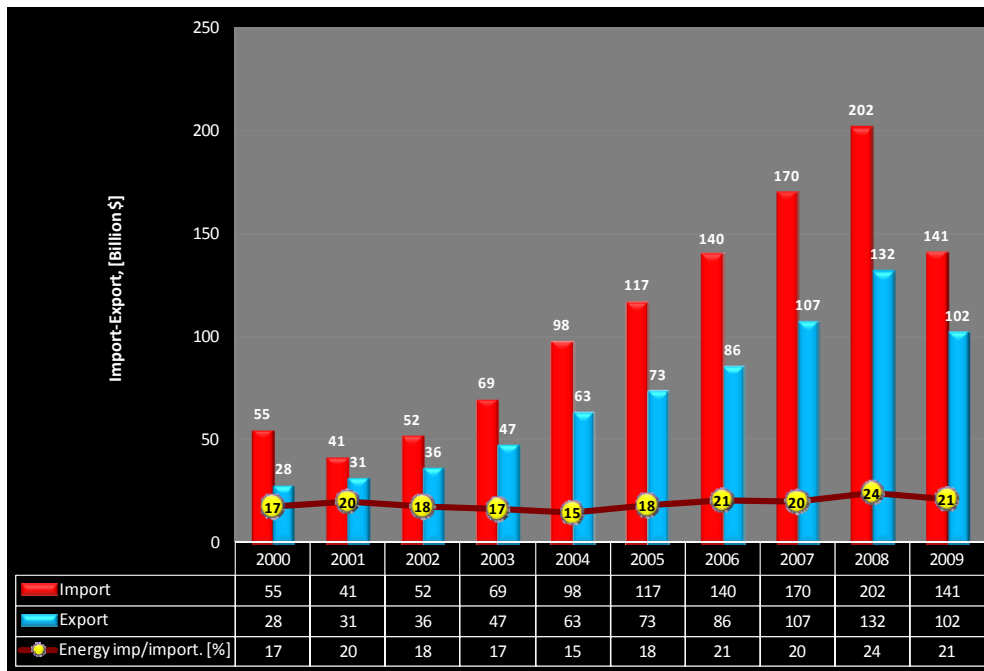
Fig. 23. Load of energy source imports on Turkey's economy

The largest energy sources of Turkey are coal and renewable energy. Turkey should use these energy sources in areas where it can substitute them for oil and natural gas. The first of these areas is electricity production. In projections of Turkey (Fig. 22), it is proposed that 50% of the electricity production will be imported. It is planned that the overall demand for electricity will be 500 billion kWh in 2020. However, there is a potential for producing reliable electricity from renewable energy sources (480 billion kWh) and lignite thermal power plants (100 billion kWh), which are operative and of which the projects are completed, economically (Table 2.). In other words, Turkey has a potential for producing electricity it demands by using only its own sources. It is obligatory to comply with the environmental pollution and emission limits in use and production of coal. The required measures in this regard has been taken in most of the operative power plants and the studies for taking such measures continue rapidly in the other power plants. It is vital for Turkey to take operating the coal reserves by using environment-friendly technologies and utilizing its sources at the highest level among its priorities (Yılmaz, 2008).

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Experiences of Community Wind Electrification Projects in Bolivia: Evaluation and Improvements for Future Projects

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1. Introduction

Currently, early in the XXI century, an estimated 2400 million people depend on traditional biomass for heating and cooking and 1500 million people lack access to electricity (IEA, 2009). Lack of electricity particularly affects rural areas of developing countries (Kanagawa and Nakata, 2008), exacerbating the urban-rural gap. In Bolivia, 35% of the population, more than 3.5 million people do not have access to electricity.

Electrification systems based on renewable energy have proved being adequate to provide decentralized electricity to isolated rural communities around the world (Chaureya et al., 2004). These autonomous systems are often much cheaper than the interconnected grid extension and use local resources, avoiding external dependencies which, in turn, promotes long-term sustainability of projects. In particular, micro-wind systems are an alternative with great potential to generate power in rural areas (Lew, 2000), although their use has been limited to date. In South America, a significant institutional effort was made in Argentina to develop rural electrification projects using wind energy in the province of Chubut (Seitz, 2006). In Peru, there are some demonstrative projects of the use of wind power to electrify isolated communities, the first one in El Alumbre (Ferrer-Martí et al., 2010).

In Bolivia, the government's policies on rural electrification are governed by the Rural Electrification Regulation, which states that the Department of Energy is responsible for promoting sustainable development, seeking expanded coverage of electricity services throughout the country. Therefore it has the responsibility to update and develop the rural energy strategy, including the Indicative Rural Electrification Plan to facilitate the work of agents in the development of rural electrification. The basic principles that are taken into account are:

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- Legitimacy of demand, which is to prioritize energy projects according to the law of popular participation and decentralization of administrative management.
- Accessibility, facilitating access to potential consumers to energy services in market conditions.
- Adaptation of technology, using energy resources in accordance with the conditions of each region and the lowest cost alternative.
- Co-financing, which is to encourage public and private funding for energy projects.
- Sustainability, through the application of the principles of environmental conservation.

Despite commitments made by Bolivia at the international level to reverse the rates of coverage in basic services until 2015, the millennium goals are far from being met.

In this context, the NGOs CINER (Bolivia), Mosoj Causay (Bolivia) and Engineers Without Borders (Spain) promoted the "Andean Program for Rural Electrification and Access to Renewable Energy" in Bolivia. This program was initiated by Engineers Without Borders (Spain) in different countries of the Andean Community of Nations (CAN) that present a common and problematic context. The program pursued Universal Access to sustainable energy services, through capacity development and validation of appropriate technologies for Andean environment. In 2005 the program began in Peru and Ecuador; next the program was extended to the Andean region of Bolivia, which presents very similar geographical and socioeconomical characteristics to the Andean areas of Peru and Ecuador. In this framework, in 2007 CINER, Mosoj Causay and Engineers Without Borders developed actions related to access to renewable energy in rural communities, extending the program to Bolivia to implement the knowledge acquired in both countries, and to adapt it to the special characteristics of Bolivia. The overall objective in Bolivia is to develop and disseminate knowledge, as well as human and technological capabilities to initiate demonstration projects, working with different stakeholders from the perspective of utilization of renewable energy sources, and promoting and participating in the selection and management of technology solutions.

Within the overall program, the project "Improving Access to Renewable Energy in Rural Communities in Bolivia" aims to improve the quality of life of rural population by having access to energy in remote areas through renewable energy. The specific objectives of this project were:

1. To improve technical and management capabilities of the Bolivian plateau for access to the energy in the population, local governmental bodies and other stakeholders.
2. To increase access to efficient and sustainable energy through improved use of biomass and the production of electricity through renewable energy sources.

The actions were carried out with specialists in social and technological issues to promote that users, through processes of participation and training, learn to manage, to maintain and to make sustainable their energy systems. These actions will contribute improving their level of human development, life expectancy, increasing opportunities for women, and access to education for children and adults, protecting natural environment through more friendly family economies. All the actions were performed jointly with the efforts of the beneficiaries - in coordination with the municipal government.

Specifically, this paper examines the interventions in the municipalities of Turco and Challapata led by Engineers Without Borders, CINER and Mosoj Causay, with the collaboration of both municipal governments, the financing of the Spanish Agency for International Development (AECID) and the Government of Navarra (Spain). Within the

municipalities of Turco and Challapata, two communities were selected with 13 and 9 households, respectively, that were electrified with individual wind systems. The electrification with renewable energy corresponded to the priorities and needs of the beneficiary population; before running the project, beneficiaries considered the lack of electric power as one of the main problems of both communities. The system installation was completed in December 2009. A year later, an external evaluation was conducted to analyze the performance and progress of the projects and it confirmed the level of satisfaction of the beneficiaries of the renewable energy equipment.

This article aims to describe and evaluate two community projects on wind power generation, both in technical and social aspects. These two examples provide lessons on management models at the community level. Moreover, we analyze the alternative design of projects that try to solve some of the drawbacks identified for the assessment of future project designs and implementations. The experience in Bolivia has shown the interest and willingness of rural indigenous populations to participate in electrification projects.

The remainder of this paper is organized as follows. Section 2 presents the economical analysis of the communities. Section 3 explains the wind resource assessment and section 4 describes the electrification project. Section 5 presents the evaluation methodology and section 6 presents the results and their analysis. Section 7 discusses alternative project designs. Finally, Section 8 summarizes the conclusions.

2. Socioeconomical analysis of the communities

This section presents the socioeconomical characteristics of the two communities, highlighting the differences between them. The purpose of this study was to analyze the characteristics of communities and families: the economy, consumption and energy demand, the level of organization, and individual and group capabilities. The instruments used to collect the information include socioeconomical surveys to each family, interviews with the local authorities and the representatives of the inhabitants, and a focus group with local organizations. This study was a key first step in the design and development of the management model with the administration.

2.1 Rural area in Bolivia
The household energy consumption in rural areas with no conventional energy supply is dominated by the demand for cooking (89% of total energy consumption). Lighting, communication (audiovisual, mobile, etc.) and other energy uses account for 11% of energy demand. Although not large amounts, lighting (5%) and entertainment (2%) are key demands to improve the quality of rural life and the integration of people through media. Productive uses of energy in these families represent a marginal percentage of total consumption; whenever they exist they are very specific, and must be analysed in particular way.

The structure of economic costs of energy source in rural scattered communities is different from population centers: batteries represent the largest amount of expenditure (34.3%), followed by the consumption of diesel (20%), LPG (18.8%), kerosene (15.3%) and candles (11.6%). In the highlands, average annual spending in U.S. dollars on traditional energy sources is the lowest in the country with a total of $ 40 U.S. for the population in extreme poverty.

Due to low income of people in remote rural areas, the ability to pay is weak. However the amount of money previously used for the purchase of other energy sources (candles, kerosene, batteries, gas, etc.) may now be used to cover the cost of the electricity service. It is estimated that nearly all population strata might pay a US\$ 2.5 monthly fee, considering that the payment will be for more convenient energy services than those previously used. It is noteworthy that the percentage of expenses for energy supply with respect to income is higher when the income level is lower.

Some people have expressed their desire to obtain higher rates of public or international cooperation funding for electrification systems; this is probably due to very welfare practices developed by institutions in the past plans in these rural areas. However, it is obvious the willingness of communities and families to finance their consumption in case of having electricity. Moreover, it is worth to consider that making periodic payments for the energy service is not a common practice; traditional energy sources were acquired on specific occasions when families had available economic resources.

2.2 Area and population

The municipality of Turco is located in the western area of department of Oruro, in the province of Sajama, at an altitude of 3860 m. Turco has an area of around 3873 km², its topography is flat and rugged, with a large flat surface combined with hills and low hills with slopes of 5 to 15% and mountain slopes up to 60%. Most towns and villages of Turco are located at altitudes ranging between 3738 and 4200 meters, the mountain range has peaks reaching 5300 m. In general, the weather is cold, with annual mean minimum temperature of -1.6 ^{o} C and maximum of 19.8 ^{o} C. Turco is characterized by two very distinct seasons: a dry season from April to September and a rainy season between October and March.

On the other hand, the Municipality of Challapata belongs to the province of Avaroa, in the south-eastern department of Oruro. Challapata has an area of around 3014 km². The municipality has a semi-rugged relief in the mountainous territory of the central plateau, which stretches from north to south. Most towns and villages of Challapata are located between 3700 and 4300 m. The municipality has a cold and dry weather with average annual temperatures of around 4.4 ^{o} C in July and 11.6 ^{o} C in February, but sometimes can drop to -10 ^{o} C in the cold months. The rainy season starts in October or November and runs until March, and is characterized by heavy rains followed by periods of 10-20 days without rain. The remaining months are dry season flows.

According to the national census of population and housing, in 2001 Turco has 3818 inhabitants, composed almost evenly of men and women and represented by young under 25 years that form nearly 50% of the population. However, the estimated population in 2009 was 3771 inhabitants, a slightly decrease is mainly explained by migration to the cities in search of jobs and better opportunities. There are few major population centers and most populations are small villages with few houses. The estimated density of the municipality is 0.98 inhabitants per km². According to the 2001 census, the life expectancy at birth in the municipality of Turco is 49.6 years. Challapata has a much larger population with 24370 inhabitants almost evenly distributed between men and women being 50% of the population under 20 years. In contrast, in Challapata the population is increasing, it was estimated for 2009 a total of 27517 inhabitants. The density of the population of the municipality is 8.08 inhabitants per km². According to the 2001 census, the life expectancy at birth in the municipality of Challapata is 53.7 years.

The 2001 census data showed that the global literacy rate for the entire Turco municipality is 86.4% that is below the departmental average of 94.0%. The average years of study at the municipality are 5.7. Women still are disadvantaged in their access to education, as an example their illiteracy rate is 10.7%, while for men it has decreased to 4.2%. In the municipality of Challapata the situation is even more limited, with the overall literacy rate of 76.9% and the average years of schooling of 4.4.

The lack of permanent jobs and income security causes migration of the population of both municipalities to larger towns and cities from the department of Oruro, other departments of Bolivia, or even neighbouring cities of Chile. According to the Municipal Development Program (PDM) of 2007, 7.48% of the population of Turco has emigrated temporarily or permanently . This occurs more frequently among men (74.59%) from 10 to 50 years, children and youth because of higher level studies and for jobs to supplement the family income. In Challapata, according to the PDM 2002, the migration amounts to 29.21% of the population.

2.3 Basic services

According to the laws of municipal management, basic services are under the responsibility of municipal government. However, the municipality of Turco has not assumed responsibility for developing municipal policies aimed to ensure the coverage of basic services to the population, while the municipality of Challapata, has developed this task with moderate success. It is clear that in both cases the resources are not sufficient to meet the needs of the communities and, moreover, the operational capacity of the technical teams of the municipalities is limited.

The attention of medical services is poor and does not cover the expectations of the population. Firstly, the equipment they have is limited, and secondly, the treatment provided by officials and health professionals to patients does not meet the desired quality. In short, it is estimated that by 2007 there was approximately 1 doctor for 1909 people in the municipality of Turco and 1 doctor to 2437 people in the municipality of Challapata. Most of the population lives in communities of few houses that lack basic services; people must travel long distances to reach education and health services.

According to the PDM (2007), communities, farms and other remote areas have no electricity and rely on the use of kerosene or other methods of illumination at night. A study and evaluation of future energy demand estimated it (to meet the needs of households) as about 180 Wh / household / day. This study assumed a rational and efficient use of the energy and considered the power supply for each benefited the use of little appliances (radio, television, etc.).

2.4 Economy

Given the predominantly rural characteristic of both municipalities, economic activity is based on agriculture (99% of families according to the PDM 2007 in the case of Turco). Cattle ranching hs two main purposes: sale and household consumption (to a lesser extent). Both live animals and in meat as well as other products (portion of meat, fibber and leather for processing before being marketed) are used for sale. Own consumption is complemented by an interfamilial exchange. Marketing is carried out fortnightly and annual fairs especially in urban centres. Agricultural activity is highly subject to climate risks, and therefore the incomes of families are in constant insecurity, making families to diversify their economy by

engaging in minor or complementary activities, such as handicrafts. Agricultural production is geared directly to consumption. Potato and quinoa are the products that are prevalent among families in the municipality of Turco and barley in the case of Challapata.

2.5 Community organization and leadership

A community workshop in each municipality of Turco and Challapata was realized to know the institutional actors in municipality that should be considered allies when designing in the management model of the electricity service. These institutions are considered depending on the area in which they operate, from the communal, municipal, provincial, departmental, national and international levels. The participants of the workshop did not identify all the institutions, but only those related to the Municipal Government and Ayllu, the indigenous and original management and decision organization at community level. Therefore, to complete the institutional landscape the PDM was used as well as observations and findings in the towns.

3. Wind resource assessment

Since June 2010 Bolivia has a new Wind Atlas, which identifies the potential of wind anywhere in the country, with the usable energy to generate electricity or direct use in a mechanical way. The Atlas was commissioned by TDE (Transportadora de Energía – nationalized by the Bolivian Government) and the World Bank to the consultancy 3 TIER specialist on meteorological simulation models. The model was developed ased on geological, topographic and satellite statistics over the past 30 years, and the results were validated with records from weather stations in Bolivia.

The Atlas is based on data and maps on a platform of universal and indefinite access via the Internet and through entities that have offered themselves as managers of the base (www.3tier.com/firstlook). Bolivia Wind Atlas identifies areas of high potential use of wind, as is the case of the Santa Cruz region, the provinces of North and South Lopez in Potosí, a corridor between Santa Cruz, Cochabamba and La Paz, a northern-southern corridor between the shores of Lake Titicaca, Oruro and west of the city of Potosí, where the project area is.

Although the atlas gives an indication of interesting potential areas and communities, for the study of the project it is necessary to carry out a detailed micro-scale wind resource evaluation in the community. The first identification visits to Turco and Challapata and in particular the communities of the project, confirmed that the area appears to have good wind potential. Anemometers were installed to assess the wind resource in the communities in 10 meters high towers. Given the dispersion of electrified homes, two anemometers were installed in Turco (Figure 1), one in Iruni and one in Villacollo. Another anemometer was installed in Challapata (Figure 2). Wind measurements were taken for over a year. To ensure that generates enough electricity to meet demand throughout the year, wind resource evaluation focused on the periods of the year with less wind resource. Thus, although the energy generation varies along the year, the minimum generation to fulfil demand is always met. The least windy month was March in Turco (in both anemometers) and April in Challapata, with an average speed of about 2.5 to 3.5 m/s. This is the data considered in the project design.

To get the detailed wind map not only from specific points but also for the whole community, a specific wind simulation software WAsP, The Wind Atlas Analysis and Application Program, by RISO, were used. This software extrapolates wind data collected by the anemometer located at a point and calculates the distribution of the wind resource throughout the surrounding area, considering the height map of the region. The topographic maps of the area were acquired in the Military Geographic Institute (La Paz, Bolivia). The energy generated by a wind turbine at each point of the community is also calculated by WAsP considering the power curves of wind turbines.

Next, we presented the height and maps of Turco (Figure 1) and Challapata (Figure 2) obtained with WAsP. As shown in the pictures, the highest elevation points are usually the areas with most wind potential.
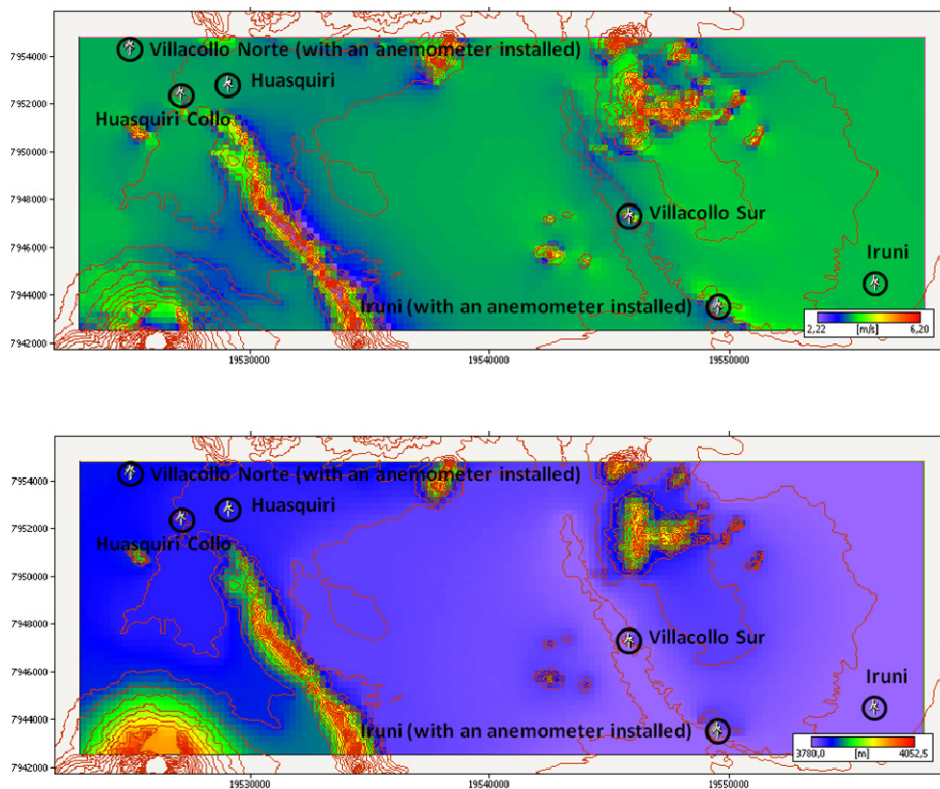
Fig. 1. Wind (up) and height (down) maps of the community of Turco.
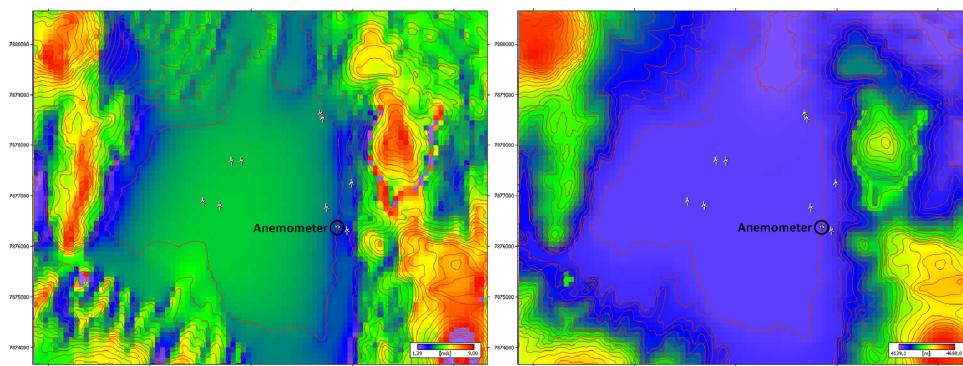
Fig. 2. Wind (left) and height (right) maps of the community of Challapata.

From the different technological options and according to the result of the wind resource evaluation, the promoters of the project decided to use wind energy to electrify these households of the communities (in front of photovoltaic solar systems, for instance).

4. Electrification project description

In 2009, 22 wind turbines were installed, 13 in the municipality of Turco and 9 in Challapata; in total, 80 people were beneficed. To ensure proper operation and maintenance of systems throughout the year, only households with permanent residents throughout the year were electrified.

4.1 Technical description

In Turco, the 13 beneficiaries of the project are grouped in five villages: Iruni, Villacollo Norte, Villacollo Sur, Huasquiri and Huasquiri Collo with 5, 3, 2, 2 and 1 households, respectively. In Challapata the 9 beneficiaries are dispersed and only two of them are close to each other. Given the dispersion of the households, the project promoters decided to install one individual wind turbine at each household. The chosen were the AIR-X-South West Windpower, which were distributed by SIE, a Bolivian company which offers the distribution, installation and maintenance service.

The design of wind systems at each household was carried out taking into account that turbines operate at a rated voltage of 12 V direct current-CC, and includes the generation system, regulation (directly incorporated into the wind turbine) and energy storage. The home system components are as follows:

- Generation. It consists of a wind turbine that converts the kinetic energy of wind into electrical energy.
- Regulation. Regulation to avoid over charging the battery is performed by a controller included in the turbine itself. If necessary, an inverter may be installed to prevent deep discharge by cutting consumption. However, in these projects, simple controllers that act as a viewfinder of the state of battery charge were installed.
- Storage. The accumulation and storage of electrical energy is done in batteries. Batteries are loaded when there is generation and discharged to supply power when the generation is insufficient.

- Conversion. Inverters are used to convert direct current (coming out of batteries) to alternating current (which work for most electric devices) to allow the use of conventional devices, but having a power limit.
- Distribution. The electricity is distributed within the household at a nominal voltage level of 220 V.

Figure 3 shows a breakdown of the basic outline of individual wind electrification, with connections between different equipments.
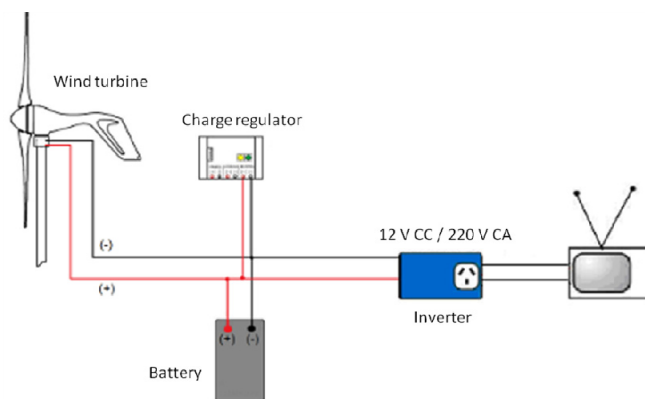
Fig. 3. Configuration of a wind individual electrical system.

4.2 Management model description

A common challenge in isolated electrification systems is to ensure the long-term project, for instance, in terms of sufficient maintenance and access to spare parts. To reinforce this challenge, the organizers of the project focused on developing an appropriate "management model".

The management model is a management tool developed in consensus with all stakeholders involved in the project, which aims to develop business service structure, and skills and abilities for the collective and individual sustainability. It contains regulations and operational rules governing the role of each different actor. Specifically, there is an operator-manager of the community that is in charge of the maintenance and management of all the systems. Users pay a monthly fee that goes to a fund for the maintenance of systems and possible replacements of equipment (batteries, etc.). A committee of users is also formed to supervise the technical and financial performance. The municipalities and town halls are the owners of the systems and are responsible for their long term sustainability.

The coordination mechanisms among stakeholders in these projects are:

- During the design and development of the project a fluid communication was guaranteed within a board of directors composed by beneficiaries and technicians responsible for implementing the planned activities.
- Once the installation finished and once the company that installed the systems and promoter institutions left the communities, the municipality and the town hall became the responsible of sustainability of the systems. The commitment is embodied in an agreement to support the management committees in which they agree to take charge of a consideration when replacing parts of the system (whenever required).

- Once the project finished, the management committees are required to perform preventive maintenance and to collect monthly contributions from users. In addition, each committee has at least one technical operator per municipality, who is also a beneficiary and each member received additional training which has been provided to them focusing on equipment maintenance and financial management.

5. Evaluation methodology

The purpose of external evaluation is to determine and assess the degree of progress of the project in relation to fulfilment of the outcomes of intervention in the implementation period (2008-2010). This analysis allows to detect the strengths and weaknesses of the project and to make corrections of the deviations detected, aiming to improve future interventions in the area. The evaluation team that conducted the evaluation presented in this paper focused most of his work on analyzing the following main sections:

- Real coverage of the project, in terms of direct and indirect beneficiaries, whether individuals or institutions.
- Degree of appropriation of activities by the beneficiaries.
- The scope of the intervention at the regional level and the integration of the logical intervention and complementarities between the different levels.
- The degree of impact of the first actions, depending on the time of project implementation, with special attention to indicators and real achievement.
- The effectiveness of tracking and monitoring mechanisms initially planned, and improvements in relation to the interaction with regional participants throughout the implementation process.
- The level of involvement of local and regional activities planned, as well as the beneficiaries.

5.1 Evaluation activities
The work consisted of office work and field work. The office work consisted of:
- Identification and analysis of available documentation on the context.
- Analysis of available information on the interventions to evaluate: formulation of the project, the technical and economic progress reports, annual programming documents and sources of verification.
- Design of methodological tools for collecting, processing and analyzing information to ensure the reliability of sources and the rigor and analysis in the field.
- Planning of field work and structuring of the surveys.
- Design of indicators for the analysis of the evaluation criteria.

Fieldwork was conducted in October 2010 in the municipalities of Turco and Challapata and essentially consisted of:
- Interviews with key officials of the municipalities involved: the Mayor, Council Members, and the indigenous heads.
- Interviews with technicians of the project team.
- Semi-structured interviews to members of the Management Committee or representatives of their organizations according to their customs.
- Visit to households of the beneficiaries in order to inspect the installed equipment, and collect information via surveys to each of the users.

The data collected from the surveys was processed and systematized in a database; SPSS was the information processing computer software used. In the same way, data collected from interviews was processed and compared providing greater reliability evaluation.

5.2 Definition of the evaluation criteria

The evaluation criteria were defined between the technical and social specialists of the promoter institutions and the external evaluator team. Criteria were defined before starting to collect information and results to ensure maximum objectivity. The defined evaluation criteria were:

1. RELEVANCE. This criterion assesses the suitability of the intervention in terms of local needs. It evaluates whether the proposal is technically valid, solves real problems and is appropriate to the context in which it is framed.
2. EFFICIENCY. This criterion examines the relationship between enforcement activities and compliance with the results and the relationship of these with the investment.
3. EFFECTIVENESS. This criterion measures the degree of compliance with the initial specific objectives of the projects and the actual outcome of the expected benefits to the beneficiaries.
4. IMPACT. This criterion examines the net effects of the project from a broad perspective, taking into account all stakeholders, and projects in the medium term.
5. SUSTAINABILITY. This criterion analyses the possibility of consistent positive effects of the project once the foreign aid ends, taking into account all relevant factors.
6. COHERENCE. This criterion analyses the compatibility between the objectives, activities and expected results of public policies and recommendations of international organizations.
7. FACILITIES: This criterion checks the compliance with the Bolivia IBNORCA NB - 1056.

Table 1. summarizes the indicators and related components for each of the criteria.

CRITERIA	INDICATORS	COMPONENTS
Relevance	Adequacy of the project to local needs	Does the intervention correspond to priorities and needs of the population?
		Have the needs of communities changed after the first identification? What changes have there been?
		Have the actions proposed in the project been able to solve the problems identified? Have they taken into account the socioeconomic context?
	Adequacy of the project to local priorities	Which are the priorities of government intervention in the territory and the sector involved in the project?
		Which are the priority interventions of local government in the area?
		Is the project aligned with the priorities of national and local government?
	Complement with other actions	Does the project being completed in a real way in the area?
		Are there mechanisms for coordination between different actors?
	Design of the intervention	Has the project taken into account the views and opinions of local staff? Which have been the levels of participation of them in their formulation?
		Do the planned activities actually lead to the fulfillment of the intended outcomes? Is internal logic of the program the best way to address the identified problems?

CRITERIA	INDICATORS	COMPONENTS
		Are the results feasible and relevant to the achievement of the logical framework? Are they formulated in terms of impact?
Efficiency	Analysis of the achievement of individual results from realized activities	What was the level of compliance with each of the activities? What factors facilitated and hindered compliance?
		What was the degree of compliance with each of the results? What factors facilitated or hindered performance?
		Were there any unanticipated results? Which ones?
	Analysis of the relationship between results and resources invested	What was the relationship between invested resources and obtained results?
		What were the results in relation to time spentlike ?
	Analysis of management in relation to the results	Has the management of staff been adequate? Which was the commitment of staff with the communities?
		Has the project follow-up been adequate? How was the relationship with the field team?
Effectiveness	Performance analysis of the specific objectives	What is the level of compliance of the specific objectives?
		Which factors have facilitated/ impeded the fulfilment of the specific objectives?
	Usefulness and availability of the specific objectives	Were the benefits of the project well received by the population? Were there problems to access to these benefits?
		What is the perception of utility that people and community leaders have about the objectives of the project?
Impact	Analysis of compliance of logical framework	Contribution of the project to the achievement of logical framework
		Factors that have facilitated / impeded the project's contribution to the achievement of logical framework
	Impacts from a broad perspective	Project's positive impacts on beneficiaries, on the economic, environmental, social, and organizational aspects.
		Project's negative impacts on the social, economic, organizational and environmental aspects
		Unexpected impacts (positive and negative, on all players and dynamics)
		Factors and interventions outside the project have been able to generate positive or negative effects on the impacts
Sustainability	Analysis of the possibility that each of the processes and their positive impacts are sustainable	Is there a local government department responsible of the processes established by the project?
	Factors that facilitate / impede the permanence of the positive effects	Political factors, Institutional factors, Gender factors, Economic factors, Technological factors, Other factors
Coherence	Relation with the strategical policies of public sector	Do the identified problems correspond to the purposed objectives?
Facilities	The design of the facilities meet the regulation	The design of the facilities meet the needs of the usersand the standard IBNORCA NB-1056
	Facilities are in accordance with the design	Facilities are in accordance with the design and standards
	Facilities are operating according to design	Facilities are operating according to the design

Table 1. Criteria, indicators and assessment components.

6. Results of the evaluation

This chapter provides the information, the analysis and the results of the external evaluation in terms of each of the criteria and carries out global evaluation.

6.1 Relevance

The results of the evaluation confirmed that these projects have made a direct benefit for the families supplying access to electricity in their households. The field assessment after the implementation of the project has revealed that electric service has given them the ability to access telephone communication (cell phones had network coverage only needed electricity to recharge) and audiovisual media (television, radio, etc.).

However, the degree of satisfaction of the beneficiaries is not for all the same. Some of the beneficiaries are completely satisfied with the recent access to electricity, whereas others are only partially satisfied because their expectations were superior to actual performance and possible uses of electricity. Some of the beneficiaries confirm they use electricity for lighting and some low power appliances, as it was planned in the logical framework of the project but, at the same time, they claim that they wish to have more energy for other uses. In Turco, 6 out of 11 beneficiaries are completely satisfied and 5 are partially satisfied. In contrast, In Challapata almost all beneficiaries are completely satisfied, 7 out of 8. Among other factors, the difference is probably due to the difference in wind potential in the communities; the wind potential available in the Challapata is greater than in Turco, thus, the same generation equipment generates much more energy.

6.2 Efficiency

The results indicate that the projects justify the investment and that the management of staff has been adequate. It is noteworthy the commitment of the staff to the beneficiary communities that was reflected in the interviews. Results of the evaluation confirmed that the objectives and results defined in the logical framework of the project were achieved with an optimal degree of compliance.

However, the short time available to carry out the activities has been identified as a negative factor. The key aspects that influence and make the time needs critic are:

- The fieldwork itself needs a lot of time, in particular due to the remoteness of the communities. The need of technological and logistic external support and their availability also constrained the schedule.
- In terms of community activities, the communication process that involves speaking Spanish as well as native language (Quechua, Aymara) requires more time. Moreover, gaining the confidence and trust of the beneficiaries and overcoming some internal conflicts in the communities also require dedication and perseverance. The education and training according to the needs of the community and implementation of management models must be repeated in a lengthy process to ensure the correct appropriation.
- The coordination with municipal governments, as well as making effective their economic commitment was also a long process.

However, the only weakness found caused by the short time spent in the project was that the management committee was concerned about not being self-sufficient to keep equipment running. Although the interviewees say their organization does work, the correct

performance may be threatened by the lack of commitment tools that would help to ensure the fulfilment of the obligations of the users. In particular, they claim more training and time for a proper comprehension of the rules of the new organization because the management committee has no element of coercion to require monthly contributions, and the technical operator receives no remuneration for his work as inspector. These deficiencies are repeated in Turco and Challapata but with different intensity.

6.3 Effectiveness

One of the specific objectives of this project aimed to train the users in the maintenance of wind power systems and organizational management techniques for the sustainability of the systems. A key point is the emphasis on training and awareness of people through workshops and seminars. The results of the evaluation confirmed the population received good training, are aware of the benefits of the project and have a positive perception of usefulness. Users are also aware of the existence and significance of the management committee although no regularity when making the respective contributions has been achieved. These delays have had no negative consequences so far because there have been no need to replace elements, because the projects have been running for a short time.

In terms of uses of electricity, the beneficiaries use the energy depending on their economic possibilities to buy electric appliances, from lighting to communication and leisure. The most noteworthy nightlife activities are spinning, knitting or sewing by women and schoolwork by children. Table 2 shows the number of users per municipality using different types of appliances.

	Focus	TV	Radio	Cell Phone	Battery chargers	Others
Turco	11	0	1	10	1	0
Challapata	8	0	4	2	1	0

Table 2. Number of users of each appliance in each community.

6.4 Impact

In terms of the logical framework, the project has largely achieved its objectives and actually incorporated renewable energy in Turco and Challapata communities as demonstration projects in Bolivia.

The main factors that facilitated the success were:

- Training of all users and technicians from the municipal governments.
- The development of management manuals.

The most noteworthy positive impacts of the project are:

- Improved quality of life, preserving the environment.
- The achievement of an organization to manage the systems designed according to customs.

From the economic point of view, almost all beneficiaries agree that now with the new electricity service they spend less money on the provision of electricity than they used to spend on traditional energy sources (kerosene, candles, etc.). Apart from that, some of them state they no longer have to breathe smoke like when they used kerosene, burners or candles. Beneficiaries state they have a solid and consolidated organization, although this is not directly reflected at the time of monthly contributions.

Table 3 shows the qualitative assessment of the changes resulting from the project in the organizational, economic, social and environmental aspects; it shows the percentage of beneficiaries that state the changes have been positive, negative or non significant (no change). The most significant changes occur in the economic area, thanks to a reduction of costs on energy provision, and in the environmental aspects, by decreasing smoke of candles, lighters and kerosene lamps.

		positive	negative	no change
Turco	Organizational	100%	0%	0%
	Economical	60%	0%	40%
	Social	10%	10%	80%
	Environmental	100%	0%	0%
Challapata	Organizational	100%	0%	0%
	Economical	100%	0%	0%
	Social	0%	0%	100%
	Environmental	100%	0%	0%

Table 3. Assessment of the changes.

The only negative impact found in the evaluation is that people who are not beneficiaries of the project are now in an unequal position and feel they are now in a situation of inferiority. It is noteworthy to remind that only homes with at least one permanent resident throughout the year were electrified, to ensure proper operation and maintenance.

6.5 Sustainability
The promoters (Engineers Without Borders, CINER and Mosoj CAUSAY), and the management committees of the projects signed an agreement with the mayors involved in the projects, where the municipalities assumed to take over the sustainability of actions. The management committees are afraid of not being self-sufficient to maintain the systems of electrification (lack of regular payments, technical operator's temporary absence, etc.) and so the mayors involved agreed to give support and to take over the long term sustainability of projects. However, changes in the technical and municipal authorities, bureaucracy, lack of financial resources, lack of continuity in the training of technicians of the municipality and other stakeholders may hinder the fulfilment of commitments.
Moreover, the future of these systems is contingent on the proper use and proper maintenance of each of the equipments. The company that installed the wind systems is committed to maintain and to repair themfor a period of two years. So far, the company repaired the systems when needed but has taken some time, so some beneficiaries have had no electricity during weeks or months.

6.6 Coherence
The results of the evaluation confirmed there is a clear coherence between identified problems in the area and goals of the project. The project has successfully overcome one of the main problems identified in the area: lack of electricity and reliance on traditional energy sources (candles, lighters, wood and other fuels). Now beneficiaries say they no longer breathe smoke (of kerosene or candles), and state they spend less money on energy supply.

In addition, the evaluation confirmed this project is not against any plan, program or policy; on the contrary, it contributes to the government's obligation to provide basic services to the population.

6.7 Facilities

The verification of the quality of the facilities is conducted as part of the field work, making home visits to most users of both Turco and Challapata. To check the correct design and installation of the facilities, the standard guidance document IBNORCA Bolivian NB 1056 was used. All components were verified in each household, taking into account the data of the original design. Most equipment was found to be working properly and user feedback was favourable. Only minor problems were detected which were easily solved (low batteries, bearing noises, light poles with vertical offset).

6.8 Evaluation and analysis

The rating scales and the weighting of each criterion were discussed and agreed at a meeting between the evaluation team and CINER and Mosoj Causay. This meeting was held before the start of the collection and analysis of information to ensure maximum objectivity.

From the analysis of the results of the evaluation and the defined rating scales (1 to 5), each of the components of each criterion was quantified. The resulting score of each component of each indicator is shown in the following table (Table 4).

Figure 4 shows the results of the evaluation according to each criterion. The project achieved an overall weighted evaluation of 89.33%, which corresponds to a qualitative assessment of "functioning under optimal conditions".

CRITERIA	Total	Nª	COMPONENT	Value
RELEVANCE	4.35	1	Adequacy of the project to local needs expressed	4.33
		2	Adequacy of the project to local priorities	3.57
		3	Complement with other actions	5
		4	Design of the intervention	4.5
EFFICIENCY	4.50	5	Analysis of the achievement of individual results from realized activities	4.17
		6	Analysis of the relationship between results and invested resources	4.33
		7	Analysis of management in relation to the results	5
EFFECTIVENESS	4.67	8	Performance analysis of the Specific Objectives	4.63
		9	Usefulness and availability of the Specific Objectives	4.71
IMPACT	4.75	10	Analysis of compliance of the logical framework	5
		11	Impacts from a broad perspective	4.5
SUSTAINABILITY	4	12	Analysis of the possibility that each of the processes and their positive impacts are sustainable	5
		13	Factors that facilitate / impede the permanence of the positive effects and the processes	3
COHERENCE	5	14	Relation with strategic public sector policies	5
FACILITIES	4.33	15	The design of the facilities meet the regulation	4.5
		16	Facilities are in accordance with the design	4.5
		17	Facilities are operating according to design	4

Table 4. Evaluation of the external evaluation process.
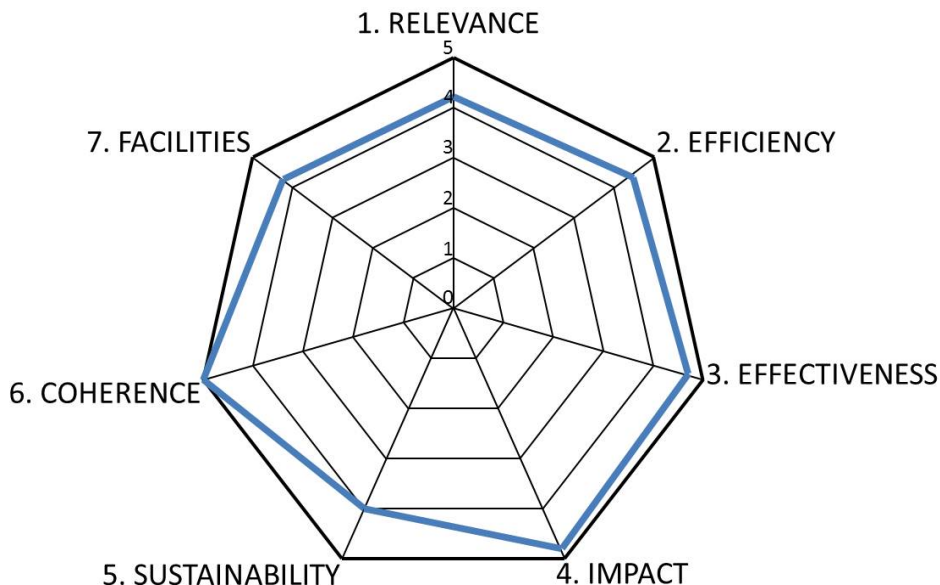
1. Relevance: 4.35/5 (weight: 25%)
2. Efficiency: 4.50/5 (weight: 10%)
3. Effectiveness: 4.67/5 (weight: 10%)
4. Impact: 4.75/5 (weight: 15%)
5. Sustainability: 4/5 (weight: 15%)
6. Coherence: 5/5 (weight: 10%)
7. Facilities: 4.33/5 (weight: 10%)

Fig. 4. Results from the multicriteria evaluation.

6.9 Recommendations of use and maintenance

The following recommendations are deduced from the evaluation and are proposed to proper use and maintenance of systems and to promote long term sustainability:

- To facilitate the sustainability of the project, the management was transferred to the involved municipalities, and should be monitored periodically by these entities. The mayors should support the preventive maintenance plan for wind turbines and should include training for users at least once a year, especially to the young.
- Management committees in coordination with Installation Company must check the level of the batteries and the wind systems performance. The maintenance plan for wind systems must check the status of bearings, the load control system and the verticality of the poles.
- Users must remember that when they buy a radio or TV their power must be appropriate for the wind systems. The maintenance plan should ensure that the light output of focus fulfils the standard NB IBNORCA -1056 and users should paint rooms in white for greater light efficiency.
- Batteries must be in a suitable container for efficient and secure use. The municipal government should provide a battery charger as a backup system for each community.

7. Analysis of alternative designs

Due to the characteristic dispersion of communities, rural electrification projects tend to install individual systems at each point of consumption, as the cases presented in this paper. Alternatively, design of a single point of generation and distribution of electricity with microgrids (Kirubi et al. 2009) has its advantages:

- Flexibility in use: energy generation and storage is shared among several users, thus one or more users can increase their consumption at a specific moment if needed.
- Easier integration of future users: new users may be electrified just extending a wire.
- Robustness against failure: microgrids facilitate feeding users with more than one generator. Thus, in case of failure of a generator, energy supply decreases but no user is completely left without access.
- Cost savings: microgrids facilitate to use more powerful equipment, which are proportionally cheaper.

In particular, the electrification with microgrids in Turco and Challapata would have avoided some of the problems identified in the assessment:

1. Some users were expecting to have more energy availability. The use of microgrid generation facilitates the use of more powerful and proportionally cheaper turbines, so more energy can be generated and supplied with the same investment. Moreover, higher energy supply scenarios can be considered with lower cost increase.
2. People that do not live permanently in the community were not electrified to avoid operation and maintenance problems. In systems with microgrids generation equipment is not installed at each household and, therefore, not living permanently is not a problem because the maintenance is common and not necessarily the responsibility of each user.
3. The lack of supply during breakdowns. In case of breakdown of a generator, no user is completely left without access, so the time taken to repair the system is not that critic.

7.1 Design models with microgrids

To study the possible use of microgrids in future projects, the electrification options with microgrids in Turco and Challapata are analysed. Although in both communities most households are scattered, there are small groups of households close to each other that could have been electrified with a microgrid.

To optimize the design of these alternatives a Mixed Integer Linear Programming (PLEM) model (Ferrer-Martí et al., 2011) is used. This model is based on the definition of a set of parameters (which specify the input data of the problem), variables (which define the configuration of the solution) objective function (which defines the standard resolution) and constraints (that specify the set of conditions to be satisfied that the solution is feasible). The solution of this model determines the point of generation and micro design to minimize costs, taking into account the demand, the wind resource and power generation equipment available in the area (cost and technical characteristics).

Next, the parameters, variables, objective function and constraints of this model are briefly introduced.

- Parameters
  - Demand: Energy and power consumption of each point and days of autonomy.

- Generation and accumulation: Turbines with built-in controller (type, cost, maximum operating power, and maximum power generated at one point) and batteries (type, cost, capacity and discharge factor).
- Definition of the network: Distance between points, conductors (types, cost including the infrastructure, resistance and current carrying capacity), rated voltage distribution and voltage drop.
- Equipment: Inverters (type, cost and power) and meters (cost).
- Variables
  - Equipment: number of each type of equipment installed at each points.
  - Definition of the network: connections between two points, and energy and power flow between the two points.
- Objective function: To minimize the investment cost considering wind turbines, batteries, inverters, meters and conductors.
- Constraints
  - Generation and accumulation: Energy and power balances at each point, required energy capacity in the batteries at each point of generation.
  - Definition of the microgrid: It establishes the relationship between energy and power flows and the existence of a conductor between two points, compliance of maximum voltage drop and maximum intensity, the structure of microgrid (if any) should be radial.
  - Equipment. Inverters are installed at the points of generation; the meters are installed at points of microgrid.

To specifically assess all the advantages of the microgrids, a constraint that forces to form microgrids to feed the households that were close to each other at each community is included.

7.2 Results of the design of the projects with microgrids

Next, the data and parameters considered in the generation and study of alternative designs are summarized. In particular, this experiment considers the use of the equipment installed in the real projects and more power equipment for their possible use in microgrids that feed several households.

- Demand
  - Two demand scenarios: the first for a basic consumption (energy 140Wh/day, power 100W) and the second to promote the development of productive activities (energy 280Wh/day, power 200W).
  - 2 days of autonomy.
- Generation and accumulation
  - 4 types of turbines: Air X, Whisper 100, Whisper 200 and Whisper 500) at a cost of $1000-$4600 and 550W- 3300W, respectively, by South West Windpower.
  - Regulators are incorporated into each type of turbine.
  - 3 types of batteries: $240-325 and 150-250Ah capacity discharge 60%.
- Microgrids
  - 3 types of conductors: cost $4.05- 4.4 per meter.
  - 220V distribution voltage and a 5% maximum voltage drop.
- Equipment

- 1 type of inverter: cost $ 255, power 350W.
- 1 type of meter: cost $ 50.

Table 5 shows the obtained results. The table is divided into two columns for each demand scenario and two rows for each municipality. The sub-columns show the obtained results considering: 1) the individual solution (one generation equipment per household); 2) the solution with microgrids with one type of wind turbines (the type used in the real projects, Air X) and 3) the solution with microgrids with 4 types of wind turbines (the type used in the real projects, Air X, and 3 more powerful ones). The sub-rows present the investment cost, the difference of the cost of individual generators in the low demand scenario, the total energy, wind turbines used, the microgrids and the number of users in each one and number of individual users.

		Low Energy Demand (140Wh/day; 100W)			High Energy Demand (280Wh/day; 200W)		
		Individual	Microgrid (1 w.t.)	Microgrid (4 w.t.)	Individual	Microgrid (1 w.t.)	Microgrid (4 w.t.)
Turco	Total cost [$]	19423	17862	16862	26423	26277	22777
	Difference (%)	-	-8,0%	-13,2%	36,0%	35,3%	17,3%
	Energy [Wh/day]	4460	4234	4166	6086	6124	6227
	Wind turbine (type)	13 (Air X)	12 (Air X)	8 (Air X) 2 (Whis. 100)	20 (Air X)	20 (Air X)	7 (Air X) 3 (Whis. 100) 1 (Whis. 200)
	Microgrids (users)	-	1 (4) 1 (3) 2 (2)	1 (4) 1 (3) 2 (2)	-	1 (4) 1 (3) 2 (2)	1 (4) 1 (3) 2 (2)
	Individual users	13	2	2	13	2	2
Challapata	Total cost [$]	14447	13886	13886	16447	16867	15867
	Difference (%)	-	-3,9%	-3,9%	13,8%	16,8%	9,8%
	Energy [Wh/day]	4641	3381	3381	5185	5196	5161
	Wind turbine (type)	10 (Air X)	8 (Air X)	8 (Air X)	12 (Air X)	12 (Air X)	9 (Air X) 1 (Whis. 100)
	Microgrids (users)	-	3 (2)	3 (2)	-	1 (2)	1 (2)
	Individual users	9	3	3	9	7	7

Table 5. Analysis of the electrification solutions of Turco and Challapata with microgrids.

In Turco, in the low demand scenario, the cost of real implemented project, that installed an individual wind turbine at each household, is $19423. The design with microgrids reduces the cost by 8% when only one type of wind turbine is available ($19423 vs. $17862); the cost reduction is higher 13.2% when 4 types and more powerful wind turbines are considered ($19423 vs. $16862). In both solutions one microgrid of 4 households is formed in Iruni, another of 3 households is formed in Villacollo Norte and 2 microgrids are formed in Villacollo Sur and Huasquiri.

In the high demand scenario in Turco, the cost of electrification solution increases by 36% when only individual generators are considered ($19423 vs. $26423). This increase is significantly reduced to 17.3% when microgrids and 4 types of wind turbines are considered ($19423 vs. $22777); thus, twice energy and power demand only implies a cost increase of 17.3%. The formed microgrids are always the same in all cases.

In Challapata, in the low demand scenario, the cost of real implemented project is $14447. The design with microgrids reduces the cost by 3.9% ($14447 vs. $13886); 3 microgrids of 2 users each are formed. In the high demand scenario, the cost of electrification solution in Challapata increases by 13.6% when only individual generators are considered ($14447 vs. $16447). This increase is reduced to 8.8% when microgrids and four type of wind turbines are uses ($14447 vs. $15867).

8. Conclusions

This article aims to describe and evaluate two wind generation projects implemented in Bolivia, in the municipalities of Turco and Challapata, department of Oruro. This multi-criteria evaluation was conducted when the systems had been running for one year by an external evaluation team. The results of the evaluation showed that the project has achieved its main objectives giving a weighted mark 89.33%, which corresponds to a qualitative assessment of "functioning under optimal conditions." This confirms that renewable energy is the best choice for access to modern energy in isolated communities.

Among the main strengths of the project s the positive acceptance of the beneficiaries and access to electricity in remote areas must be highlighted. The main weaknesses of the project are the bureaucracy that slows down municipal governments and internal conflicts among beneficiaries. The assessment highlighted limitations in the systems that must be resolved in future projects, for instance, the training should be extensive in time. The biggest risk is long term sustainability if the municipalities do not fulfil their commitments.

Furthermore, alternative designs were analyzed with microgrids to improve some of the drawbacks identified in the assessment: the continuity of supply against breakdowns, supply of electricity to non-permanent residents and the possible increase in energy supply to cover more applications. The results recommend taking advantage of microgrids for projects in future, to feed groups of households, improve the quality of electric service and reduce costs.

9. Acknowledgments

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Taxes Incentives to Promote Res Deployment: The Eu-27 Case

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1. Introduction

The share of renewable energy source (RES) in gross final energy consumption was 10.3% in the European Union (EU-27) in 2008; the remaining 89.7% was covered through the use of conventional fuels such as natural gas or oil products (Eurostat, 2010). The renewable energy share in gross final energy consumption was used for the production of heat (5.5%), electricity (4%) and transport fuels (0.8%).

Deployment of RES contributes to two of the four targets of the EU-27 energy strategy: the need to reduce primary energy dependency and the stress of demand on primary energy resources. In addition, the Green House Gas (GHG) abatement due to a more intensive use of RES contributes to improve the EU-27's target related to climate change, this being the fourth target in its energy strategy.

From a legal point of view, The Green Paper (EC 1996), which was the first attempt of establishing a common policy on renewable energies in the European Union, settled down the goal of duplicating the contribution of RES in the gross domestic consumption in 15 years. From the year 1996 until the present, the European Union has developed an intense ruling activity around the promotion of RES.

An important step forward the construction of the Community framework about harmonized fiscal treatment was the passing of the Directive (EC, 2003/96), that restructures the community regime about taxation over energy products and electricity.

In order to improve on energy efficiency, the most important EU policies for the households sector are the EPBD (EP&C, 2010), "The Energy Services Directive (ESD)" (EP&C, 2006) and "The Eco-design Directive" (EP&C, 2009).

The renewable energy Directive 2009/28/EC covers renewable energy use in three sectors:
1. Gross final consumption of electricity from renewable energy sources;
2. Gross final consumption of energy from renewable sources for heating and cooling (H & C); and
3. Final consumption of energy from renewable sources in transport.

IEA (2009) has recently pointed out that part of renewable energies growth is due to strong policy support. Therefore, policy measures to promote RES are becoming an interesting issue in its deployment.

In November 2010 the Commission presented the new strategy for competitive, sustainable and secure energy (COM 2010/0639). The communication, named "energy 2020", fixes the priorities in the field of energy for the next ten years and the actions that should be performed to save energy, achieve a competitive market, and guarantee the safety of supply, promoting at the same time technological leadership.

Focusing on green electricity, RES for Heating and Cooling and its use in transport, this chapter offers an overview of the main tax incentives that have been implemented to promote their use by the Member States (MSs) of the EU-27. In a general way, along with the reduction of investment costs, tax incentives can also be used to make the energy generated from RES more profitable than that generated by conventional energy sources.

Chapter has been structured as follows. Section 2 analyzes tax incentives to promote green electricity. Section 3 is dedicated to study the same topic in promoting RES for H & C. Section 4 focus on the way MSs promote the use of biofuels in transport by using tax incentives. Finally, section 5 includes a political discussion and main conclusions.

In a summarized way, Section 2 provides a comprehensive overview of the main tax incentives used in the EU-27 MSs to promote green electricity. Sixteen MSs use tax incentives to promote green electricity along with other promotion measures as quota obligations and price regulation. Section 3 shows the main tax incentives used to promote RES for H&C by EU-27 countries up to 2009. Although subsidies is the most widely used instrument to promote RES for H&C, twelve MSs have used tax incentives as deductions, exemptions and reduced tax rates. Section 4 analyses the tax incentives that MSs have used to reach the target of a share of 5.75 % in final consumption of energy biofuels in transport in 2010. This is the target fixed by Directive 2009/28/EC. Although green electricity for transport and hydrogen vehicle are included in the Directive 2009/28/EC framework, this chapter focuses on the policy measures, mainly those related with taxes, that have been used to promote the use of biofuels in transport.

2. Tax incentives to promote green electricity

This section provides a comprehensive overview of the main tax incentives used in the EU-27 MSs to promote green electricity[1]. As stated Cansino *et al*. (2010), in promoting green electricity, there are probably no "perfect" fiscal incentives that should be widely applied in all situations and countries. These incentives are applied simultaneously with other promotion's measures, specially quota obligations and price regulation.

In UE-27, seventeen MSs have used fiscal incentives to promote green electricity. Mainly designed as tax exemptions, rebates on taxes, tax refunds and by applying lower tax rates on activities promoted. However, not all disposable technologies are always promoted. Table 1 provides an overview of the use of these tax incentives in the EU-27 MSs.

Fiscal incentives in direct taxes are used to promote electricity from RES by seven MSs. Czech Republic, Belgium, France and Luxembourg use the personal income tax as it allows either tax deductions or exemptions depending on the source of income and the capacity installed.

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[1] In this section, in addition to the country-specific information, we have taken into account the country reports in EREC (2009) titled "Renewable Energy Policy Review", the information obtained from Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit (2011), the "Taxes in Europe" database published by the European Commission (2011) and the paper of Cansino *et al*. (2010).

Czech Republic has a total exemption of the tax revenues that the taxpayer obtains coming from the generation of this type of energy. A similar exemption is also contemplated in the corporate tax. In Belgium and in France an exemption is allowed in the personal income tax (on the taxable income) on behalf of the cost of the investment of the system installation PV. In the French case, the exemptions not only cover the cost of the investment in system PV but also in the systems with small capacity which use wind energy, hydraulics and biomass. Luxembourg promotes solar photovoltaic electricity with an exemption from income tax of the sale of electricity generated by this system and whose capacity is small.

	Personal Income Tax	Corporate tax	Property Tax	VAT	Others Excise Duty Exemptions	CCL	Other Taxes
Belgium	✔	✔					
Czech Rep.	✔	✔					
Denmark					✔		
Finland							✔
France	✔			✔			
Germany					✔		
Greece		✔					
Italy			✔	✔			
Luxembourg	✔						
Netherlands							✔
Poland					✔		
Portugal				✔			
Romania					✔		
Slovakia					✔		
Spain		✔	✔				
Sweden					✔		
United Kingdom						✔	

Source: Cansino *et al.* (2010)

Table 1. Fiscal incentives to promote green electricity

Belgium, Greece and Spain allow the deduction of a percentage of the investment made in systems that generate green electricity from the net tax base in the corporate tax. In the first two cases, the exemption is allowed by the company that has spent the funds in building the systems that generate green electricity. In Spain, it is allowed a deduction of a percentage of the investment that the company carries out in the installation of systems for the green electricity from the net tax base.

Finally, only Italy and Spain have used property taxes to promote green electricity. In Italy, municipalities may establish rates lower than 4 per 1000 of ICI ('Imposta comunale sugli immobili') for taxpayers who install or have installed a system of renewable energy to produce electricity or heat for domestic use. In Spain, municipalities may reduce the IBI, which is a similar tax to ICI, under specific conditions, up to 50% of the full share of the tax for real state to promote the establishment of solar energy systems. However, this measure has been used by few municipalities because are borne by them.

Fiscal incentives in indirect, pigouvian and others taxes are used to promote electricity from RES by twelve MSs. The Value Added Tax is theoretically one of the most suitable indirect tax to promote renewable energies. However, only three MSs have chosen this tax as an instrument to boost green electricity: France, Italy and Portugal.

A cut in the Value Added Tax rate has to follow European guidelines about state helps that favour the environment (EC, 2001) and also has to get the Commission's authorization in order to prevent disproportioned effects over competition and economic growth. France allows a 5.5% reduction when buying basic products related to improvements, changes and installation in residential buildings that incorporate technology based on solar power, wind power, hydro-electric power and biomass. Italy charges a reduced tax rate on sales and services related to wind and solar power generation. There is also a reduced tax on investments in green electricity distribution networks. Finally, Portugal allows a reduction in buying systems which generate green electricity.

Electric energy excise duty exemption is the most pervasive measure to encourage the use of renewable electricity of all. Actually, six MSs use it: Germany, Denmark, Romania, Slovakia, Sweden and Poland. In general, they use this measure because produces two types of benefits, known as the double dividend (Goulder, 1995). The first is to preserve the environment and the second can be obtained in several ways, as a positive impact on employment levels (De Mooij, 1999). This measure has been also use for reducing the higher prices of production of this type of energy. In that sense, this type of exemption is being usually applied to biofuels sales (Bomb *et al.*, 2007; Van Beers, C *et al.* 2007). Nevertheless, some EU countries have applied to renewable electricity with the same propose. Fossil fuels and nuclear generations' benefit of a competitive advantage with respect to RES because its lower marginal costs than new renewable technologies and they are able to cope with downward price pressure. Because of that, taxation is important for decreasing most costs of RES sector, by allowing exemptions, reductions and accelerated depreciations (Di Domenico, 2006).

In Germany the law provides exemptions to encourage the use of friendly sources of energy when the electricity is generated exclusively from renewable sources and taken for use from a power grid. In the same sense, Romania has included an exemption from the payments of excises duties for energetic products and electricity when the electricity is generated by RES. is (also) promoted in Slovak Republic renewable energy is promoted through the exemption of the excise duty on electricity. Finally, the new Polish legislation continues to exempt from excise duty electricity from RES.

In the other hand, some countries have introduced electricity excise exemptions for renewable electricity only if they are generated by determinate technology. In Denmark, it is only exempt for excise duty, the electricity produced by wind, waterpower or solar cell systems or in a small plant. In Sweden, the electricity produced in a wind power station is not taxable if it is for own consumption although the electricity surplus might be sold. The exemption value depends on the consumption area. Also, during a transition period all wind energy production has been also entitled a tax reduction (environmental bonus).

Some other tax exemptions are used to promote green electricity. In the United Kingdom, electricity from RES is exempted from the 'Climate Change Levy –CCL-', which can characterize as a typical pigouvian tax. This tax is borne by agents that generate carbon emissions because it pursues to reduce negative externalities which come from human activities (Viladrich, 2004). The CCL was forecast to cut annual emissions by 2.5 million tons by 2010, and forms part of the UK's Climate Change Program.

The CCL has to be paid by the electricity suppliers, who pass the costs to the industrial and commercial final consumers. To be tax-exempt, is required an authorization which may be given only under some conditions which involve consumers, suppliers and electricity producer. As requirements in the contract enter the electricity consumer and the electricity supplier, an agreement enters the electricity supplier and the electricity producer and some obligation of the electricity producer with the Office of Gas and Electricity Markets.

In Netherlands, electricity from RES is granted by a reduction of the ecotax, if it is produced within and outside the Netherlands but with the condition that has to be supplied to Dutch. All technologies used for the generation of electricity from RES are promoted.

Finally, in Finland, the consumption of electricity from RES is also taxable by the excise duty electricity. Nevertheless all operators of plants generating electricity from RES are entitled to a subsidy by statutory law, in order to offset the tax they must pay, which normally is transferred to the consumer. So, this subsidy is used to reduce the price of renewable energies. The application for the subsidy has to be lodged with the Customs District of the area of the domicile of the power plant and no subsidy is paid when the volume of electricity referred to in the application is small.

3. Tax incentives to promote RES for H&C

This section shows the main tax incentives used to promote RES for H&C by EU-27 countries up to 2009. Although subsidies is the most widely used instrument to promote RES for H&C, twelve MSs have used tax incentives as deductions, exemptions and reduced tax rates (Cansino *et al*., 2011).

In addition to subsidies, RES H&C are often promoted through a range of tax incentives, although with a lower intensity compared with green electricity and biofuel promotions (Cansino *et al.,* 2011 and Uyterlinde *et al.,* 2003). The main tax incentives used by EU-27 MSs are deductions, exemptions and reduced tax rates.[2] Table 2 provides an overview of the use of these tax incentives in the EU-27 MSs.

3.1 Deductions
There are six MSs that offer different direct tax deductions to encourage the use of RES H&C (Belgium, Finland, Greece, Italy, The Netherlands and Sweden), as Table 2 shows.

In Belgium, all RES H&C technologies benefit from a tax deduction from taxable profits. For all RES and CHP installations, companies can receive a tax deduction of 13.5% for all investments in equipment used to reduce energy consumption. Since January 2003, the Federal Public Service of Belgium offers tax reductions for individuals undertaking energy efficiency and certain renewable energy investments in their homes. In 2009, a tax reduction of 40% of the investment cost was introduced on personal income tax with a maximum of 2,770 € for investment in heat pumps and biomass heating, and 3,600 € for investments in solar boilers. However, for every investment, the taxpayer can only obtain the maximum support for four years.

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[2] In this section, in addition to the country-specific information, we have taken into account the country reports in EREC (2009) titled "Renewable Energy Policy Review", the Intelligent Energy Europe (2010) report titled "Re-Shape Renewable Energy Country Profile", the EuroACE (2009) report on tax incentives that affect buildings in Europe, the "Taxes in Europe" database published by the European Commission (2011) and the paper of Cansino *et al*. (2011).

	Deductions	Exemptions	Reduced tax rates
Austria		✔	
Belgium	✔		
Bulgaria		✔	
Denmark		✔	
Finland	✔	✔	
France			✔
Germany		✔	
Greece	✔		
Italy	✔		✔
The Netherlands	✔		
Sweden	✔	✔	
UK		✔	✔

Source: (Cansino *et al.*, 2011)

Table 2. Member States that use tax incentives to promote RES H&C

Finish consumers can also benefit from tax deductions provided the expenses are used to promote the use of more efficient systems and RES. Since 2006, a 60% household tax deduction has been available to offset labor costs incurred in replacing, upgrading and repairing the heating systems of small residential houses. The maximum amount of the tax deduction per household is 6,000 € (EuroACE, 2009).

Related to Greece, a 20% deduction is available on personal income tax up to 700 €, for money spent on the installation of RES, such as solar panel systems, thermal insulation and district heating. In Italy, personal income tax deductions up to a total of 55% of the investment outlaid on solar thermal systems (and any other energy efficiency investment), spread over ten years, can be obtained. This deduction decreases to 36% if the national fund set aside for each year is exhausted.

In the case of The Netherlands, in order to stimulate investments in RES, a scheme implemented by Senter Novem and the Dutch Tax Authorities allows Dutch companies that investment in RES (including those related to H&C) a deduction of 44% on such investments from their fiscal profit up to a national maximum of €108 million per year. The investment threshold is 2,200 € and no investment allowance is granted for investments exceeding 113 million € in a tax year.[3] Among the criteria for the deduction is whether the purchased equipment is on the 'Energy List'. The allowable list of technologies included in the Energy List has varied over the years around an average of 50. The Energy List 2010 contains examples of investments that have proven, in practice, that they meet the International Energy Agency (IEA) criteria. These examples are not exclusive – all investments that meet the energy-performance criteria are eligible for IEA support. However, if investments are not listed among the examples, entrepreneurs will need to prove that they meet the IEA criteria. For example, solar-thermal systems are on this list.

Sweden sponsors innovative programs to promote the use of alternative fuels for home heating. For example, a central furnace that consumes biological fuels if it is used to provide hot water for nearby homes. Oil furnaces have been replaced by boilers that use wood-based

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[3] A more detailed study of these measures can be found in the report for the RES-H Policy Project by Menkveld and Beurskens (2009).

pellets, thereby dramatically reducing Sweden's dependence on oil for home heating. Among the actual fiscal measures that exist in Sweden to promote the use of alternative fuels, tax rebates for consumers to stimulate market adoption of renewable technologies should be mentioned. This measure is reinforced with a high carbon tax on fossil fuels (by applying the Polluter Pays Principle). According to the EuroACE (2009) report (related to the fiscal incentives that are applied to European buildings), since 2006, households in Sweden benefited from a 30% tax credit when converting from direct electric heating and oil-based heating to systems based on biomass or heat pumps. Solar heating support was prolonged until 2010.

3.2 Exemptions

Seven MSs have implemented tax exemptions to promote RES H&C (Austria, Bulgaria, Denmark, Finland, Germany, Sweden and UK).

Biomass fuels used for heating are also exempt from fossil fuel taxes in Austria. According to the EuroACE (2009) report, a Building Tax Exemption has been in place in Bulgaria since 2005. From 6 July 2007, the Amendment to the Local Taxes and Fees Act established that the owners of buildings, having obtained a category A certificate issued under the terms of the Energy Efficiency Act and Building Certificate Regulation, are exempt from building tax for a term of 10 years. This exemption starts from the year after the year of issue of the certificate, and is only valid if RES are used in the building's energy consumption. Under the same terms and conditions, buildings with a category B certificate are exempt from building tax for a term of 5 years.

In the case of Denmark, solar heating plants are exempt from energy tax. Meanwhile, in Germany, to promote environment-friendly sources of energy for heating, there is a tax exemption on the energy tax for all solid biofuels used for heating as stated in the Energy Duty Law. In Sweden, bioenergy solid waste and peat are tax-exempt for most energy uses while taxes on fossil fuels have risen.

Finally, in the UK, renewable heat installations commissioned since July 2009 are due to receive a Feed-In Tariff, or the Renewable Heat Incentive of around 0.06 € per kWh. This income received by domestic users and other income tax payers will not be taxed.

3.3 Reduced tax rates

While the use of reduced tax rates to promote RES is an instrument largely used in RES promotions such as biofuel use (see Del Río and Gual, 2004 and Uyterlinde *et al.*, 2003), only three MSs (France, Italy and the UK) have introduced reduced value-added tax (VAT) rates on components and materials required for eligible heating and cooling systems (EuroACE, 2009).

In France, a reduced VAT of 5.5% is applied to the supply of heat if this is produced from at least 60% biomass, geothermal energy from waste, and recovered energy. Consumers in Italy can also benefit from a reduced VAT (10% instead of 20%) in the case of the refurbishment of a house when this includes the installation of solar-thermal systems. Finally, in the UK, a reduced VAT of 5% is charged on certain energy-saving materials if these are used in non-business buildings or village halls.[4]

Furthermore, in the case of Finland, taxes on heat are zero for RES.

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[4] The reduced VAT covers installations of solar panels, wind and water turbines; ground-source and air-source heat pumps and micro-CHP; and wood/straw/similar vegetal matter-fuelled boilers.

4. Promotion of biofuels in transport via tax incentives

A large variety of biofuel support policies have been in place in MSs, ranging from command and control instruments such as standards and quotas, over economic and fiscal measures such as tax exemptions, to information diffusion[5]. However, from the early 90's of the past century there have been two main instruments which were the basis of biofuels supports schemes in EU: those were subsidization to compensate extra costs of biofuels compared to fossils fuels or prescription of a mandatory uptake in the market.

The first option has been usually implemented by tax exemptions schemes and the second one obliges fuel suppliers to achieve a certain biofuel share in their total sales. Any case, in practice both instruments can be used by national authorities of EU at the same time of others promotion measures.

We focus on tax incentives instruments oriented to promote the use of biofuels in transport. Sections develop above include tax incentives to also promote the biofuels use for green electricity generation and for H & C uses.

From Pelkmans *et al.* (2008) we can conclude that MSs strategies to reach the biofuels targets differ strongly from country to country. This is a result we observe also in the cases of green electricity and H &C exposed above. Some MSs have focused mainly in pure biofuels, while others have stimulated low blending from the beginning.

This section contains an actualized overview in which authors will mention the main tax incentives. It is not intended to give a comprehensive overview.

The use of tax exemptions to promote biofuels in EU is feasible under the conditions settled by the EU Energy Taxation Directive[6]. The most relevant conditions are:

- The tax exemption or reduction must not exceed the amount of taxation payable on the volume of renewable used.
- Changes in the feedstock prices are accounted for in order to avoid overcompensation.
- The exemption or reduction authorized may not be applied for a period of more than six consecutive years, renewable.

But before the EU Energy Taxation Directive came into force, some MSs with a large agricultural sector introduced some tax incentives at the same time at the European Common Agricultural Policy (CAP) reform of 1992. Those were the cases of Germany and France[7]. The fact of having a large agricultural sector with a long tradition and social influence motive those MSs to stimulate the production and use of biofuels. Next, environmental protection was also added as an additional and significant driving force.

The cases of Germany and France were followed in the following years by others MSs as the same time the EU area were expanded. In fact, some MSs add tax incentives to promote biofuels with direct subsidies to farmers who produce feedstock for biofuels uses (i.e. France, Bulgaria, Slovenia, Latvia, Lithuania, Poland and Czech Republic).

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[5] Wiesenthal *et al.* (2009) give information about these complementary policies and measures: support to the cultivations of agricultural feedstock production in the framework of the Common Agricultural Policy, capital investment support to biofuel production facilities and biofuel standards to estimulate the wide market introduction of biofuels.

[6] Council Directive 2003/96/EC of 27 October restructuring the Community framework for the taxation of energy products and electricity.

[7] Eastern countries like the Czech Republic also introduced tax exemptions in theses years although wasn´t an EU MSs in 1992.

A correct overview of tax measures to support biofuels in transport must divide incentives into three main groups. Firstly tax incentive measures have been implemented as tax exemptions included in national mineral oil tax. Secondly, others taxes on GHG emissions have been also used to implemented these types of measures. Thirdly, some incentives were introduced to reduce taxation on ecological cars and biofuel industry.

Related with the first group of measures and following Pelkmans *et al.* (2008), since 1993 until 2003, the German fiscal authority determined that pure biofuels were exempted from the national mineral oil tax although mixed biofuel components fall under full taxation like traditional fossil fuels. However, an amendment of the Mineral Oil Tax Act up to 2004 established that not only pure biofuels, but also mixed biofuels were exempted from the excise tax on mineral oils in proportion to the amount of biofuel that they contain. In 2006 the government switched from the tax exemption policy to obligation schemes. The Netherlands authorities have followed a similar path.

Since 1991 pure biodiesel enjoys a full tax exemption in the Austria's mineral tax and since 2007 there is a tax reduction also for gasoline blended with bioethanol. Tax exemption for ethanol is also allowed in Sweden since 1992 but for all of biofuels full tax exemption is only permit for pilot projects since 1995.

The France incentive system is particularly conductive to the development of biofuels. Since 1992 biodiesel enjoys a total exemption from the internal tax on petroleum products (TIPP). In the case of bioethanol incorporated as ETBE in gasoline the exemption is a partial one (80 %). An interesting tax reform was implemented in France up to 2005. In order to raise the share of biofuels in the market, the French Parliament introduced a general tax on polluting activities (TGAP) for fuel resellers. TGAP is zero if an annual target percentage biofuels is reached[8].

Joint with France, the Spanish incentive system is particularly conductive to the development of biofuels as they enjoy total exemption from the hydrocarbons tax until 31 December 2012. This special rate is applied to the biofuel volume contained in the mixture.

In 1992 Czech Republic established a zero excessive duty on produced biodiesel. This incentive was valid until 2007 when national government decided to change to a compulsory system (mandatory quotas). Different form Czech Republic, the Poland government maintains the tax exemption introduced in 1993. Incentives also remain valid in the United Kingdom where a duty incentive of 0.30 euro per liter for biodiesel is allowed since July 2002 and for bioethanol since January 2005. Incentives also remain valid in Lithuania (since 2005).

Over the past 4 years, a number of MSs have moved towards obligation or mixed systems to lower the revenue losses. Belgium is a significant case of mixed system where since 2006 exist a quota system for biodiesel (2007 for bioethanol) with tax reduction.

If we considered now taxes on GHG emissions –the second group of tax incentives-, since 2002 CO_2 neutral fuels are exempted from the Sweden CO_2 tax. This is also the case of Denmark.

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[8] A similar scheme was introduced in Germany since 2006 when the government switched from the tax exemption policy to obligation schemes. Then the Germany authorities introduced penalties in case of non-compliance the annual targets for biofuels consumptions. Penalties for non-compliance were been set rather high (> 0.50 euros/litre). As Pelkmans *et al.* (2008) pointed out this gave a good motivation for fuel distributors to fulfil the obligation.

Finally, a third group of tax incentives involves a heterogeneous set of measures oriented to promote industrial activities (biofuels production and the installation of points of sales for biofuels in traditional gas stations) or to promote ecological cars.

Many MSs as Germany have implemented tax incentive in the corporate tax to biofuels industry and to firms with projects related with biofuels.

Flexible Fuel Vehicles (FFV) have also enjoyed tax incentive in some MSs. In 2007, Spain implemented a reduction in the tax on matriculation of vehicles (Cansino and Ordoñez, 2008). This tax exemption is a total one in Ireland and in the case of electrical cars.

Table 3 summarizes our analysis and gives an overview of the MSs which have implemented tax incentives to promote biofuels in the last years.

	Low biodiesel blends (B5)	B30	B100	Low ethanol blends (E5/ETBE)	E85	PPO
Austria	✔		✔	✔	✔	✔
Belgium	✔				✔	✔
Bulgaria	✔		✔	✔		
Cyprus	✔		✔	✔		
Czech Rep.	✔	✔				
Denmark	✔			✔		
Estonia	✔			✔		
Finland						
France	✔	✔		✔	✔	
Germany	✔		✔	✔	✔	✔
Greece	✔					
Hungary	✔			✔	✔	
Ireland	✔		✔	✔	✔	✔
Italy	✔	✔				
Latvia	✔	✔	✔	✔	✔	✔
Lithuania	✔			✔		
Luxembourg	✔		✔	✔		✔
Malta	✔					
The Netherlands	✔			✔		✔
Poland	✔	✔	✔	✔		
Portugal	✔					
Romania	✔			✔		
Slovakia	✔			✔		
Slovenia	✔		✔	✔		
Spain	✔			✔		
Sweden	✔		✔	✔	✔	
UK	✔			✔		

Source: Pelkmans *et al*. (2008)

Table 3. EU MSs and tax incentives

As tax exemptions provoke the losses in revenues for governments, it is interesting the case of Belgium. In this country and to overcoming the revenue losses, authorities promoted a simultaneous increase in the fossil fuel tax so as to render the policy budget-neutral.

The use of tax exemptions to promote biofuel has and additional advantage. As Wiesenthal *et al.* (2009) pointed out; the increasing number of available production pathways with different characteristics in term of GHG emissions, production costs and potentials implies that MSs may employ differentiated biofuel strategies, favoring specific types of biofuels in order to better serve the objectives underlying their biofuel support policy.

However, the use of tax exemptions provokes a revenue loss. This explains that in the last years it is observed a switch from these types of measures to obligation schemes.

5. Political discussion and main conclusions

Proliferation of RES is a political question. Many measures can be implemented for it. Among them, tax incentives have been used to promote green electricity, RES for H&C and biofuels. Table 4 summaries these tax measures. This Table also shows the electricity generated from renewable sources as a percentage of gross electricity consumption, the combined heat and power generation as a percentage of gross electricity generation and the share of renewable energy in fuel consumption of transport in 2006 and the incremental points in 2006-2008.

In general, countries that show high percentages also are those that have implemented tax incentives. However, these data do not allow us to assess specifically the effects of tax incentives as they are not isolated actions but in general all countries use a mix of measures to advance the development of RES. Among these measures, the fiscal measures, the others economic measures and the non economic measures such as advertising campaigns are some of them. Among the economic measures should be highlighted feed in tariffs and financial incentives. Among the non-financial measures include the regulation especially important for buildings and fuel. Therefore, besides presenting the data in Table 4, the specific effects of the measures in each country are discussed below.

After analyzing the energy policies of EU-27 MSs, it can be pointed out that the main tax incentive used to promote green electricity by the MSs is the exemption from the payments of excises duties for electricity when the electricity is generated by RES (Germany, Romania, Slovak Republic, Denmark, Sweden, Poland and Finland). This measure has been basically used for reducing the higher prices of production of this type of energy. With the same aim, tax incentives in CCL are implemented in the United Kingdom, a reduction of the ecotax is implemented in Netherlands and some subsidies are used in Finland to offset the excise duty on electricity. Also, lower tax rates in VAT are applied in three MSs, France, Italy and Portugal. Fiscal incentives in direct tax are applied in personal income tax, corporate tax and in property tax. In direct taxes, Belgium and France have designed these incentives as a deduction on the taxable income, which is calculated as a percentage of investment cost of system installed. While Czech Republic has designed it as a tax exemption of the taxpayers income that come from generate green electricity and Luxembourg as a tax exemption to electricity producers that produce electricity exclusively for their own use. The corporate tax incentives consist mainly in a deduction of the profit obtained (Belgium, Greece and Spain), but in Czech Republic, it consist in a tax exemption of the income obtained from generating green electricity. Finally, it can be said that only Spain and Italy uses fiscal incentives in terms of a tax exemption.

UE-27	Green electricity			Heating and Cooling			Biofuels		
	F.I.	2006	Δ2006-2008	F.I.	2006	Δ2006-2008	F.I.	2006	Δ2006-2008
Austria		16.1	-0.8	✔	16.1	-0.8	✔	2.2	4.9
Belgium	✔	8.7	---	✔	8.7	---	✔	0.1	1.1
Bulgaria		6	4	✔	6	4	✔	0.2	0
Cyprus		0.3	0		0.3	0	✔	0	2.1
Czech Rep.	✔	15.1	-0.9		15.1	-0.9	✔	0.1	0.1
Denmark	✔	40.7	5.4	✔	40.7	5.4	✔	0.3	0
Estonia		10.7	-2.1		10.7	-2.1	✔	0	0
Finland	✔	34.9	0.7	✔	34.9	0.7		0.4	1.8
France	✔	3.2	-0.1	✔	3.2	-0.1	✔	2	3.6
Germany	✔	12.5	0	✔	12.5	0	✔	6.7	-0.2
Greece	✔	1.7	0.2	✔	1.7	0.2	✔	0.7	0.3
Hungary		22.4	-1.3		22.4	-1.3	✔	0.1	3.8
Ireland		5.6	0.6		5.6	0.6	✔	0.1	1.1
Italy	✔	9.8	-0.3	✔	9.8	-0.3	✔	0.9	1.4
Latvia		42.6	-9		42.6	-9	✔	1.1	-0.2
Lithuania		14.3	-1.6		14.3	-1.6	✔	1.6	2.4
Luxembourg	✔	10.9	1		10.9	1	✔	0	2
Malta*		0	0		0	0	✔	0	0
Netherlands	✔	29.9	3.7	✔	29.9	3.7	✔	0.4	2.1
Poland*	✔	16	0.9		16	0.9	✔	0.9	2.4
Portugal	✔	11.6	0.3		11.6	0.3	✔	1.3	1.1
Romania	✔	18	-8.4		18	-8.4	✔	0.8	2
Slovakia	✔	27.6	-3.6		27.6	-3.6	✔	0.5	5.8
Slovenia		7.4	-0.7		7.4	-0.7	✔	0.4	1.1
Spain	✔	7.2	-0.2		7.2	-0.2	✔	0.7	1.2
Sweden	✔	8	1.6	✔	8	1.6	✔	4.9	1.4
UK	✔	6.3	0.1	✔	6.3	0.1	✔	0.5	1.5

Source: Own elaboration.

Table 4. Effects of fiscal incentives to advance RES deployment

Literature about energy requirements for heating and cooling has largely focused on new building standards. Government interventions in heating and cooling have mainly consisted of establishing construction standards for buildings in an attempt to increase energy efficiency with respect to heating and cooling requirements.

The revision of the energy policies of EU-27 MSs and the government interventions concerning energy use with respect to heating and cooling, make us to conclude that 23 MSs have adopted additional measures to promote the use of RES for heating and cooling. The implementation of such measures corroborates the opinion of those experts who explain that the increased use of RES can only be achieved if it is accompanied by additional support from government authorities.

Twelve MSs have used tax incentives with a dual purpose, to reduce investment costs and to make renewable energy profitable through a decrease in relative prices. In the first case, the use of tax deductions has the advantage of involving ex-post incentives, although they do not lower the hurdle of the initial upfront payment. Some MSs have thus resorted to reducing tax (VAT) rates to overcome this. In the second case, these measures have been relatively successful when they have been accompanied by other measures that tend to increase the price of alternative energy sources.

Finally, if we focus on the tax measures to support the use of biofuels in transport, we can conclude that, until now, subsidies through partial or total exemptions have proven to be the most successful instruments to raise the share of biofuels use for transport, especially when tax incentives are complemented by other measures.

Additionally, the tax exemptions allow steering the market by applying different reduction rates to various types of biofuels by considering its effects on GHG emissions.

However the losses in revenues for governments which have implemented tax exemptions become high with rising market volumes. As a consequence of that over the past 7 years, a number of MSs have moved towards obligation or mixed systems to lower the revenue losses.

The actual economic crisis has forced the MSs to review the incentive measures of RES. All the measures studied are linked to tax restrictions, so that in times of deficit reduction, all these policies may be affected.

6. Acknowledgement

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Part 2

Applications

Structural Design of a Dynamic Model of the Battery for State of Charge Estimation

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1. Introduction

For a standard interconnected electrical power network, the problem of optimal management of production arises from randomness of users demand. When using renewable energies, an additional critical problem is that the resource itself is random. The difficulty is still more pregnant when dealing with small isolated production networks, in locations where photovoltaic systems or wind generators should be a promising solution. To resolve the difficulties induced by intermittent production or consumption, these systems must make a consistent use of the energy storage. For example, in the case of an individual photovoltaic system, storage is essential to the scale of at least 24h, in order to overcome the daily fluctuations.

Among the various methods used to store electrical energy, electrochemical batteries constitute the most readily available, with good performance and a reasonable cost (Riffonneau et al.,2008). Renewable Energies are concerned by stationary storage, for which lead acid batteries are a good choice. Despite decades of use and its apparent simplicity, the battery maintains a complex and poorly understood dynamical behavior. Moreover, possible degradation of the battery is largely related to poor control of periods of deep discharge or full load with gassing. For efficient use of this device, a detailed knowledge of operation, and thus a good electrochemical modeling, is essential. Otherwise, it could constitute the most fragile element in a photovoltaic or wind systems because of premature aging resulting in a loss of capacity or a failure risk (Garche et al.,1997).

A lot has been done in the domain of batteries modeling from two opposite ways.

On the one hand, a purely phenomenological approach has been developed by engineers. In particular, very valuable tests are commonly performed using battery cycling with constant charge and discharge currents. In particular, there appears a reduction of the effective capacity when the cycling current increases (Peucker's law (Manwell Jams, 2003)). These results may have direct application for charge monitoring in systems with alternate charging and discharging sequences (for instance traction vehicles); unfortunately, they do not apply to wind turbines or photovoltaic applications subject to random electrical current variations.

On the other hand, extensive physical studies have been made by electrochemists concerning the physics of electrochemical cells. Descriptions of the cell behavior have been

proposed in terms of equivalent electrical circuits (Bard, 2000). In particular, associated to diffusion phenomenon, the Warburg impedance Zw has been introduced, involving integration with a non integer order. In Laplace notation (where p denotes the equivalent derivation operator) the Warburg impedance has the form: $Z_w = A\, p^{-\frac{1}{2}}$. In a previous communication, we demonstrated that the effective cell capacity reduction described by Peucker's law may be connected to the step response associated to the Warburg impedance (Marie-Joseph et al., 2004).

Anyway, some midway solution must obviously be found between underlying fundamental physics and the need of the engineers for a computationally efficient simplified model.

In this chapter, we discuss the major processes resulting in a voltage drop that occurs during a redox reaction sitting in storage electrochemical. The phenomena of diffusion/storage and activation are identified as the main factors for the voltage drop in the batteries (Esperilla et al.,2007). These phenomena occur when the battery is subjected to an electric current, which is to say when there is mass transport in electrochemical interface; they are called faradic phenomena. Focusing particularly on transport mechanism of carriers in the battery, we observed strong similarities between electrochemical interfaces and PN junction diodes (Coupan et al., 2010). Based on the approximation of the physics of semiconductor PN junction, we propose a physical analysis coupled to experimental investigation.

Along these lines, in this chapter, we introduce a dynamical model of the battery, which explains in terms of a simplified equivalent circuit how the total stored charge is distributed along a cascade of individual elements, with increasing availability time delays. This explains why short cycling makes use only of the closer elements in the chain. It opens the way to a wise design of systems combining short delay storage (for instance super-capacities) and conventional batteries used for long term full range cycling.

2. Analysis methodology

At steady state (without current), according to the electrical charges of the reactants in the redox reaction, the chemical potential gradient across the interface may be balanced by an electrical potential gradient. This electric field, integrated across the interface, results in the equilibrium potential given by the Nernst relationship (Marie-Joseph, 2003).

When a current is applied to the electrochemical cell, the electronic flow in the metal terminals corresponds to an ionic flow, in proportion defined by the redox reaction stoechiometry at the electrolyte interface. Corresponding carriers which are present in the electrolyte can then move either under the effect of an electrical potential gradient (migration) or the effect a concentration gradient (diffusion). Occasionally, electrolyte transport by convection may also be of influence (Linden et al., 2001). This movement of carriers causes a change in battery voltage compared to the steady sate potential, called over-potential. Note that it is a nonlinear function of the current, depending not only on the present value of the current but on its past variations: it is termed a dynamical non linear relationship. The phenomena responsible for this over-potential involve a number of different and complex processes that overlap each other: that is to say, the kinetics of electron transfers, mass transfers, but also ohmic effect and other non-faradic effects. In this study, we focus on the phenomena of diffusion/storage and activation.

- The diffusion/storage overvoltage is connected to variation of the ionic concentrations in the electrolyte: average value related to the state of charge, and gradient related variation at the interface in presence of current. However this phenomenon always

appears in agreement with the Nernst equation. We propose a linearisation by inversion of this relation and a dynamical model drawing from the analogy of diffusion equation with a capacitive transmission line. Diffusion phenomena predominate for response times ranging from 10^3 to 10^5s.

- The activation overvoltage may be related to injection of sulfate ions in the oxide film at the surface of electrodes. These constitute solid electrolytes no longer governed by Boltzmann but by Fermi-Dirac statistics. There are strong similarities which the injection of minority carriers in PN junctions. In the literature, this phenomenon is usually described by the semi empirical Butler-Volmer relation. We propose a dynamical model drawn from the charge driven model of PN diodes, with given relaxation time (typically in the order of some 10^2 s).

- Full description of the battery includes conventional circuit modeling of non faradic effects. This is taken into account by an RC "input cell" including plates electrostatic capacitance, Ohmic resistance and the plates double layer capacitances, with typical time constants between 1s and 100s. High frequency models may include inductive effects (Blanke et al, 2005).

3. Input cell and diffusion voltage for lead acid batteries

3.1 Input impedance cell

With a simplified assumption of symmetrical electrochemical impedance for the electrodes (denoted $Z'/2$), we can infer equivalent circuit of fig 1-a, γ being an inter-plates capacitance, R the electrolyte resistance and $2C_0$ the double layer capacitance of the interface. The corresponding reduced input circuit is given fig 1-b.

Elements of the input cell are easily identified experimentally at small operating currents and high enough frequencies. Due to the activation threshold, impedance Z' is quite high at low current, so that the double layer impedance C_0 dominates for frequencies greater than about 0.1 Hz.

Once the elements of the cell are known, current and voltage may easily be corrected for. In the following, we are interested only in the internal electrochemical impedance Z'.
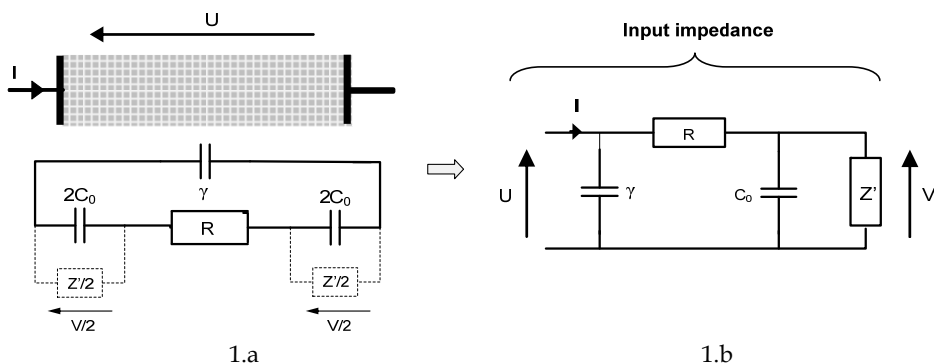

Fig. 1. Input impedance cell (simplified symmetric plates model)
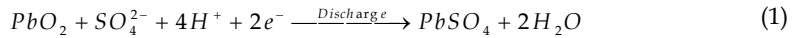
3.2 Diffusion overvoltage

For the sake of clarity, a good part of the analysis will be carried in the stationary case, corresponding to constant current. We use a one dimensional battery model, the variable being the abscissa z between the negative ($z=0$) and the positive plate ($z=L$). Results are then extended with a constant cross section S. to the general dynamical case, including time dependency.

3.2.1 Constant current analysis

3.2.1.1 General presentation

During the discharge of the lead acid battery, sulfate ions are "swallowed" by both electrodes according to chemical reactions:
Positive electrode:

$$PbO_2 + SO_4^{2-} + 4H^+ + 2e^- \xrightarrow{Discharge} PbSO_4 + 2H_2O \qquad (1)$$

Negative electrode:

$$Pb + SO_4^{2-} \xrightarrow{Discharge} PbSO_4 + 2e^-$$
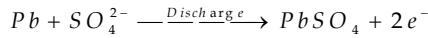
Figure 2 illustrates the transport of ions along axis Oz associated with the two half-reactions at the electrodes (inter-electrode distance L):
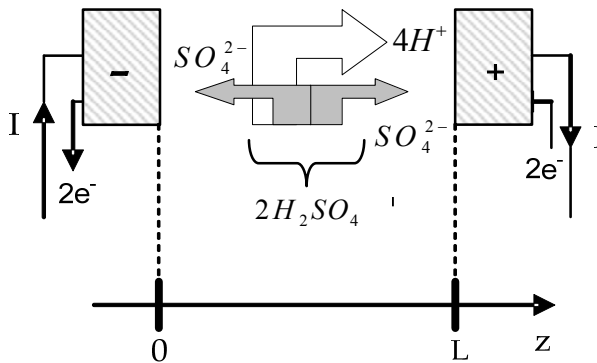
Fig. 2. Battery operation: case of discharge

So, two types of ions are responsible for current transport through the electrolyte. Those are sulfate ions (subscript S) and hydrogen ions (subscript H). In terms of currents:

$$I(z) = I_H(z) + I_S(z) \qquad (2a)$$

Let S be the section area between the plates (constant for à one dimensional model). The same relation holds in terms of current densities:

$$J(z) = \frac{I}{S} = J_H(z) + J_S(z) \qquad (2b)$$

In the electrolyte, as can be seen in figure 2, there is an inversion of the sulfate ions flow along the z axis. More precisely according to the simultaneous equations (2), we obtain the boundary conditions at the electrodes:

$$I_S(0) = I \text{ and } I_H(0) = 0 \qquad (3a)$$

$$I_S(L) = -I \text{ and } I_H(L) = 2I \qquad (3b)$$

As it will be seen in section 3.2 the constant current case corresponds to a stationary solution of the dynamical case with $\partial^2 I/\partial z^2 = 0$, which implies a linear variation of the current between the given limits. The profile of currents $I_S(z)$ and $I_H(z)$ is then obtained according to Figure 3:
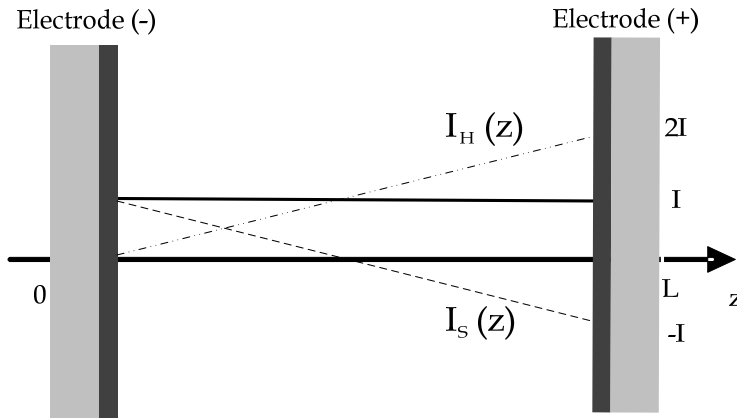

Fig. 3. Linear model of current $I_S(z)$ et $I_H(z)$

Main steps in diffusion phenomena analysis

The mains steps in our analysis will be the following:
a. The total current is equal to the sulfate ion current at the negative electrode (see equation 3.a)
b. Sulfate ion motion is dominated by diffusion (see next section)
c. According to b), we will establish that there is a linear relationship between sulfate concentration and density current (trough linear Partial Derivative Equations)
d. The Nernst cell voltage may be expressed as a non linear function of the sulfate concentration for z=0 (section 3.2.1.3)

As a consequence, for given boundary conditions, from a) and c) we deduce that there exists a relation of linear filtering between the total current $I(t)$ and the sulfate anode concentration $n_s(0,t)$.

According to d), we find that the cell voltage $V(t)$ may be directly expressed as a (non linear) logarithmic function of this concentration (sect 3.1.3). We propose a linearization of the problem, by the use of an exponential mapping on $V(t)$: in this way we introduce a "pseudo-potential" proportional to the sulfate concentration (sect 3.2.1.3). This pseudo-potential is then related to the current by linear impedance. This impedance may be simplified in terms of a RC network (3.2.2.4).

3.2.1.2 Diffusion fields and currents

In the electrolyte, the carriers are transported under the influence of an electric field E and the diffusion field ξ, connected to the concentration gradient. For the two types of carrier (k: Boltzmann constant; e: charge of one electron):

$$\xi_S = -\frac{kT}{q_S}\frac{1}{n_S}\frac{dn_S}{dz}$$
$$\xi_H = -\frac{kT}{q_H}\frac{1}{n_H}\frac{dn_H}{dz} \tag{4}$$

Note that, from the relation: $q_S = -2q_H = -2e$, and the neutrality condition, we get the relation between concentrations: $n_H = 2\,n_S$. By substitution in (4), we derive the corresponding relation between the diffusion fields:

$$\xi_H/\xi_S = q_S/q_H = -2 \tag{5}$$

The corresponding expression of the currents, for each type of carrier, is then given by the relation:

$$J_S = \mu_s q_s n_s \left(E + \xi_S\right)$$
$$J_H = \mu_H q_H n_H \left(E + \xi_H\right) \tag{6}$$

In this relation, J_H and J_S have a similar magnitude (see fig 3). The mobility of hydrogen ions being much higher than the sulfate ions, this implies that $E + \xi_H$ is very small, so that: $E \approx -\xi_H$. From this result and (5), we find that the current densities may be expressed in terms of the diffusion field ξ_S alone:

$$E \approx -\xi_H = 2\,\xi_S\; E + \xi_S \approx 3\,\xi_S$$

Whence

$$J_S = \mu_S\, q_S\, n_S\, (3\,\xi_S) \tag{7a}$$

Or, according to (4):

$$J_s(z) = 3\mu_s kT\left(\frac{dn_s}{dz}\right) \tag{7b}$$

And from (2):

$$J = J_s(0) = 3\mu_s kT\left(\frac{dn_s}{dz}\right)_0 \tag{7c}$$

This establishes the step c) of our diffusion analysis exposed in section 3.2.1.1
We may introduce in (7b) the linear profile of the current, valid in the stationary case. We then derive a parabolic symmetric profile of the concentration of sulfate ions (Fig. 4), with $n_S(0) = n_S(L)$.
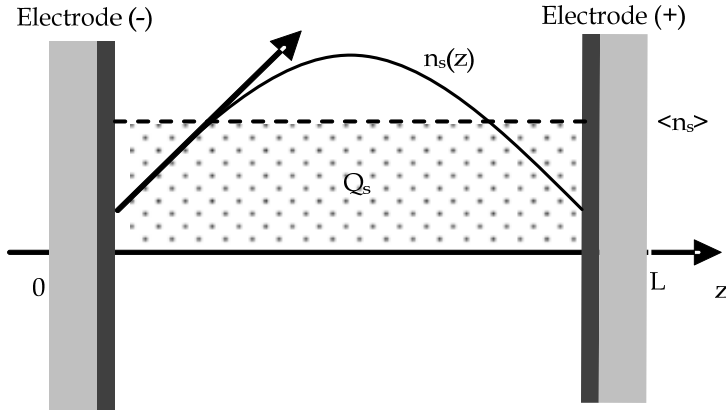
Fig. 4. Concentration profile (Stationary 1D Model)

Let us point out this symmetry property which will generalize for the dynamical case. Following the boundary condition (3a and 3b) we find:

- For currents, the **anti symmetry** property: $I_S(L-z) = -I_S(z)$
- For densities, the **symmetry** property: $n_s(L-z) = n_s(z)$

3.2.1.3 Voltage and concentration

According to the electrochemical model defined above, while applying Nernst's equation (Marie-Joseph, 2003); we obtain the expression of voltage as a function of the limit concentrations in the form:

$$. V = A_1 + \frac{kT}{2e}\ln\left(\frac{n_s(0)}{a_{PbSO_4}(0)}\right) + \frac{kT}{2e}\ln\left(\frac{n_s(L)n_H(L)^4}{a_{PbSO_4}(L)}\right). \tag{8a}$$

In this relation, we may use the fact that:

- According to the neutrality condition (section 3.2.1.2), $n_H = 2n_S$
- Due to the symmetry of concentrations, $n_s(L)=n_s(0)$.
- Concerning PbSO4 activity, it is equal to one, unless we are very close to full charge (this will not be considered here).

In such conditions, the expression of battery voltage may be set in the form:

$$V = A_2 + \frac{3kT}{e}\ln(n_s(0)) \tag{8b}$$

Let n_0 be a reference sulfate concentration and E_0 the corresponding Nernst voltage, then the relation may be written in the form:

$$\begin{cases} V = E_0 + V_L\ln\left(\dfrac{n_s(0)}{n_0}\right) \\ V_L = \dfrac{3kT}{e} \end{cases} \tag{8c}$$

This result corresponds to point *d)* in introduction (3.2.1.1).

3.2.1.4 "Linearised" pseudo-voltage using an exponential transformation

We suggest to introduce a "pseudo-voltage" which is à linear function of the concentration, and which aims to the voltage *V* when it is close to the reference voltage E_0, according to figure 5:

$$\tilde{V} = E_0 + V_L \left(\frac{n_s - n_0}{n_0} \right) = E_0 - V_L + V_L \left(\frac{n_s}{n_0} \right) \tag{9}$$
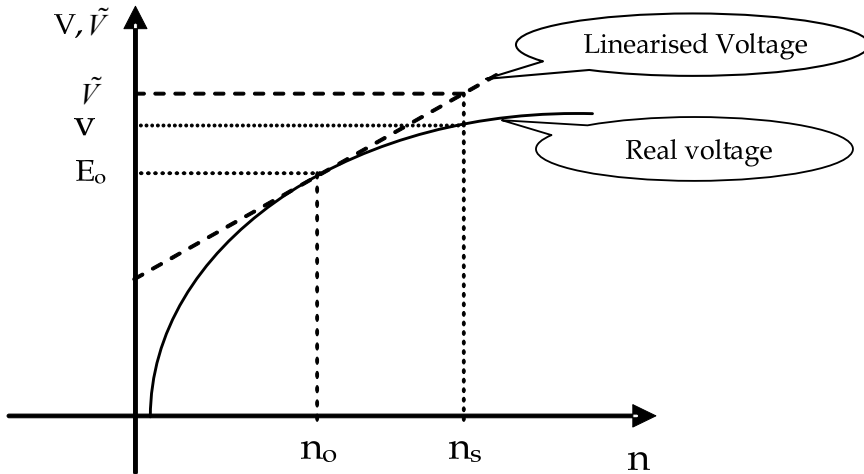
Fig. 5. Linearised Pseudo-voltage

The pseudo voltage may then be obtained by an exponential transformation of the original voltage according to the expression:

$$\tilde{V} = E_0 + V_L \left(\exp\left(\frac{V - E_0}{V_L} \right) - 1 \right) = E_0 \cdot V_L + V_L \left(\exp\left(\frac{V - E_0}{V_L} \right) \right) \tag{10}$$

3.2.1.5 Constant current equivalent circuit

According to figure 4, the limit concentrations (for z=0 and z=L) are easily expressed, and may be related to the total stored charge Q_S and the internal current I:

$$\begin{cases} n_s(0) = n_s(L) = \langle n_s \rangle - \frac{L}{6} \left(\frac{dn_s}{dz} \right)_0 \\ Q_s = SL \langle n_s \rangle \\ I = I_s(0) = SJ_s(0) = 3S\mu_s kT \left(\frac{dn_s}{dz} \right)_0 \end{cases} \tag{11}$$

According to equations (8) and (11), the voltage may be expressed in terms of the stored charge Q_s and the internal current I according to:

$$\begin{cases} V = E_0 + \dfrac{3kT}{q} \ln\left(\dfrac{Q_S - \theta I}{Q_0}\right) \\ \\ \theta = \dfrac{L^2}{18\mu_s kT} \end{cases} \tag{12}$$

Relation (12) may be written in terms on an RC model valid only for constant current charge or discharge in the form:

$$\tilde{V} = V_L \frac{(Q_s - \theta I)}{Q_0} = \frac{Q_s}{C_D} - R_D I \tag{13}$$

With $C_D = Q_0/V_L$ and $R_D = \theta/C_D$
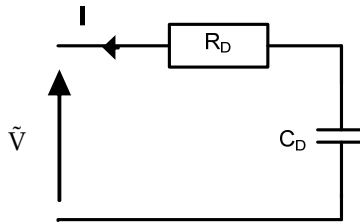
Fig. 6. RC equivalent circuit for constant current (after linearization)

3.2.2 Dynamical model for time varying current

3.2.2.1 General diffusion equations (one dimension)

In the general case, current densities and concentrations densities depend both on z and t. Equation (7) may be written in term of partial derivative:

$$\frac{\partial n_S}{\partial z} = \frac{J_S}{3\mu_S kT} \tag{14}$$

We may add the charge conservation equation:

$$\frac{\partial J_S}{\partial z} = -\frac{\partial \rho}{\partial t} = 2e\frac{\partial n_s}{\partial t} \tag{15}$$

These two coupled Partial Derivative Equations define the diffusion process (Lowney et al., 1980).
The driving condition is given by relation:

$$J_S(0,t) = J(t) = \frac{I(t)}{S} \tag{16}$$

And the bounding condition resulting of the current anti symmetry:

$$J_S(L,t) = -J_S(0,t) \tag{17}$$

3.2.2.2 General electrical capacitive line analogy

In the diffusion equations (14) et (15), making use of relation (9), the sulfate ion density n_S may be expressed in terms of the pseudo potential $\tilde{V}$, and the current densities Js may be replaced by currents $Is = S\,Js$. We then obtain a couple of joint partial derivative equations between the pseudo voltage $\tilde{V}(z,t)$ and the sulfate current $Is(z,t)$:

$$\begin{cases} \dfrac{\partial \tilde{V}_S}{\partial z} = \dfrac{V_L}{n_0}\dfrac{\partial n_S}{\partial z} = \dfrac{V_L}{n_0 \mu_S kT}\left(\dfrac{I_S}{S}\right) \\[4mm] \dfrac{\partial I_S}{\partial z} = S\dfrac{\partial J_S}{\partial z} = 2eS\left(\dfrac{n_0}{V_L}\dfrac{\partial \tilde{V}_S}{\partial t}\right) \end{cases}$$

(18a)

These are the equations of a capacitive transmission line with linear resistance ρ and linear capacity γ as defined below. (Bisquert et al., (2001).

$$\dfrac{\partial V_S}{\partial z} = \rho I_S \qquad\qquad \rho = \dfrac{1}{\mu_S e S n_0}$$

$$\dfrac{\partial I_S}{\partial z} = \gamma \dfrac{\partial V_S}{\partial t} \qquad\qquad \gamma = \dfrac{2 e n_0 S}{V_L}$$

(18b)

Taking in account the symmetry of the concentrations, we obtain an equivalent circuit consisting in a length L section of transmission line, driven on its ends with symmetric voltages. The current is then 0 in the symmetry plane at L/2. The input current is the same as for a L/2 section with open circuit at the end.
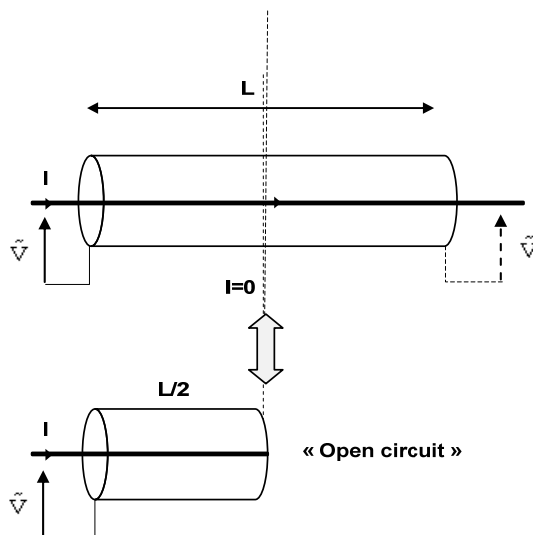
(Open circuit capacitive transmission line of length L/2)

Fig. 7. Equivalent electrical circuit for the pseudo-voltage

3.2.2.3 Equivalent impedance solution

For linear systems, we look for solutions in the form A exp(pt) for inputs, or A(z) exp(pt) along the line, p being any complex constant.
Let:

$$\begin{cases} I(z,t) = I(z)\exp(pt) \\ V(z,t) = V(z)\exp(pt) \end{cases} \tag{19}$$

Then we obtain the simplified set of equations

$$\begin{cases} \dfrac{dV_s}{dz} = \rho I_s \\[2mm] \dfrac{dI_s}{dz} = \gamma p V_s \end{cases} \tag{20}$$

Whence $\quad \dfrac{d^2 I_s}{dz^2} = \rho \gamma p I_s$

Let $\rho \gamma = \tau / L^2$. Then $-\alpha$ and α be the solutions of :

$$\alpha^2 = p\rho\gamma = p\frac{\tau}{L^2} \tag{21}$$

Then solution for Is(z) is a linear combination of $\exp(\pm\alpha z)$. If we impose $I_s(L/2)=0$, then

$$I_S(z) = Ish\left(\alpha\left(z - \frac{L}{2}\right)\right) \tag{22}$$

Whence:

$$V_S(z) = \frac{1}{\alpha}\rho Ich\left(\alpha\left(z - \frac{L}{2}\right)\right) \tag{23}$$

We then get the Laplace impedance at the input of the equivalent circuit:

$$Z(p) = \frac{V_S(0)}{I_S(0)} = \frac{\rho}{\alpha th\left(\dfrac{\alpha L}{2}\right)} \tag{24}$$

if $|\alpha L| << 1 \qquad th\left(\dfrac{\alpha L}{2}\right) \approx \dfrac{\alpha L}{2}$

$$\begin{cases} Z(p) \approx \dfrac{1}{Cp} \\[2mm] C = \dfrac{\gamma L}{2} \end{cases} \tag{25}$$

In case of harmonic excitation (p = jω) this corresponds to small frequencies (ωτ<<1). The impedance is the global capacity of the line section. In practice for batteries (Karden et al., 2001), this corresponds to very small frequencies (10^{-5}Hz)

if $|\alpha L| \gg 1$ $\qquad th\left(\dfrac{\alpha L}{2}\right) \approx 1$

$$Z(p) \approx \sqrt{\frac{\rho}{\gamma}} p^{-1/2} \tag{26}$$

In case of harmonic excitation (p = jω) this corresponds to high enough frequencies (ωτ>>1) the impedance is the same as for an infinite line (Linden, D et al., 2001), corresponding to the Warburg impedance.

3.2.2.4 Approximation of the Warburg impedance in terms of RC net

An efficient approximation of a $p^{-1/2}$ transfer function is obtained with alternate poles and zeros in geometric progression. In the same way, concerning Warburg impedances an efficient implementation (Bisquert et al., 2001) is achieved by a set of RC elements in geometric progression with ratio k, as represented in figure 8.

Let $\omega_0 = 1/RC$. Note that the progression of the characteristic frequencies is in ratio k^2.
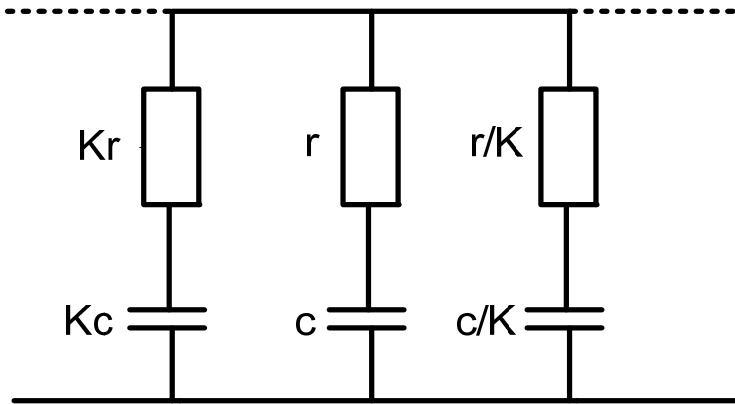
Fig. 8. RC cells in geometric progression

Let Y(ω) be the admittance of the infinite net. It is readily verified that
-    For ω= ω_0 , Y(ω_0) may be set in the form Sk/(1-j), with real Sk (complex angle exactly π/4)
-    Y($k^2 \omega_0$) = k Y(ω_0) (Translation of one cell in the net)
It can be verified by simulation that the fitting is quite accurate, even for values up to k=3.

3.2.3 Approximation of a finite line in terms of RC net
The simplest approximation would to use a cascade of N identical RC cells simulating successive elementary sections of line of length $\Delta L = L/2N$. with: $r = \rho \, \Delta L$ and $c = \gamma \, \Delta L$
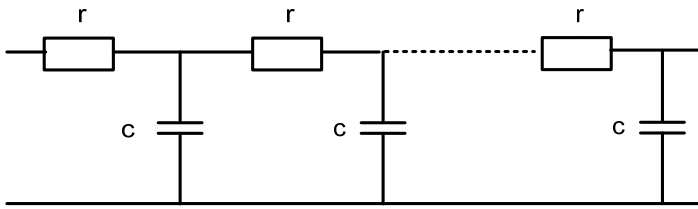
Fig. 9. Elementary approximation by a cascade of identical RC cells

This approximation introduces a high frequency limit equal to the cutoff frequency of the cells $f_N = 1/2\pi rc$. Drawing from the previous example concerning Warburg impedance, we propose to use ($M+1$) cascaded sections but with impedance in geometric progression.
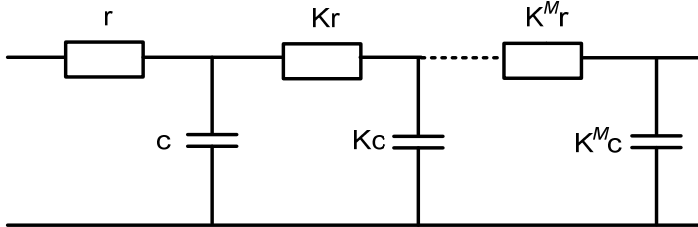
Fig. 10. Approximation by a cascade of RC cells in geometric progression

The total capacity will be equal to the total L/2 line capacity. The frequency limit for the approximation remains given by the first cell cutoff frequency.

For instance for k =3 this may result in a drastic reduction of the number of cells for a given quality of approximation.

3.2.4 Practical RC model used for experimentations

In practice, the open circuit line model will be valid only if the entire electrolyte is between the cell plates. In practice this is usually not true. For our batteries, about one half of the electrolyte volume was beside the plates. In such case there is an additional transversal transport of ions, with still longer time constants. This could be accommodated by an additional RC cell connected at the output of the line.
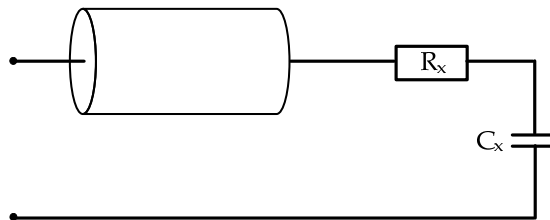
Fig. 11. Transmission line with additional RC cell

Satisfactory preliminary results for model validation were obtained with a much simplified network, with an experimental fitting of the component values (Fig 11).

We may consider that c and c1 (c<<c1) account for the transmission line impedance, while Cx, Rx (Cx in the order of C1) accounts for external electrolyte storage.
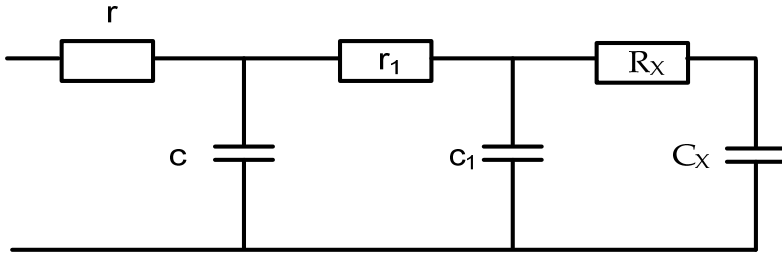
Fig. 12a. Diffusion/storage model -1-

Provided that C_D << C_1 connection as a parallel RC cell should not modify drastically the resulting impedance. This model was introduced in order to separate "short term" and "long term" overvoltage variations in the experimental investigation.
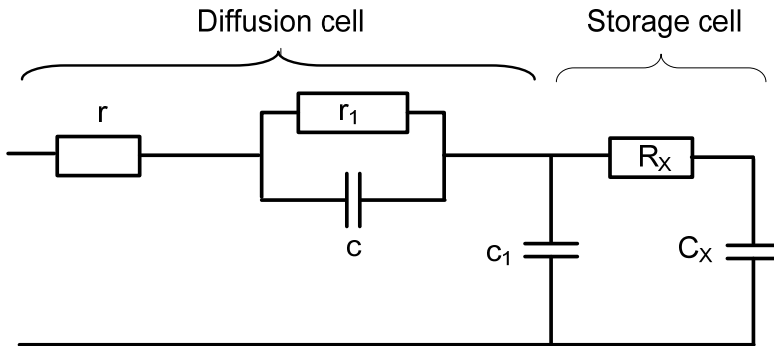
Fig. 12b. Diffusion/Storage model -2-

4. Activation voltage

4.1 Comparison to PN junction

A PN junction is formed of two zones respectively doped N (rich in electrons: donor atoms) and P (rich in holes: acceptor atoms). When both N and P regions are assembled (Fig. 13), the concentration difference between the carriers of the N and P will cause a transitory current flow which tends to equalize the concentration of carriers from one region to another. We observe a diffusion of electrons from the N to the P region, leaving in the N region of ionized atoms constituting fixed positive charges. This process is the same for holes in the P region which diffuse to the N region, leaving behind fixed negative charges. As for electrolytes, it then appears a double layer area (DLA). These charges in turn create an electric field that opposes the diffusion of carriers until an electrical balance is established.
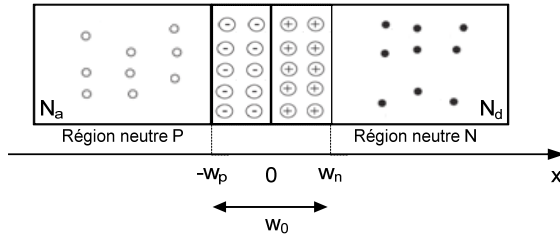
Fig. 13. Representation of a PN junction at thermodynamic equilibrium

The general form of the charge density depends essentially on the doping profile of the junction. In the ideal case (constant doping "N_a and N_d"), we can easily deduce the electric field form $E(x)$ and the potential $V(x)$ by application of equations of electrostatics (Sari-Ari et al.,2005). In addition, the overall electrical neutrality of the junction imposes the relation:

$$N_a W_n = N_d W_p \qquad (27)$$

with W_n and W_p corresponding to the limit of DLA on sides N and P respectively (Fig. 13).
It may be demonstrated that according to the Boltzmann relationship, the corresponding potential barrier (diffusion potential of the junction) is given by:

$$V_0 = U_T \ln\left(\frac{N_a N_d}{n_i^2}\right), U_T = \frac{kT}{e} \qquad (28)$$

where n_i represents the intrinsic carrier concentration. On another hand, note that the width of the DLA may be related to the potential barrier (Mathieu H, 1987).
The PN junction out of equilibrium when a potential difference V is applied across the junction. According to the orientation in figure 14, the polarization will therefore directly reduce the height of the potential barrier which becomes (V_0-V) resulting in a decrease in the thickness of the DLA. (Fig. 14)
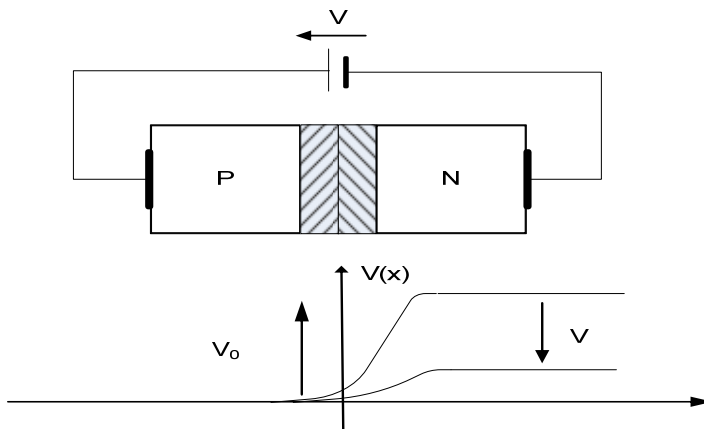
Fig. 14. Representation of a PN junction out of equilibrium thermodynamics

The decrease in potential barrier allows many electrons of the N region and holes from the P region to cross this barrier and appear as carriers in excess on the other side of the DLA. These excess carriers move by diffusion and are consumed by recombination. It is readily seen that the total current across the junction is the sum of the diffusion currents, and that these current may be related to the potential difference V in the form (Mathieu H, 1987):

$$J = J_S \left(\exp\left(\frac{V}{U_T}\right) - 1 \right) \qquad (29)$$

where Js is called the current of saturation.

On the other hand the diffusion current is fully consumed by recombination with time constant τ, so that the stored charge Q may be expressed as Q = τ J. This expression will be used for the dynamic model of the diode.

4.2 Comparison of PN junction and electrochemical interface

From the analysis of PN junction diodes, following similarities can be cited in relation to electrochemical interfaces (Coupan and al., 2010):

- The electrical neutrality is preserved outside an area of "double layer" formed at the interface electrode / electrolyte.
- In the neutral zone, conduction is predominantly by diffusion.
- The voltage drop located in the double layer zone is connected to limit concentrations of carriers by an exponential law (according to the Nernst's equation in electrochemistry, the Boltzmann law for semi-conductors).

However, significant differences may be identified:
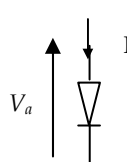
- For the PN junction, it is the concentration ratio that leads to predominant diffusion current for the minority carriers by diffusion. For lead acid battery, it is the mobility ration that explains that SO_4^{2-} ions move almost exclusively by diffusion
- There is no recombination of the carriers in the battery. As a result, in constant current operation the stored charge builds up linearly with time, instead of reaching a limit value proportional to the recombination time.
- The diffusion length is in fact the distance between electrodes, resulting in very long time constants (time constants even longer if one takes into account the migration of ions from outside the plates).
- within the overall "double-layer", additional "activation layers" build up in the presence of current, corresponding to the accumulation of active carries close to the reaction interface.

Based on method for modeling the PN junction, and the comparison seen above, we propose to analyze and model the phenomenon of activation in a lead-acid battery.

4.3 Phenomenon of non-linear activation
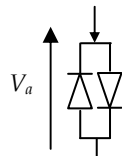
The activation phenomenon is characterized by an accumulation of reactants at the space charge region. This electrokinetic phenomenon obeys to the Butler-Voltmer: exponential variation of current versus voltage, for direct and reverse polarization (Sokirko Artjom et al., 1995). Dynamical behavior can be introduced using a "charge driven model", familiar for PN junctions, connected to an excess carrier charge Q stored in the activation phenomenon. Bidirectional conduction can be accommodated using two antiparallel diodes. Based on the

for one single PN junction, the static and dynamic modeling of a diode is given by the current expression:

$$\begin{cases} I_{st} = J_s \left(e^{\left(\frac{V_a}{v_0}\right)} - 1 \right) = \frac{Q}{\tau_0} \\ I = \frac{Q(t)}{\tau} + \frac{dQ}{dt} \end{cases} \tag{30}$$

with Q representing an amount of stored charge and a time constant τ associated.

It is noted that one can easily model the current through the diode with an equivalent model of stored charge; this approach is valid for one current direction and not referring to the battery charge. We must therefore provide a more complete model that can be used in charge or discharge. This analysis therefore reflects a model with two antiparallel diodes. The static and dynamic modeling of the two antiparallel diodes is given by the current expression (simplified symmetric model):

$$I_{st} = G(V_a) = J_s \; sh\left(\frac{V_a}{v_0}\right) \tag{31}$$

The static relation corresponds to the Butler Volmer equation (symmetric case). It is completed by the charge driven model:

$$\begin{cases} Q = \tau I_{st} = \tau G(V_a) \\ I = I_{st} + \frac{dQ}{dt} \end{cases} \tag{32}$$

After an analysis resulting static (and dynamic) and an experimental validation, we get the model of the phenomenon of activation with a parallel non linear capacitance and conductance circuit (fig.15) whose expressions are given by the following equations:

$$I_{st} = G(V_a) = \frac{J_0}{v_0} sh\left(\frac{V_a}{v_0}\right) \quad and \quad Q(V_a) = \frac{c_0}{v_0} sh\left(\frac{V_a}{v_0}\right) \tag{33}$$
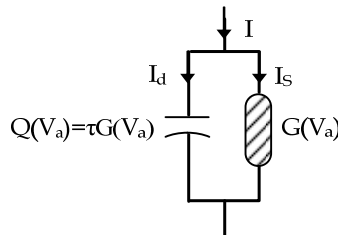
Fig. 15. Activation model : non-linear capacitance and conductance

5. Overvoltage model and experimental validation

By combining models obtained (diffusion phenomena/Storage, activation and input cell) and experimental measurements, we propose a simple and effective model of the battery voltage.
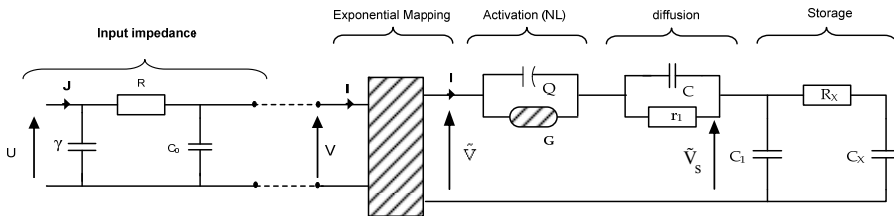
$(R \approx 2.5 \ 10^{-3} \ \Omega, \ \gamma = 400F, \ C_0 = 2.3 \ 10^4F, \ c = 3.2 \ 10^4F, \ r_1 = 2.5 \ 10^{-3} \ \Omega, \ c_1 = C_x = 5 \ 10^5F, \ R_x = 0.01 \ \Omega)$

Fig. 16. Overvoltage model of lead acid battery

5.1 Experimental analysis
Identification of a linear model may be delicate, but there are a lot of classical well trained methods for this.
For a non linear system, it is difficult to find a general approach.
For most cases, it is possible to separate steady state non linear set point positioning, then local small signal linear investigation.
For battery, the set point should be defined by the state of charge and the operating current. But the fact that when you apply a non zero operating current, the state of charge is no longer fixed. This is an important practical problem, all the more critical as there is a the strong dependence of the activation impedance with respect to the current. The experimental methodology presented is centered on this non linearity topic.

5.2 Separation on the basis of the time constant
Our objective is to establish the static value of the activation voltage as a function of current. The problem is that if the current scanning is too slow the variation of the state of charge will corrupt the measure.In such condition we can never reach the static value. Typical results are given in fig 17, compare to charge driven dynamical models as discussed in section 4.

5.3 Correction of battery voltage connected to the state of charge
A first hypothesis is that for slowly varying current the voltage drift is a function of the stored charge Q, computed by summation of the current. 3D plots are made as a function of the couple I, Q, with current steps to identify the relaxation time and asymptotic value as representative of the storage voltage or activation steps. (Fig.18)
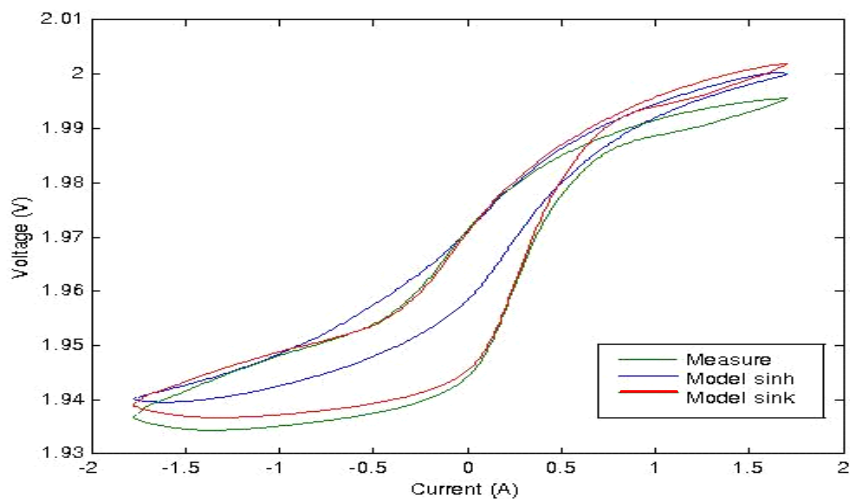
Fig. 17. Experimental analysis and simulation of activation phenomena
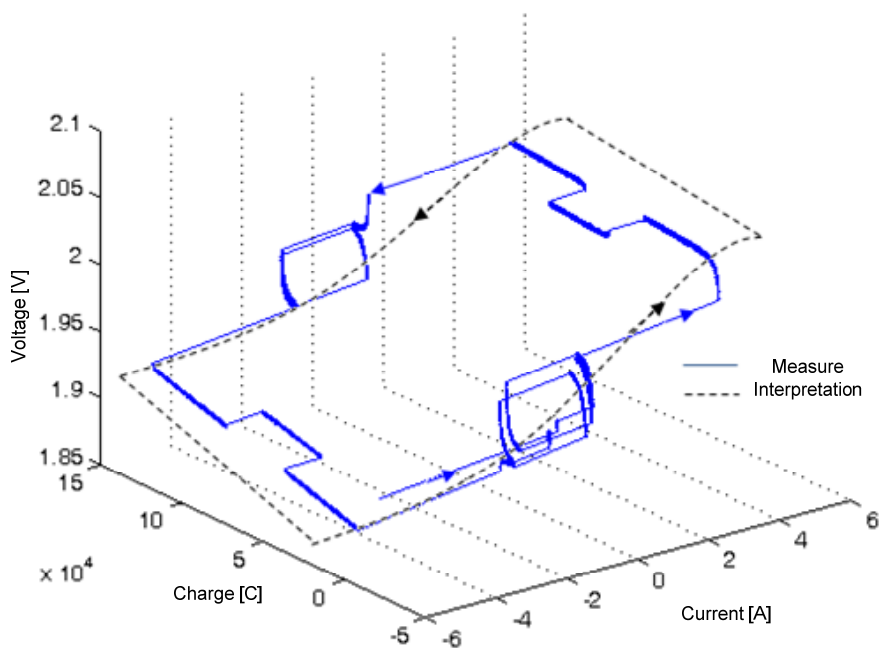
Fig. 18. Highlight of the diffusion and activation process

5.4 Improved storage voltage estimation

Instead of using Q as a reference for the storage voltage, we use the voltage given by the optimized RC storage net. Again the plot is made for steps between constant values of the current. We can see that between curves corresponding to two given values of the current, there remains a variation of the activation voltage.

V_{in-Eo}
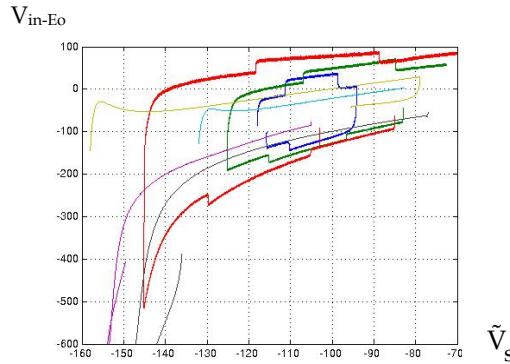
Fig. 19a. General Validation of diffusion/stockage and activation phenomena

5.5 Effect of the non linear voltage transformation

The same points are plotted using the pseudo-voltage after exponential transform. We see that now the plot between two given values of the current, which constitutes a good validation of the non linear model.

$\tilde{V}$
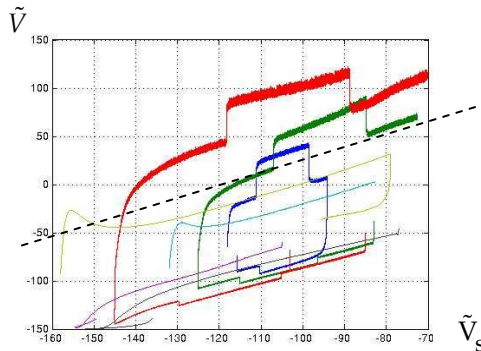
Fig. 19b. Reduction of activation voltage variations by linearisation

6. Conclusion

Electrochemical batteries are becoming quite usual components for electrical engineers. One of our purposes was to provide a good understanding for such users, by the way of a short form equivalent circuit.

This equivalent circuit sums up the different steps of a simplified physical analysis. Two most important aspects may be cited:

- Investigation of nonlinearities
- Efficient lumped model for diffusion

6.1 Investigation of nonlinearities

Characterization of dynamical non linear systems is quite complex. Purely phenomenological description may lead to a huge number of parameters for imperfect results.

From our physical analysis, nonlinearities are summarized by two simple elements:

- The exponential mapping of voltage into a "pseudo-voltage" proportional to ionic concentration. Diffusion processes may then be described in terms of linear equivalent impedance
- The activation overvoltage, described in static by Butler Volmer equations, for which we propose a dynamical model drawing from an analogy with semiconductor diodes (charge driven model with given relaxation time)

6.2 Efficient lumped model for distributed parameters systems

For non specialists, the "Warburg impedance" may look a very esoteric electrochemical topic. We introduce an analogy with a subject quite trivial for electronic engineers, capacitive transmission lines. Approximation of such distributed parameter device by lumped RC network has been the subject of a lot of papers (Kuhn et al., 2006 and Mauracher et al., 1997). We propose an efficient approximation with RC cells in geometric progression.

6.3 Possible extensions

We consider that our analysis constitutes an important contribution to the understanding of battery operation, in particular for electronic engineers. It opens the way for inclusion in efficient control of complex systems, either in the field of power managing or signal processing.

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8

Parameterisation of the Four Half-Day Daylight Situations

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1. Introduction

The International Commission on Illumination (C.I.E) in its Technical Committee TC 3-08 for Daylight initiated in 1983 the so called International Daylight Measurement Programme (IDMP). This programme was officially launched by the CIE President Bodmann (1991) and several CIE IDMP stations were established world-wide and now relatively long-term regular data are available for studies and analysis (Kittler et al., 1992). Although some daily courses served to characterise luminance sky patterns and local daylight climate, there are possible more detail analysis of half-day situations with relation to sunshine duration, cloudiness and turbidity influences parametrised. This chapter tries to show the theoretical basis with documented applications using examples of several parametrised evaluations of measurements taken at the Bratislava and Athens CIE IDMP general stations which can be taken as instructing samples to be imitated using local measured data. The aim is also to show how momentary illuminance values correspond with hourly averages under four different daylight situations and how these half-day situations can be simulated when only monthly relative sunshine duration is available and when monthly or year-round random daylight conditions are needed and could be approximated.

2. Regular daylight measurements and their possible analysis

Since the CIE (2003) and ISO (2004) fifteen general homogeneous sky luminance patterns were standardised many CIE IDMP (International Daylight Measurement) stations recording regularly long-term daylight parameters try to evaluate the frequency of typical skies in their localities. Because the general CIE IDMP stations without sky luminance scanners sometimes do not record even zenith luminance L_{vz} simultaneously with diffuse skylight illuminance measurements D_v there are missing either sky scans or the classifying parameter L_{vz}/D_v, which could identify the momentary sky type. Thus, usually are only available data of regularly measured illuminance parameters in one minute steps during daytime, i.e.:
- Global horizontal illuminance by an unshaded detector G_v,
- Diffuse skylight illuminance on a horizontal sun-shaded detector D_v,
- Parallel sunbeam illuminance is sometimes measured by a sun tracker with a sky-shading cylinder and a detector placed perpendicularly to sunbeam flux $P_{v\perp}$,
- Global vertical illuminances on planes oriented to North G_{vvN}, East G_{vvE}, South G_{vvS} and West G_{vvW} excluding the ground reflection.

A clock controling system starting every minute count has to be recorded too either in local clock time LCT or true solar time TST. These regular measurements can serve for the specification of daylight situations during the half-day or to the rough identification of the sky type in any minute, hour or date.

In fact even in absence of the sun tracker the $P_{v\perp}$ illuminance can be derived from G_v and D_v recordings as

$$P_{v\perp} = \frac{G_v - D_v}{\sin\gamma_s} = \frac{P_v}{\sin\gamma_s} \ [\text{lx}], \tag{1}$$

where $P_v = P_{v\perp}\sin\gamma_s$ is the horizontal illuminance caused by only parallel sunbeams in lx, γ_s is the momentary solar altitude which can be determined for any station location, date and clock time after:

$$\sin\gamma_s = \sin\varphi\sin\delta - \cos\varphi\cos\delta\cos(15°H) \ [-]. \tag{2}$$

The station location is given by the geographical latitude φ in deg., while date is specified by solar declination δ and hour number H during daytime in TST.

Solar declination angle can be calculated for any day number within a year J (i.e. for 1st January $J = 1$ and for 31st December $J = 365$) using different approximate equations (e.g. Kittler & Mikler, 1986). The simplest is that introduced by Cooper (1969)

$$\delta = 23.45°\sin\left[\frac{360°}{365}(284 + J)\right] \ [°], \tag{3}$$

and a more accurate approximation was recommended by EU after Gruter (1981)

$$\delta = 23.45°\sin\left[\frac{360°}{365}(J - 80.2°) + 1.92°\sin(J - 280°)\right] \ [°]. \tag{4}$$

Because usually CIE IDMP stations record all measurements in local clock time LCT the value H in TST has to be recalculated without consideration of summer shift time, after

$$H = LCT + \eta + \frac{(\lambda_z - \lambda_L)}{15°} \ [\text{h}], \tag{5}$$

where η is the equation of time in hours approximated after a simpler formula by Pierpoint (1982)

$$\eta = 0.17\sin\left[4\pi(J - 80)/373\right] - 0.129\sin\left[2\pi(J - 8)/355\right] \ [\text{h}], \tag{6}$$

or a more accurate formula by Heindl & Koch (1976)

$$\eta = 0.008\cos\frac{360°J}{365} - 0.052\cos 2\frac{360°J}{365} - 0.001\cos 3\frac{360°J}{365} - \\ -0.122\sin\frac{360°J}{365} - 0.157\sin 2\frac{360°J}{365} - 0.005\sin 3\frac{360°J}{365} \ [\text{h}], \tag{7}$$

λ_z is geographical longitude of the time zone in deg.,

λ_L - geographical longitude of the location in deg.

The perpendicular parallel sunbeam illuminance at the ground level can be also calculated applying the Bouguer law, i.e.

$$P_{v\perp} = LSC \in \exp\left(-a_v m T_v\right) \text{ [lx]},\qquad(8)$$

where LSC is the luminous solar constant (Darula et al., 2005), which is the normal extraterrestrial illuminance on the outer border of the atmosphere for the average distance between sun and earth, approximately $LSC = 133\,800$ lx., which is corrected for any date by the ellipticity factor $\in$, which is often approximated by IESNA (1984)

$$\in = 1 + 0.034 \cos \frac{360°}{365} (J - 2) \text{ [-]},\qquad(9)$$

m - relative optical air mass approximated by Kasten & Young (1989)

$$m = \frac{1}{\sin\gamma_s + 0.50572\left(\gamma_s + 6.07995°\right)^{-1.6364}} \text{ [-]},\qquad(10)$$

a_v - luminous extinction coefficient of a clean and dry (Rayleigh) atmosphere after Clear (1982), later published by Navvab et al., (1984)

$$a_v = \frac{0.1}{1 + 0.0045\,m} \text{ [-]},\qquad(11)$$

or

$$a_v = \frac{1}{9.9 + 0.043\,m} \text{ [-]},\qquad(12)$$

T_v - luminous turbidity factor, which defines the number of clean and dry atmospheres in the direction of sunbeams that reduces relatively its momentary penetration. In fact, if in eq. (8) $P_{v\perp}$ is measured by a sun tracker or P_v is derived from measured $G_v - D_v$ data, then the actual value T_v can be determined as

$$T_v = \frac{-\ln\left(P_{v\perp} / \left(\in LSC\right)\right)}{a_v\,m} = \frac{\ln\left(E_v / P_v\right)}{a_v\,m} \text{ [-]},\qquad(13)$$

where $P_v = G_v - D_v$ and the extraterrestrial horizontal illuminance E_v is

$$E_v = \in LSC \sin\gamma_s \text{ [lx]}.\qquad(14)$$

Thus, once the momentary illuminance $P_{v\perp}$ or P_v is determined the actual sunlight impact on any arbitrary plane can be calculated using the cosine of its incidence angle. However, for the vertical planes oriented either to direct East or West cardinal points this cosine function is simplified to

$$P_{vvE} = P_{vvW} = P_{v\perp} \cos\delta \sin\left(15°\left|12 - H\right|\right) \text{ [lx]}. \tag{15}$$

Note, that the East and West oriented vertical planes or fasades are exposed to the morning and afternoon half-day sunlight and skylight effects as measured by global vertical illuminances G_{vvE} or G_{vvW} respectively. So, when the direct sunlight using eq. (15) can be subtracted only diffuse skylight components for these orientations can be determined, i.e. D_{vvE} or D_{vvW}.

3. Four typical half-day situations indicated by illuminance courses

In the previous paper (Darula & Kittler, 2004a) from typical half-day illuminance courses were identified four characteristic daylight situations, which need to be explained in more detail:

Situation 1: Absolutely cloudless half-day with relative sunshine duration $s \geq 0.75$ and the parameter of instability $U \leq 8.4$ is almost clear with only few smaller clouds moving over the sky vault. Except these few sunshaded events the clear sky is quite stable and all horizontal illuminance parameters P_v, G_v and D_v follow a fluent increase in level during the morning hours and similar decrease during the afternoon due to solar altitude changes in different seasons.

Examples of selected half-days with *situation 1* are using recorded data from the Bratislava CIE IDMP general station ($\varphi = 48°10'$N, $\lambda_L = 17°05'$E) with the Central European climatic influences, but these should be taken as instructional and illustrative examples characterising typical cases of *situation 1.* As examples of clear sky mornings in Bratislava, Slovakia, were chosen courses measured during a long summer day on the 20th July 2006 followed by an autumn day on 22nd September 2007, while a short winter day 26th December 2006 represents one of the shortest days and the spring day 8th April 2006 with slight veiling Cirro-Stratus influences is also documented. The measured half-day courses of global horizontal illuminance G_v and diffuse sky illuminance D_v are documented in Fig. 1. Although the measurement registration is in the local clock time without the summertime shift it is evident that the courses follow the solar altitude changes, i.e. the $\sin\gamma_s$ tendency of the extraterrestrial horizontal illuminance after eq. (14). Therefore the efficiency parameters G_v / E_v and P_v / E_v should be rather stable and showing a large amount of the extraterrestrially available luminous flux reaching the ground level, therefore these parameters can markedly characterise *situation 1* (Fig. 2). The momentary 1-minute measurements except some slight spreads on the April day show a steady rise with the solar altitude which is even better followed by the hourly averages in Fig. 3 with the stepwise rise of G_v / E_v from 0.45 to 0.75. In consequence, also the luminous turbidity factors T_v follow the stable atmospheric conditions without abrupt changes, except when the sun position is shaded by crossing cloud patches and then can reach higher short time peaks as in Fig. 4 on 8th April 2006. However, due to gradual evaporation during morning the turbidity might fluently rise with the formation of Cirrus or Cirrostartus veiling cloudiness as is shown by the trend of rising hourly average T_v values in a small range 1.5 to 3 in Fig. 5. Such rising T_v effects can be expected especially in equatorial regions with sometimes gradual cloud formation at noontime and in afternoon hours, which no longer belong to *situation 1.*
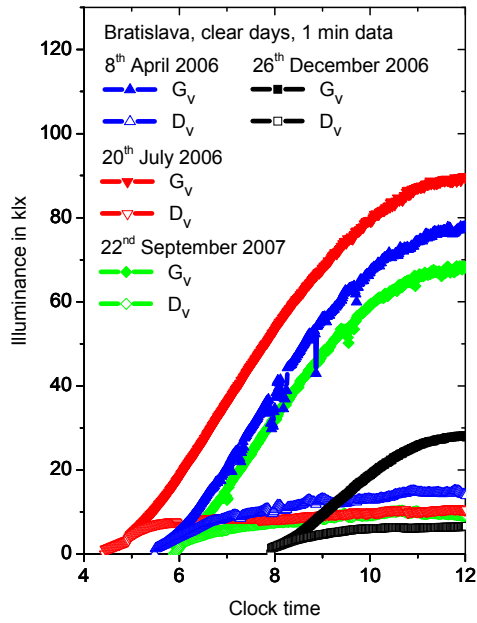
Fig. 1. Illuminance courses during clear morning *situations 1*
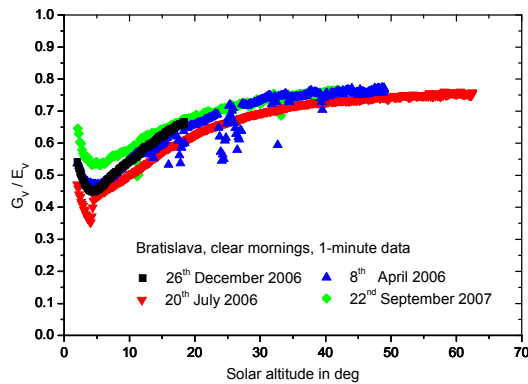
Fig. 2. G_v / E_v courses under *situation 1* after 1-minute measurements
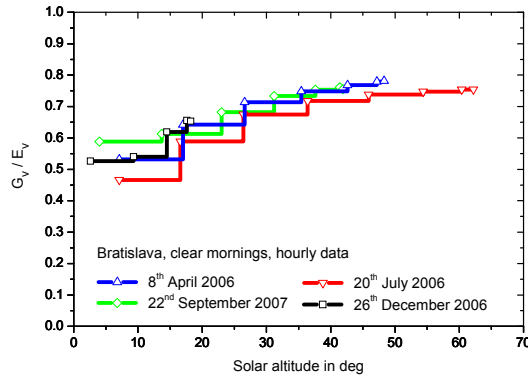
Fig. 3. G_v / E_v courses under *situation 1*:after measured hourly averages
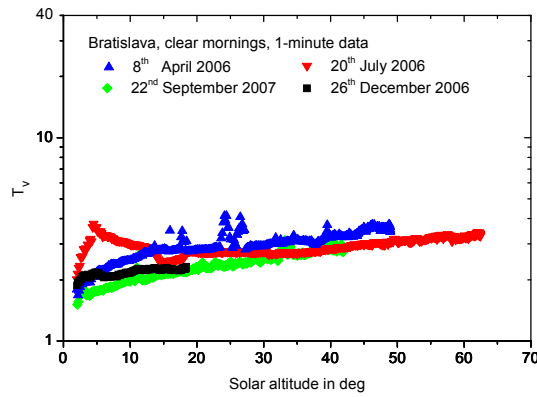
Fig. 4. T_v courses under *situation 1*: after 1-minute measurements
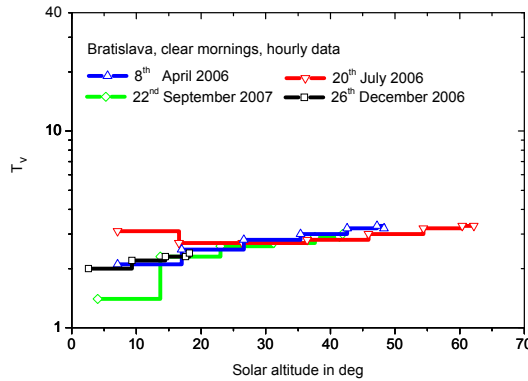
Fig. 5. T_v courses under *situation 1*: after measured hourly averages

It has to be noted that during sunrise and early morning hours the prevailing daylight is caused by skylight and therefore also on clear days the early G_v / E_v values are equal or quite close to D_v / E_v while under higher solar altitude the P_v / E_v component is rising while D_v / E_v value fluently decreases after Fig. 6 from roughly 0.5 to 0.1. The average hourly decrease is slightly distorting this range showing approximately 0.4 to 0.1 respectively (Fig. 7).
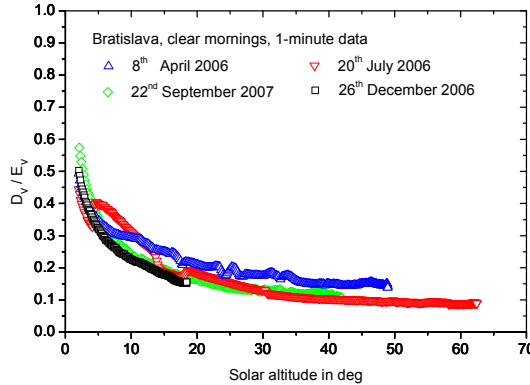
Fig. 6. D_v / E_v courses under *situation 1*: after 1-minute measurements
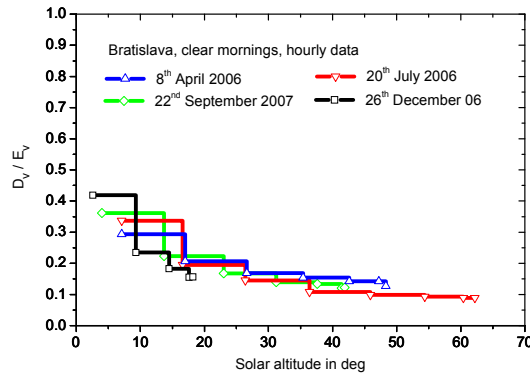
Fig. 7. D_v / E_v courses under *situation 1*: after measured hourly averages

If simultaneous measurements of the zenith luminance is recorded under clear sky conditions the classifying parameters L_{vz} / D_v , can identify the momentary sky type with the fluent rising tendency dependent on the solar altitude. In Fig. 8 this tendency is shown using 1-minute data while in Fig. 9 the same is documented after hourly mean values. Due to rather constant and fluent trends during *situation 1* besides the momentary one-minute recordings also hourly averages and appropriate parameters are quite satisfactorily reflecting clear half-days which might reduce the number of data considerably (Darula. & Kittler, 2005a).
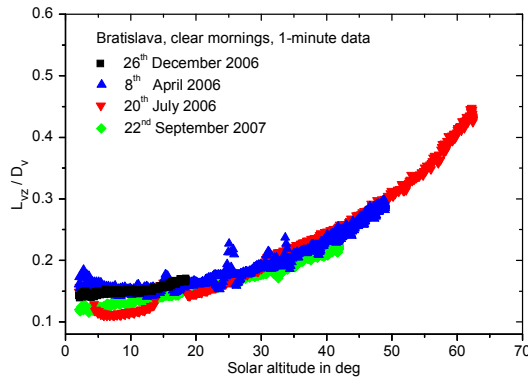
Fig. 8. L_{vz} / D_v courses under *situation 1*: after 1-minute measurements
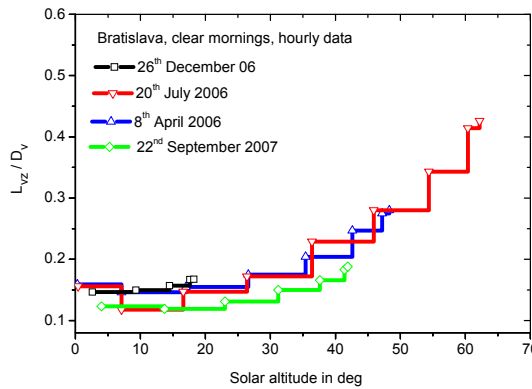
Fig. 9. L_{vz} / D_v courses under *situation 1*: after measured hourly averages

It is evident that the time period close to sunrise is untrustworthy due to an interval when solar altitude is zero and average G_v / E_v ratios are also reduced due to close to horizon mist or high turbidities. The minute courses are intersected by the hourly level in the point of hourly average solar altitude after Kittler & Mikler (1986)
where H_1, H_2 are consecutive hours

$$\gamma_{sH} = \frac{180°}{\pi} \arcsin \left[\sin\varphi \sin\delta + \frac{12}{\pi}\left(\sin\frac{\pi H_1}{12} - \sin\frac{\pi H_2}{12} \right) \right] \cos\varphi \cos\delta \ \ [\text{rad}], \qquad (16)$$

Sunrise hour H_{sr} when $\gamma_s = 0°$ is for any location and date defined by

$$H_{sr} = \frac{1}{15°} \arccos\left(\tan\varphi \tan\delta \right) \ [\text{h}], \qquad (17)$$

and due to symmetry around noon the hour of sunset H_{ss} = 24 - H_{sr} and the astronomically possible sunshine duration S_{ahd} during a half-day is

$$S_{ahd} = \frac{1}{15°}\arccos\left(-\tan\varphi\,\tan\delta\right)\ \text{[h]}. \tag{18}$$

This is an normalising amount to calculate relative sunshine duration during the half-day s_{hd} if the true measured sunshine duration in hours S_{hd} is available:

$$s_{hd} = \frac{S_{hd}}{S_{ahd}}\ \text{[-]}. \tag{19}$$

In the half-day system relative sunshine duration during the morning half-day is $s_{hd} = s_m$ while its afternoon relative duration is $s_{hd} = s_a$ either in absolute values or % respectively. If regular minute recordings are measured, then S_{hd} can be calculated as the sum of all data after the WMO (1983) and CIE 108 (1994) when the direct irradiance $P_{e\perp} \geq 120$ W/m² taken in hours or their decimals.

Situation 2: Cloudy half-days with possible foggy short periods are characterised by scarce and lower sunlight influences under a range of relative sunshine durations ($0.03 \leq s \leq 0.75$ and $U \leq 10 - 6s$) and relatively higher diffuse illuminance levels. Such situations are caused by the prevailing area of the sky covered from almost homogeneous presence of clouds layers with different combinations of cloud type, turbidity and cloud cover overlayed in their height positions and movement drifts. Therefore, usually their G_v courses are close to D_v levels and so are also ratios G_v / E_v and D_v / E_v typical for s*ituation 2*.

To document cloudy half-days were chosen from the Bratislava data again seasonally typical cases, i.e. a summer day 3rd June 2007, an autumn day on 5th September 2007, a cloudy winter morning on 20th December 2006 and a spring morning on 5th April 2006. The measured half-day courses of global horizontal illuminance G_v and diffuse sky illuminance D_v are recorded in local clock time again in Fig. 10. In early morning hours under cloudy conditions G_v / E_v and D_v / E_v are almost the same as is not so noticeable from the winter course of illuminances, but evident in Fig. 11 in 1-minute or in Fig. 12 in the hourly alternative compared with Fig. 13 and 14. In this cloudy case the G_v / E_v and D_v / E_v values is very high reaching 0.25 to 0.6 level indicating a very bright but sunless winter half-day which is indicated also by the T_v lower values compared with all other cloudy samples (in Fig. 15 and 16) as well as in rather horizontal range of L_{vz} / D_v parameters in Fig. 17 and especially their averages in Fig. 18 with the data spread within the values 0.2 to 0.38 close to overcast sky (Darula & Kittler, 2004b).

Due to cloudiness overlays and turbidity changes rather high values of T_v factors have to be expected usually dependent on the solar altitude as shown in Fig. 15 or 16. However, within the half-day courses momentary unstable P_v can occur, thus there are cases also with higher average relative sunshine durations during the half-day in the range 0.1 to 0.5, but seldom over 0.5 with lower sunlight intensities, which are usually indicated by smaller peaks within the half-day course. These drab sunlight influences are documented by the small differences between G_v / E_v and D_v / E_v values when comparing Fig. 12 and 14 respectively.

Situation 3: Overcast half-days are absolutely without any sunlight and are caused by either dense layers of Stratus or Altostratus cloudiness or inversion fog when the sun

position is uncertain as it cannot be seen or guessed behind the overall dense clouds. Under such conditions $G_v = D_v$, $P_v = 0$ and average relative sunshine duration during the half-day $s \leq 0.03$. While the D_v illuminance levels and the ratio D_v / E_v are quite low, usually in the range 0.02 - 0.25, the ratios L_{vz} / D_v are over 0.3 and stable during the half-day, i.e. without any dependence on the solar altitude (Darula & Kittler, 2004c). Under overcast sky conditions when sunbeam influences are absent the sky luminance patterns in all azimuth directions are uniform, so only gradation luminance distribution can cause the D_v illuminance rise from sunrise to noon.
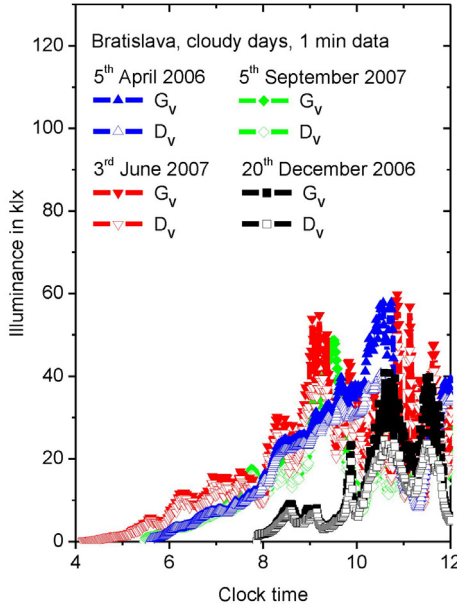
Fig. 10. Illuminance courses during cloudy morning *situations 2*
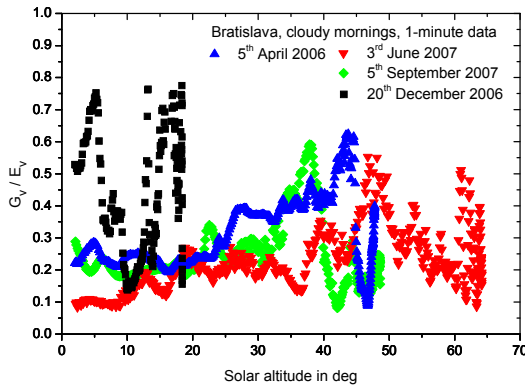
Fig. 11. G_v / E_v courses under *situation 2*: after 1-minute measurements
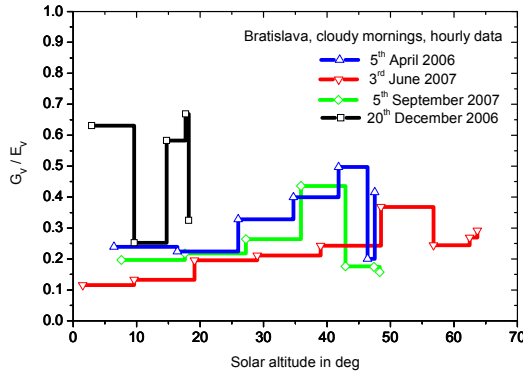
Fig. 12. G_v / E_v courses under *situation 2*: after measured hourly averages
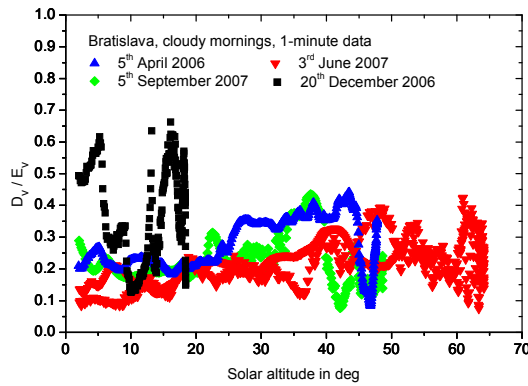
Fig. 13. D_v / E_v courses under *situation 2*: after 1-minute measurements
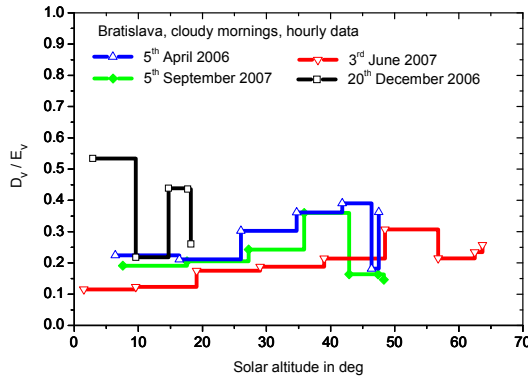
Fig. 14. D_v / E_v courses under *situation 2*: after measured hourly averages
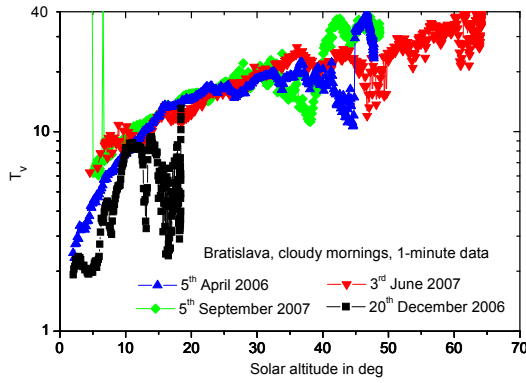
Fig. 15. T_v courses under *situation 2*: after 1-minute measurements
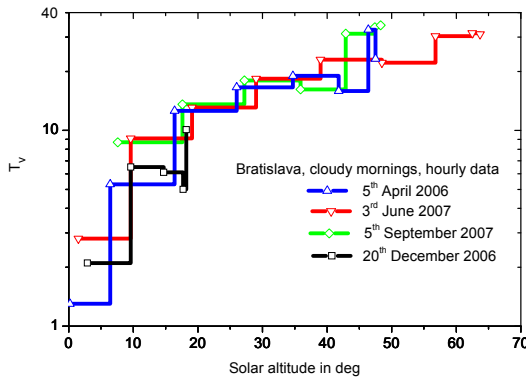
Fig. 16. T_v courses under *situation 2*: after measured hourly averages
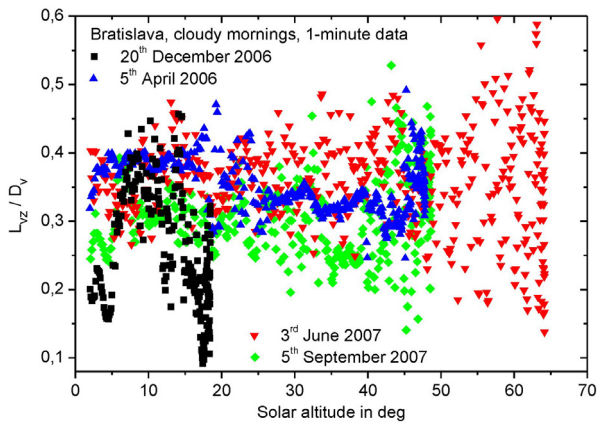
Fig. 17. L_{vz} / D_v courses under *situation 2*: after 1-minute measurements
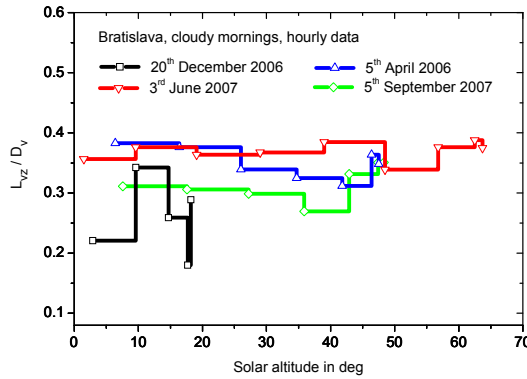
Fig. 18. L_{vz} / D_v courses under *situation 2*:after measured hourly averages

To document overcast half-days by Bratislava recordings again four seasonal examples were chosen, i.e. a winter morning on the 23rd January 2001 and a spring case on 3rd March 2001, an exceptional summer half day on 4th June 2001 and an autumn case on 6th September 2007. The half-day courses of measured global and diffuse illuminances in 1-minute intervals are in Fig. 19 with the $G_v / E_v = D_v / E_v$ analysis in Fig. 20 in 1-minute and in Fig. 21 in hourly alternatives. All four cases document the low and stable efficiency of penetration in the range 0.05-0.2 without any dependence on the solar altitude. The same stable and independent trend shows also the L_{vz} / D_v courses in Fig. 22 and 23 within the average range 0.3-0.4.
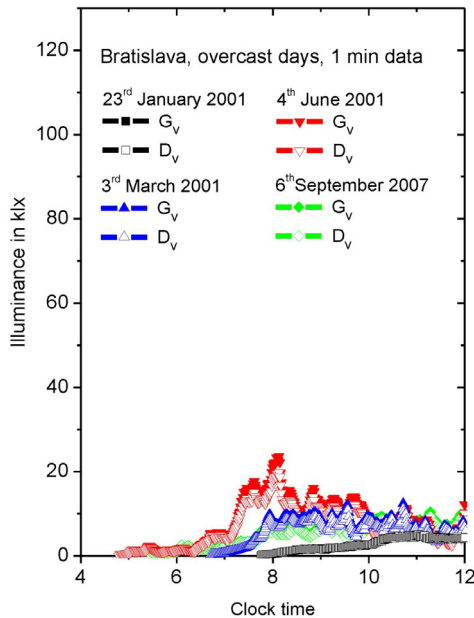
Fig. 19. Illuminance courses during overcast morning *situations 3*
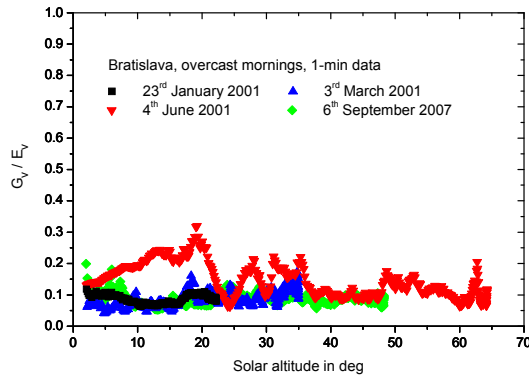
Fig. 20. G_v / E_v courses under *situation 3*: after 1-minute measurements
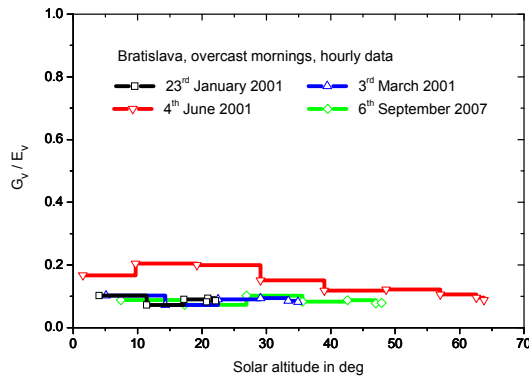
Fig. 21. G_v / E_v courses under *situation 3*:after measured hourly averages
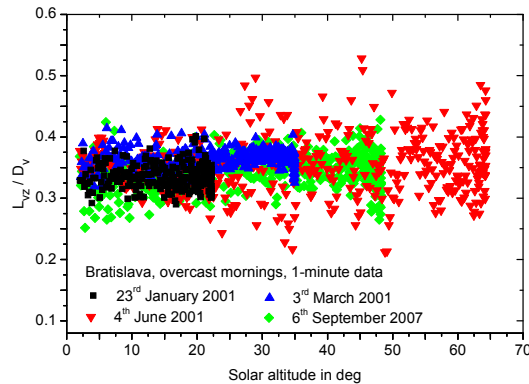
Fig. 22. L_{vz} / D_v courses under *situation 3*: after 1-minute measurements
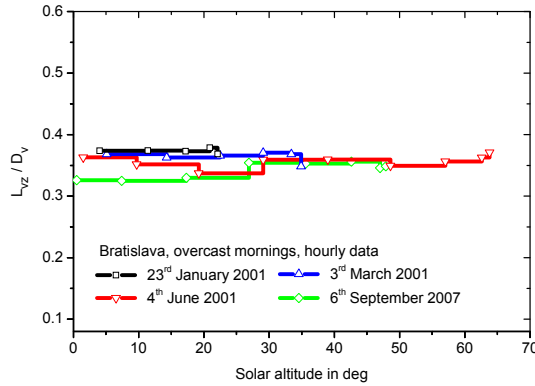
Fig. 23. L_{vz} / D_v courses under *situation 3*: after measured hourly averages

> *Situation 4*: The dynamic courses in horizontal illuminance levels happen during those half-days when the clear sky is covered by smaller cloud patches passing the sun position and shade direct sunlight in many short-term intervals or moments. Thus the overall G_v course trends can be usually kept but with many drops of temporary loss or reduction of P_v components, which mean dynamic variations between G_v and D_v levels. Because D_v levels are not affected by the P_v changes, L_{vz} / D_v ratios indicate the sky patterns when the zenith luminance is not influenced by passing clouds significantly. However, dynamic changes are reproduced also in G_v / E_v and P_v / E_v courses. In case of dynamic situations it is problematic to use hourly averages which are levelling the momentarily occurring peaks and drops replacing them by an even horizontal line. Thus is also distorted the wide range of T_v values that have to be expected in s*ituation 4.*

Due to the irregularity and occasional movement of the shading cloud patches there is a multiple number of different cases, so the selection of characteristic courses is very problematic. However, from Bratislava data were selected also four seasonal representatives, i.e. for winter the morning on 12th January 2007, for spring 14th March 2001, for the summer example the course on 29th June 2007 and for the autumn example was chosen the dynamic morning on 26th November 2007. The actual global and diffuse illuminance courses in Fig. 24 document the dynamic changes during the chosen half-days. The same dynamic variations of G_v / E_v parameters in minute representation are in Fig. 25 while hourly means erase the highest peaks and drops (Fig. 26) considerably. The D_v / E_v courses are relatively more stable and document the low borderline (Fig. 27 and 28) from which additional sunlight influences the peaks. Similarly to G_v/E_v also L_{vz}/D_v courses are very distorted in hourly averages in Fig. 30 in comparison to 1-minute fluctuating values in Fig. 29, but the former indicate a tendency of the background spring and summer clear skies. However, these background scene is also influenced by gradually increasing turbidity, which is low with lower solar altitude and considerably rising when the sunheight is over 35 degrees (Fig. 31 and 32).
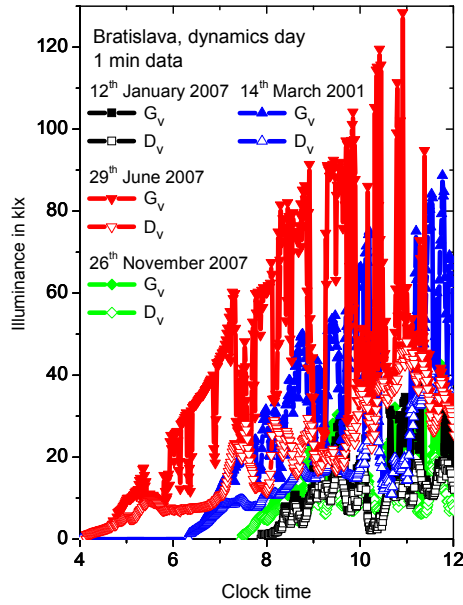
Fig. 24. Illuminance courses during overcast morning *situations 4*
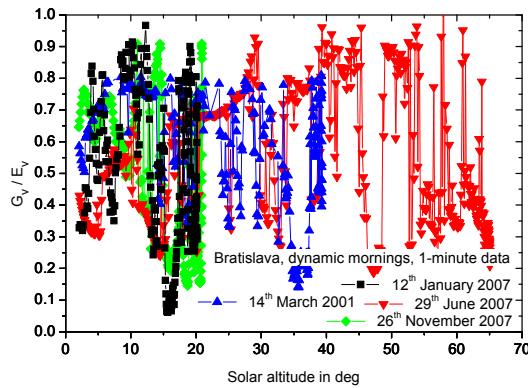
Fig. 25. G_v / E_v courses under *situation 4*: after 1-minute measurements
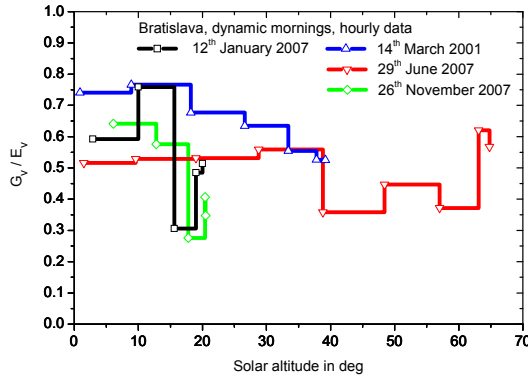
Fig. 26. G_v / E_v courses under *situation 4*: after measured hourly averages
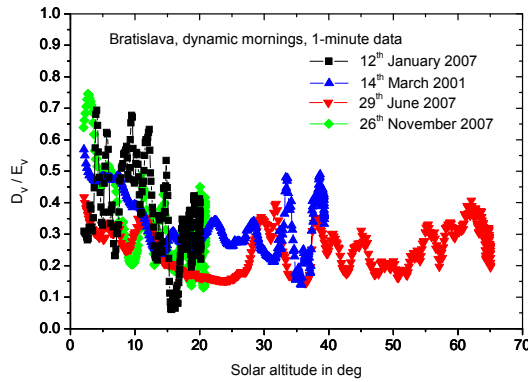
Fig. 27. D_v / E_v courses under *situation 4*: after 1-minute measurements
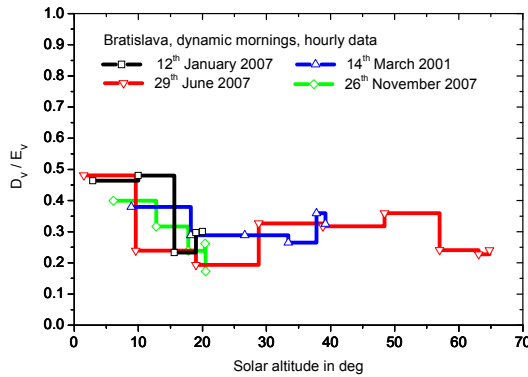
Fig. 28. D_v / E_v courses under *situation 4*:after measured hourly averages
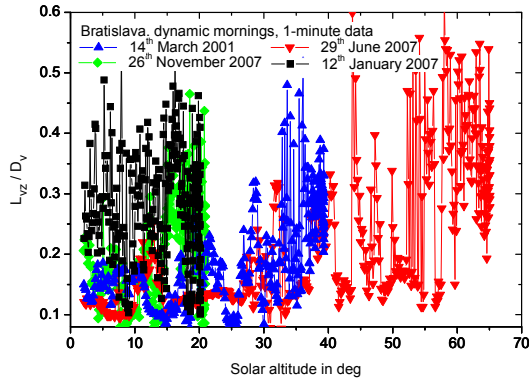
Fig. 29. L_{vz} / D_v courses under *situation 4*: after 1-minute measurements
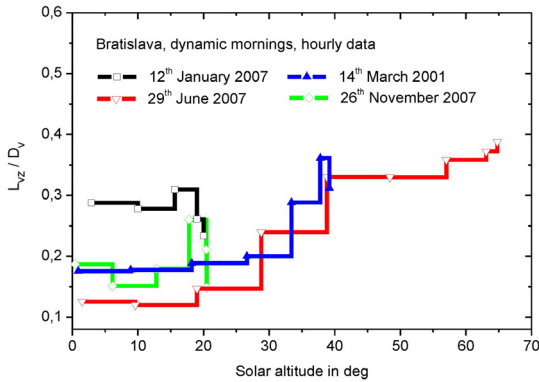
Fig. 30. L_{vz} / D_v courses under *situation 4*: after measured hourly averages
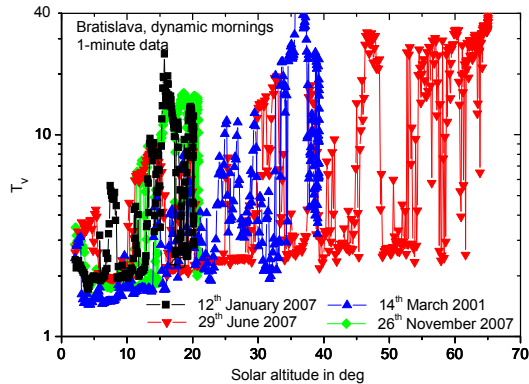
Fig. 31. T_v courses under *situation 4*: after 1-minute measurements
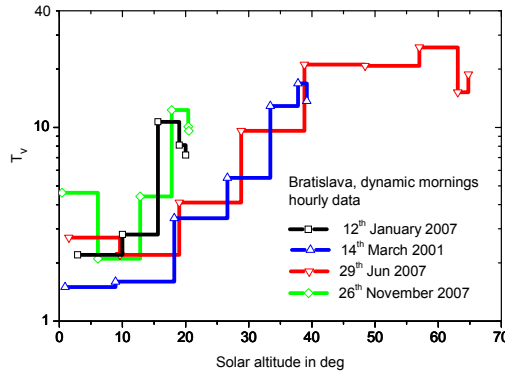
Fig. 32. T_v courses under *situation 4*:after measured hourly averages

4. Approximate dependence of the four daylight situations on relative sunshine duration

In the paper by Kittler & Darula (2002) a P-D-G diagram was published to show Bratislava 5-minute data covering the whole July 1996. From 5315 cases were 3113 with sunshine while 2202 measured cases were without sunshine according to the WMO (1983) classification. The monthly relative sunshine duration after 1-minute recordings was in July 1996 on the average $s = 0.52$ with daily changes within the range 0.022 – 0.946 which indicates the possibility of half-day situations in all four categories. Due to the averaging distortion it would seem that the prevailing sunny 5-minute intervals 3113/5315 indicate the sunshine duration roughly 0.586.

The review of daily measured illuminance courses representing July 1996 by 62 half- days can be classified into:

- *situation 1* approximately 9 morning courses and 7 in the afternoon half-day,
- *situation 2* only 2 morning courses and 2 in the afternoon half-day,
- *situation 3* only 2 morning courses and 1 in the afternoon half-day,
- *situation 4* the prevailing 18 morning and 21 afternoon half-days.

It is evident that neither the number of sunshine or sunless cases within a month in a P-D-G diagram nor L_{vz} / D_v and G_v / E_v time-averaged ratios are capable to differentiate the half-day situations when data are summarised during a day, a week or month in these mixed groups. Therefore the first step to identify, select or classify the half-day situations is to check the overall courses of G_v and D_v illuminance trends and levels and their relative efficiencies compared to the momentary extraterrestrial availability levels expressed in G_v / E_v and D_v / E_v ratios. Of course the stable or discontinuous sunshine duration follows the changes in G_v / E_v and the momentary presence of P_v / E_v ratios indicating the penetration of available extraterrestrial sunshine intensity. These half-day courses roughly characterise also the range of prevailing sky luminance patterns that can be expected and principally belong to the particular half-day situation. While situation 1 and 3 and sometimes even 2 are approximately homogeneous with evenly distributed turbidities and cloudiness cover over the whole sky vault, the situation 4 is characteristic for its unstable dynamic illuminance changes caused by complex layers of different cloud types and

distribution as well as patch movements. Thus under situation 4 can happen locally many accidental variations between quite low turbidity pockets with white-blue sky background through which direct sunshine temporarily can reach the ground while in other intervals the cloud patches cover and shade the sun beam penetration considerably.

Under homogeneous atmospheric conditions the L_{vz} / D_v ratio is quite a safe indicator of the sky luminance pattern, but during the dynamic half-day the zenith luminance as well as the sun position are influenced by passing clouds or cloud patches in several following sequence intervals.

However, for general practice and local characterisation of daylight conditions year-round long-term data are needed and should be locally available. Daylight data are also measured at the CIE IDMP stations or can be taken from the satellite database. In this respect besides global irradiation recorded in short-term variability or hourly averages at ground meteorological stations or recalculated from satellite measurements, only relative sunshine duration in daily or monthly averages have a very long tradition and are evaluated in many stations world-wide.

When inspecting monthly graphs of daily illuminance courses it becomes obvious that especially during winter and summer seasons typical weather patterns last for several days with changes either during night-time or noon. Even during perfectly clear days the symmetry around noon seems to be broken by higher turbidity in afternoon hours caused by water vapour evaporated due to rising air temperature and sunshine. Furthermore, in equatorial climate have to be expected changes in cloud cover at around noon, i.e. frequent mostly clear mornings and hours before noon but rather cloudy afternoons. During the Slovak-Greek cooperation simultaneously collected data at the CIE IDMP stations in Bratislava and Athens could serve to compare four half-day situations occurring in the temperate climate of Central Europe to those in the Mediterranean region (Darula et al., 2004). Available data was gathered during relatively long period 1994-1999.

The whole set of measured data was used to analyse the relation between sunshine duration and daily courses of illuminance. Relative sunshine duration with standard deviation *SD* for four typical situations were investigated in number with respect to their sequence of occurrence and results are documented in Table 1. Symbol *s* is relative sunshine duration calculated for the whole day while *sm* is for the morning period when local clock time was less than 12 o´clock and *sa* for the afternoon relative sunshine duration when local clock time was from 12 hours to sunset.

Except for the rapid change from overcast to clear all possible changes from morning to afternoon situations were found during the long-term of six years, i.e. 2182 days or 4364 half-days. The average relative sunshine duration corresponds perfectly with the change from the morning situation to the afternoon one respecting the tendency of the following situation change.

Although the half-day characteristics and their sequences in one or few days can form a typical year simulation, within this span any time subdivision can be utilised, i.e. Bratislava 1-minute data or Bratislava and Athens 5-minute average data can serve for analysis and comparison studies of several descriptor interrelations. However, to reach an absolute symmetry in half-days due to perfect noon time all measured momentary or average values are to be recalculated from local clock time in which these were recorded to true solar time. Of course, it has to be realised that because the daytime span between sunrise and sunset is changing during the year as well as with the local latitude the relative time of a half-day element is not constant.

Situation sequence		Number of cases	s		sm		sa	
Morning	Afternoon		Average	SD	Average	SD	Average	SD
Clear	Clear	175	0,917	0,034	0,967	0,031	0,849	0,034
Clear	Cloudy	87	0,796	0,091	0,944	0,054	0,586	0,131
Clear	Overcast	4	0,506	0,027	0,868	0,032	0,003	0,004
Clear	Dynamic	70	0,818	0,094	0,941	0,037	0,655	0,165
Cloudy	Clear	9	0,649	0,148	0,512	0,185	0,839	0,038
Cloudy	Cloudy	128	0,261	0,224	0,265	0,220	0,254	0,208
Cloudy	Overcast	201	0,049	0,074	0,082	0,080	0,000	0,001
Cloudy	Dynamic	38	0,200	0,122	0,109	0,097	0,324	0,153
Overcast	Clear	0	-	-	-	-	-	-
Overcast	Cloudy	53	0,056	0,055	0,003	0,003	0,134	0,108
Overcast	Overcast	311	0,002	0,002	0,003	0,003	0,000	0,000
Overcast	Dynamic	34	0,096	0,065	0,004	0,003	0,219	0,128
Dynamic	Clear	90	0,753	0,154	0,690	0,220	0,841	0,035
Dynamic	Cloudy	160	0,383	0,208	0,467	0,227	0,267	0,210
Dynamic	Overcast	72	0,149	0,140	0,257	0,201	0,001	0,002
Dynamic	Dynamic	750	0,504	0,219	0,536	0,252	0,462	0,205
Sum of cases		2182						

Table 1. Statistical parameters of typical courses in Bratislava, 1994 -1999

Anyhow it can be assumed that in simulation programs of a daylight reference year the half-day sequences or changes will allow to model in series of about sixty cases during a specific month either the fluent and gradual or sudden changes in weather or sky types corresponding to the probability of occurrence with its proportionality to monthly averages of relative sunshine duration. At least the mentioned four half-day daylight situations have to be foreseen for modelling the complex sun-sky coexistence with cloudiness patterns in any daylight climate, although typical cases were selected only from measurements collected in Athens and Bratislava. A research report (Darula et al., 2004) contains the detail analysis with proposals of several parameters to identify the four relevant situations from measured half-day illuminance courses and the daily average relative sunshine duration. It is evident that the stable and homogeneous *situation 1* and *situation 3* can be defined by the *s* instead of sm and sa. However, the dynamically changing illuminance courses had to be identified and classified or selected to *situation 1*, *situation 2* or *situation 4* by introducing an additional *U* parameter. Thus

$$situation = \begin{cases} 1 & \text{if } s \geq 0.75 \text{ and } U<7, \tau \\ 2 & \text{if } s<0.75 \text{ and } U<7, \tau \\ 3 & \text{if } s<0.01, \tau \\ 4 & \text{if } s \geq 0.01 \text{ and } U \geq 7, \tau \end{cases} , \qquad (20)$$

where

$$U = \ln\left(\frac{1}{n-1}\sum_{i=1}|x_i - x_{i+1}|\right), \qquad (21)$$

and x_i and x_{i+1} are consecutive illuminance values in the half-day course.

Using these classification parameters all four daylight types are interrelated by a fluent course of half-day average G_v / E_v and D_v / E_v dependent on the half-day sunshine duration as documented in Fig. 33 and 34 containing all 1994 morning and afternoon data recorded in Bratislava and in Athens first. In the second step a more detail separation of half-day situations dependent on half-day relative sunshine duration was made for morning 1994 data (Fig. 35) and afternoon (Fig. 36) in relation to G_v / E_v parameter repeated for also D_v / E_v and P_v / E_v with the best fit simulation of their dependence on the half-day relative sunshine duration. However, as most frequently are available only monthly relative sunshine durations in meteorological station reports the probability of occurrence of the morning and afternoon half-day situations was sought first for 1994 data (example in Fig. 37 for *situation 1*) and checked for 1991-2001 data. Thus best fit probability for the monthly redistribution simulation of morning and afternoon *situations 1* to *4* were predetermined solely dependent on the monthly relative sunshine duration using curves in Fig. 38 for morning half-days or in Fig. 39 for afternoons (Darula et al., 2004 and Darula & Kittler, 2005b).
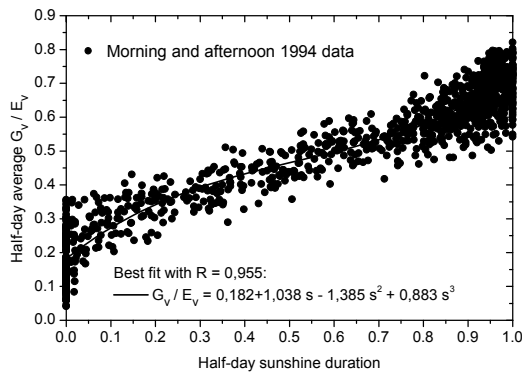
Fig. 33. Morning and afternoon G_v / E_v data after Bratislava and Athens measurements during 1994
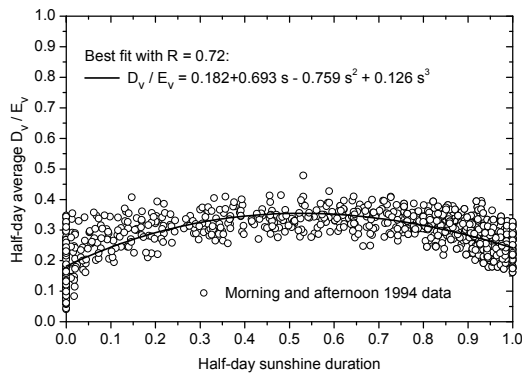
Fig. 34. Morning and afternoon D_v / E_v data after Bratislava and Athens measurements during 1994
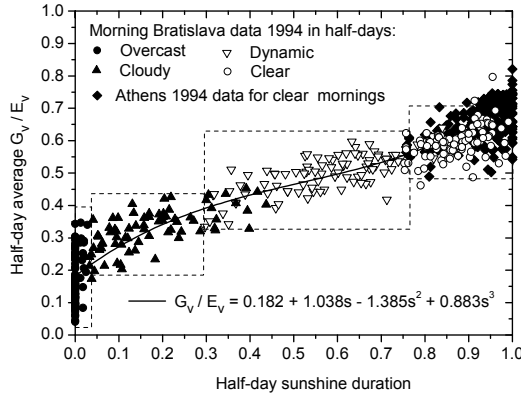
Fig. 35. Morning data for four half-day situations
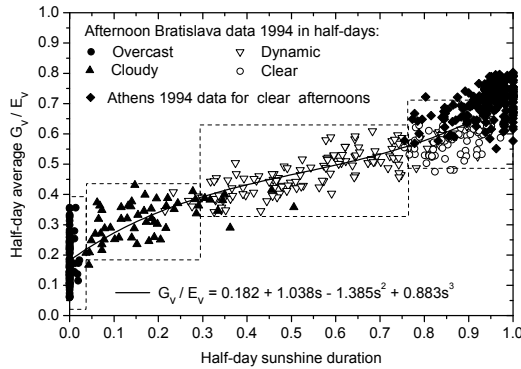
Fig. 36. Afternoon data for four half-day situations

The probability of occurrence of each of the four daylight situations in each month can be approximately estimated
- for morning half-days by:

$$Pm1 = 100(0.55s - 0.95s^2 + 1.65s^3) \ [\%], \tag{22}$$

except if $s > 0.93$, then $Pm1 = 100$

$$\text{if } s = 0 \text{ - } 0.5, \text{ then } Pm2 = 100s(1.5 - 1.85s) \ [\%], \tag{23}$$

$$\text{if } s = 0.5 \text{ - } 0.93, \text{ then } Pm2 = 66.86(0.93 - s) \ [\%], \tag{24}$$

$$\text{if } s > 0.93 \quad Pm2 = 0 \ [\%], \tag{25}$$

$$Pm3 = 100(1 - s)^{2.47} \ [\%], \tag{26}$$

$$Pm4 = 100 - (Pm1 + Pm2 + Pm3) \ [\%], \tag{27}$$

- for the afternoon half-days by:

$$Pa1 = 100(0.62s - 0.77s^2 + 1.26s^3) \ [\%], \tag{28}$$

except if $s > 0.97$, then $Pa1 = 100$

$$\text{if } s = 0 - 0.5, \text{ then } Pa2 = 100s(1.2 - 1.6s) \ [\%], \tag{29}$$

$$\text{if } s = 0.5 - 0.93, \text{ then } Pa2 = 46.51(0.93 - s) \ [\%], \tag{30}$$

$$\text{if } s > 0.93 \ Pa2 = 0 \ [\%], \tag{31}$$

$$Pa3 = 100(1 - s)^{2.7} \ [\%], \tag{32}$$

$$Pa4 = 100 - (Pa1 + Pa2 + Pa3) \ [\%]. \tag{33}$$
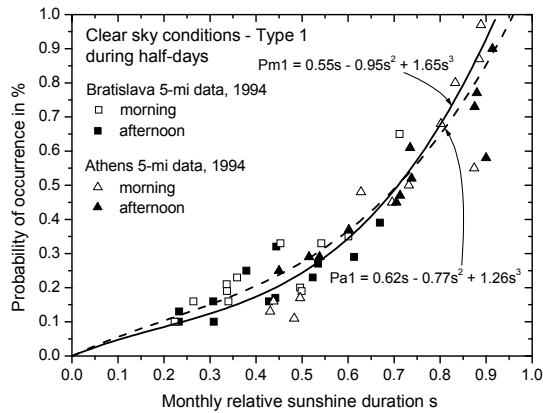
Fig. 37. Relation of clear situation to monthly relative sunshine duration in Bratislava and Athens
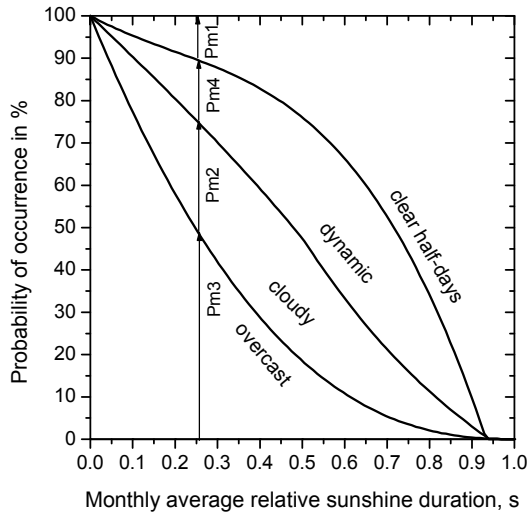
Fig. 38. Occurrence probability of half-day situations during mornings
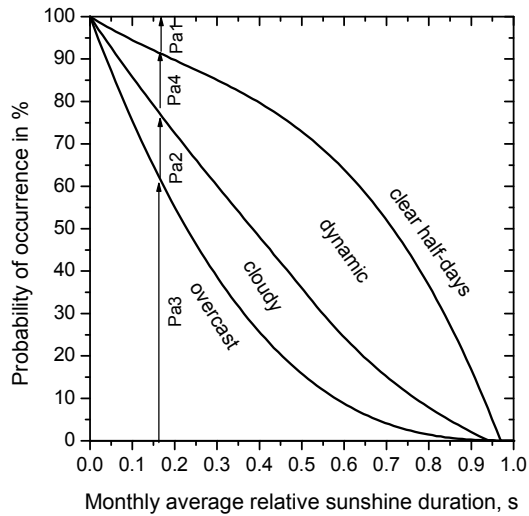
Fig. 39. Occurrence probability of half-day situations during afternoons

These probabilities of the occurrence of typical four daylight situations were derived from measurements in two different climate zones, i.e. in Bratislava as well as in Athens. So, it can be assumed that the dependence on monthly sunshine durations during morning and afternoon half-days could be valid not only in Central Europe and European Mediterranean regions but also world-wide.

5. Approximate redistribution of the four daylight situations in the yearly simulation of their occurrence

In accordance with the probability study of the four daylight situations in Bratislava morning and afternoon data during 1994-2001 the check was done using Athens data gathered in a five year period 1992-1996 (Darula et al., 2004). Because the calculated probability had to be substituted by a concrete number of days within a particular month, i.e. in integer numbers, these had to correspond with sum of half-days in that actual month. The redistribution into half-days had to dependent also on the overall monthly sunshine duration, so the redistribution model correlating the probability percentage and number of half-day situations had to be found. The best fit final solution is documented for the morning redistribution model with results shown in Fig. 40 as well as for afternoon in Fig. 41 with monthly relative sunshine duration data measured during mornings *sm* and measured during afternoons *sa.*
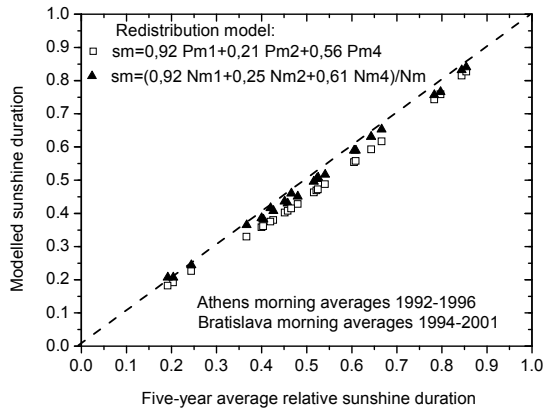
Fig. 40. Redistribution model after Bratislava and Athens morning data
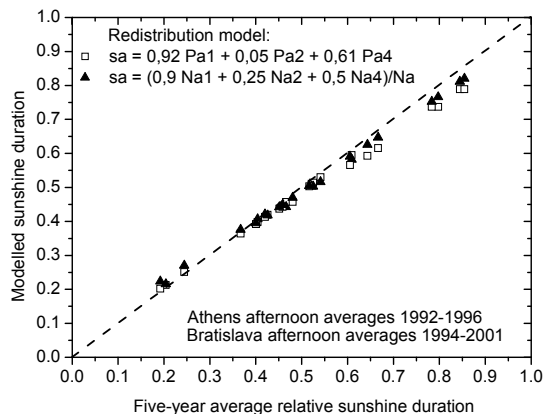
Fig. 41. Similar redistribution for afternoon half-days

In these figures besides the probability percentage notation $Pm1 - Pm4$ and $Pa1 - Pa4$ a similar notation for the number of half-days is used $Nm1 - Nm4$ and $Na1 - Na4$ while the overall number of morning half-days in a particular month is Nm for mornings and Na for afternoons in Fig. 40 and 41. These document and confirm the redistribution model that approximates the participation of the main three situations on sunlight presence and monthly sunshine duration within the particular half-day assuming that the overcast half-day is absolutely without any sunshine, thus

$$sm = (0.92Nm1 + 0.25Nm2 + 0.61Nm4) / Nm ,$$ (34)

and

$$sa = (0.9Na1 + 0.25Na2 + 0.5Na4) / Na .$$ (35)

This redistribution of half-day situations during mornings and afternoons was calculated for Bratislava and Athens data and as examples are shown in Table 2 and 3 only those for morning half-days. Although the verification of these redistributions for other localities is rather complicated it is evident that the ranges of mornings sm and those measured during afternoons sa can be in every month specific too. While during overcast situations the range of $s \leq 0.05$ is relatively small with G_v / E_v within the spread 0.05 - 0.35 (Fig. 35 and 36), the s ranges in dynamic situations are quite large i.e. 0.3 – 0.76 while Gv/Ev spread is approximately within 0.32 – 0.61.

Thus eq. (34) and (35) characterise the redistribution of sm and sa due to four half-day situations simulating Central European and Mediterranean daylight conditions. In other climate regions (like maritime and equatorial) or during rainy (April or May) or during monsoon months more general relations might be valid as

$$sm = (sm1Nm1 + sm2Nm2 + sm4Nm4) / Nm ,$$ (36)

and

$$sa = (sa1Na1 + sa2Na2 + sa4Na4) / Na .$$ (37)

Therefore in the application of this redistribution it is recommended to test whether the sm and sa for appropriate situations are within their usual ranges. Approximately this is done by checking $sm4$ and $sa4$ ranges after eq. (34) and (35). During dynamic half-days both $sm4$ and $sa4$ should be in the range 0.3 to 0.75 to be related to the rise of G_v / E_v from 0.35 to 0.6 respectively.

For an example of such a check can be taken the ten-year (1995-2004) average of relative sunshine duration in Prague, which is for May $s = 0.502$. In the book by Darula et al., (2009) after percentage probabilities the number of four half-day situations was determined (on p. 64, Tab. 5.4.1) as follows:

$Nm1 = 8$, $Nm2 = 9$, $Nm3 = 6$ and $Nm4 = 8$ with the full number of morning half-days in May $Nm = 31$;

So, after eq. (34)

$$sm4 = \frac{sm\,Nm - (0.92Nm1 + 0.25Nm2)}{Nm4} = \frac{31(0.502) - \left[(0.92)\,8 + (0.25)\,9\right]}{8} = 0.744$$

Month	s	Pm1	Nm1	Pm2	Nm2	Pm3	Nm3	Pm4	Nm4	Nm	sm
1	0,204	8,67	3	22,90	7	56,92	18	11,51	3	31	0,207
2	0,404	17,59	5	30,41	9	27,85	8	24,15	6	28	0,382
3	0,367	15,55	5	30,13	9	32,32	10	22,00	7	31	0,365
4	0,466	21,70	7	29,73	9	21,23	6	27,34	8	30	0,460
5	0,541	28,08	9	26,01	8	14,61	5	31,30	9	31	0,517
6	0,522	26,29	8	27,28	8	16,15	5	30,28	9	30	0,504
7	0,525	26,57	8	27,08	8	15,90	5	30,45	10	31	0,508
8	0,609	35,53	11	21,46	7	9,83	3	33,18	10	31	0,589
9	0,426	18,95	6	30,33	9	25,38	8	25,35	7	30	0,408
10	0,420	18,57	6	30,37	9	26,04	8	25,03	8	31	0,416
11	0,244	10,16	3	25,59	8	50,11	15	14,14	4	30	0,244
12	0,192	8,23	3	21,98	7	59,06	18	10,73	3	31	0,207

Table 2. Redistribution of half-day situations according to Bratislava morning 8 – year data related to monthly average relative sunshine duration

Month	s	Pm1	Nm1	Pm2	Nm2	Pm3	Nm3	Pm4	Nm4	Nm	sm
1	0,451	20,62	6	30,02	9	22,74	7	26,62	9	31	0,436
2	0,480	22,76	6	29,38	8	19,89	6	27,98	8	28	0,451
3	0,516	25,75	8	27,68	9	16,66	5	29,91	9	31	0,496
4	0,643	39,95	12	19,19	6	7,85	2	33,00	10	30	0,631
5	0,666	43,23	13	17,65	5	6,66	2	32,45	11	31	0,653
6	0,797	67,02	20	8,89	3	1,95	1	22,14	6	30	0,766
7	0,844	77,95	24	5,75	2	1,02	0	15,29	5	31	0,832
8	0,854	80,45	25	5,08	2	0,86	0	13,60	4	31	0,841
9	0,783	64,03	19	9,83	3	2,30	1	23,85	7	30	0,757
10	0,605	35,04	11	21,73	7	10,08	3	33,15	10	31	0,589
11	0,458	21,11	6	29,89	9	22,03	7	26,96	8	30	0,430
12	0,400	17,36	5	30,40	9	28,32	9	23,92	8	31	0,386

Table 3. Redistribution of half-day situations according to Athens morning 5 – year data related to monthly average relative sunshine duration

which means that $sm4 = 0.744$ falls to the upper range 0.75, but $sm2 = 0.25$ is suspect due to probably more sunshine intervals in May. Under such conditions probably $sm4 = 0.61$ as in eq. (34) and in May $sm2$ is higher:

$$sm2 = \frac{31(0.502) - \left[(0.92)\,8 + (0.61)8\right]}{9} = 0.369 \; .$$

Similarly a November check can be done using $s = 0.195$ for Prague with $Nm1 = 3$, $Nm2 = 7$, $Nm3 = 18$ and $Nm4 = 2$ with the full number of morning half-days in November $Nm = 30$ where after eq. (34) is

$$sm4 = \frac{sm\,Nm - (0.92Nm1 + 0.25Nm2)}{Nm4} = \frac{30\,(0.195) - \left[(0.92)3 + (0.25)7\right]}{2} = 0.67$$

which suites the dynamic range and is quite close to the assumed sm4 = 0.61.

In accordance with the already approximated monthly averaged values G_v / E_v in Fig. 33, 35 and 36 as well as D_v / E_v in Fig. 34 can be simulated also roughly half-day illuminance courses as

$$G_v = \frac{G_v}{E_v}\left(LSC \in \sin \gamma_s\right) \; [\text{lx}], \tag{38}$$

where

$$G_v / E_v = 0.182 + 1.038\,s - 1.385\,s^2 + 0.883\,s^3 \; [\text{-}], \tag{39}$$

and

$$D_v = \frac{D_v}{E_v}\left(LSC \in \sin \gamma_s\right) \; [\text{lx}], \tag{40}$$

where

$$D_v / E_v = 0.182 + 0.693\,s - 0.759\,s^2 + 0.126\,s^3 \; [\text{-}]. \tag{41}$$

It is evident that the course distribution of illuminances is caused by the sine of the solar angle with either the momentary sine value for the moment or for the chosen time interval. This sine of the solar altitude γ_s after eq. (2) for any hour number H during daytime in *TST* can be used. For a short time period a straight-line interpolation can be applied when $H = (H_1 + H_2) / 2$ or a value after eq. (16) is more precise.

A further possible step to specify the site and situation dependent illuminance stimulated a study that would show the relation of the four situations on typical sky patterns or ISO (2004)/CIE (2003) standard general skies if possible. Originally these standards were derived with the specification of indicatrix and gradation function in Kittler (1995) and finally recommended for standardisation in Kittler et al., (1997).

After a detail number of 5-minute measured cases in Bratislava specifying every year within the five year 1994 - 1998 span all four daylight situations were analysed with the following results:

1.   under *situation 1* were present
-     during mornings over 75% of clear sky types 11, 12 and 13 with the prevailing 32.55 % of sky type 12,

-     during afternoons over 76 % sky types 10, 11 and 12 with the prevailing 34.48 % of sky type 12,
2.   under *situation 2* were occurring
-     during mornings almost 50% of cloudy sky types 2, 3 and 4 with the prevailing 18 % of sky type 3,
-     during afternoons over 46 % sky types 2, 3 and 4 with the prevailing almost 17 % of sky type 3,
3.   under *situation 3* were present
-     during mornings almost 72% of overcast sky types 1, 2, and 3 with the prevailing almost 27 % of sky type 2,
-     during afternoons over 70 % sky types 1, 2, and 3 with the prevailing almost 27 % of sky type 2,
4.   under *sitation 4* were very changeable sky patterns, but the most present were
-     during mornings almost 40 % sky types 11, 12 and 13 with the prevailing over 15 % of sky type 12,
-     during afternoons almost 38 % sky types 11, 12 and 13 with the prevailing almost 15% of sky type 12.

This sky type prevalence (Darula & Kittler, 2008a) was in coherence considerably also with the seasonal frequency of dominant sky types found in the seasonal distribution (Kitttler et al., 2001) with prevailing overcast skies in type 2 and 3 and clear sky types 12 and 11 in Bratislava, while in Athens the highest frequency of clear polluted sky type 13 was documented, while uniform cloudy skies 5 and 6 were the most often occurring in dull seasons. Of course, the seasonal changes in occurrence frequency of clear and overcast skies is linked with relative sunshine duration and therefore with the number of half-days in any locality. However, it is interesting that in any daylight climate there exists a number of (Lambert) overcast sky type 5 with uniform luminance sky patterns, e.g. in Bratislava five year long-term these represented 12.6 % whithin cloudy *situation 2* during morning half-days and over 14 % during afternoons whithin overcast *situation 3* these were represented by morning 8.08 % and afternoon 7.74 % presence.

More and further measurements in different locations are expected to demonstrate the site-specific and short-term variability of illuminance levels (as recently was shown for irradiance by Perez et al., 2011). Due to dynamic situations it is important to evaluate short-term (momentary 1 or 5-minute regular measurements) because estimations of using hourly insolation data from satellite-based sources can be problematic and less accurate when subhourly variability is uncertain and especially if irradiance data are recalculated via luminous efficacy into illuminances (Darula & Kittler, 2008b). Therefore long-term regular measurements in absolute illuminance values are so important to have site-specific fundamental data with the possibility to derive also half-day situations. When modelling year-round situation frequencies it is also important to randomly distribute also some sequential ocurrence of specific situations (Darula & Kittler 2002) which can occur several half-days or even days after each other as is documented in Table 4 and 5. Of course, one situation can last during the whole day, i.e. the morning situation is the same in the afternoon, but quite frequent are also changes from clear to dynamic or cloudy to dynamic and vice versa especially in summer as shown in Table 4. In winter are typical lasting same situations except dynamic in two adjacent days, while in summer all consecutive days with the same situation are quite often except overcast.

Situation sequence		Winter		Summer		Spring and autumn	
Morning	Afternoon	Number of cases	%	Number of cases	%	Number of cases	%
Clear	Clear	44	10,35	55	12,20	52	11,38
Cloudy	Cloudy	82	19,29	56	12,42	81	17,72
Overcast	Overcast	55	12,94	1	0,22	11	2,41
Dynamic	Dynamic	29	6,82	56	12,42	62	13,57
Clear	Cloudy	13	3,06	20	4,44	13	2,85
Clear	Overcast	2	0,47	0	0,00	0	0,00
Clear	Dynamic	30	7,06	109	24,17	65	14,22
Cloudy	Clear	15	3,53	6	1,33	12	2,63
Cloudy	Overcast	18	4,24	2	0,44	4	0,88
Cloudy	Dynamic	55	12,94	75	16,63	70	15,32
Overcast	Clear	0	0,00	0	0,00	0	0,00
Overcast	Cloudy	28	6,59	0	0,00	3	0,66
Overcast	Dynamic	5	1,18	0	0,00	3	0,66
Dynamic	Clear	23	5,41	31	6,87	36	7,88
Dynamic	Cloudy	25	5,88	40	8,87	45	9,85
Dynamic	Overcast	1	0,24	0	0,00	0	0,00
Sum of cases		425	100	451	100	457	100

Table 4. Occurrence of daylight situations with typical sequences in one whole day

Situation sequence		Winter		Summer		Spring and autumn	
Morning	Afternoon	Number of cases	%	Number of cases	%	Number of cases	%
Clear	Clear	13	13,27	18	21,95	20	19,05
Cloudy	Cloudy	39	39,80	14	17,07	26	24,76
Overcast	Overcast	24	24,49	0	0,00	3	2,86
Dynamic	Dynamic	3	3,06	14	17,07	18	17,14
Clear	Cloudy	0	0,00	2	2,44	0	0,00
Clear	Overcast	0	0,00	0	0,00	0	0,00
Clear	Dynamic	3	3,06	13	15,85	14	13,33
Cloudy	Clear	3	3,06	0	0,00	0	0,00
Cloudy	Overcast	1	1,02	0	0,00	0	0,00
Cloudy	Dynamic	7	7,14	10	12,20	15	14,29
Overcast	Clear	0	0,00	0	0,00	0	0,00
Overcast	Cloudy	2	2,04	0	0,00	1	0,95
Overcast	Dynamic	0	0,00	0	0,00	0	0,00
Dynamic	Clear	1	1,02	3	3,66	2	1,91
Dynamic	Cloudy	2	2,04	8	9,76	6	5,71
Dynamic	Overcast	0	0,00	0	0,00	0	0,00
Sum of cases		98	100	82	100	105	100

Table 5. Repetition of four half-day situations in conscutive two days

6. Conclusions

Architectural and building science tries to gather and apply available human knowledge for the complex, aesthetic and functional creation of sophisticated habitable and healthy spaces with best environmental qualities encompassing shelter for human live, relaxation and work activities. Of course, the urban and structural objects with different interior spaces in their architectural plans and building forms have to respect natural conditions in various geographical locations, topography, local life stile and culture with trials for optimal solutions according to requirements concerning human health and prosperity, investor tendencies, investment and maintenance costs. To satisfy a complex sum of conditions, needs, codes and standards summarised by inhabitants, investors and national institutions leads to relatively simple and realistic criteria with a reasonable and experience-based background including simplified scientifically sound knowledge.

In case of utilising insolation and daylight conditions the traditional daylight science and technology is facing novel approaches and more real enhancements. In this sense are questionable also some older daylight criteria that were still recently used since the first calculation simplifications derived in the 18th Century. The Daylight Factor, Sky factor and Sky Component of the Daylight Factor used as basic criteria in various standards assume the existence of the unit uniform sky luminance after Lambert (1760). Although such Lambert uniform skies exist world-wide these do not represent typical sky luminance patterns in any site-specific conditions especially in subtropical, tropical and equatorial regions where mostly clear sky luminance distributions prevail that cause skylight illuminance conditions added frequently by sunlight.

This study tries to show and document that site-dependent daylight illuminance levels and their changes have to be expected in short-term, half-day, monthly or yearly variations in a realistic range under four typical half-daily situations. These situations can be classified with respect to relevant parameters which are dependent on extraterrestrially available illuminance reduced by atmospheric optical depth and air mass, turbidity and cloudiness conditions in site-specific variability. For practical purposes the probability of occurrence frequency of a particular half-day situation is related to the half-day or monthly relative sunshine duration which in absence of special measurements is available from many meteorological records world-wide. These monthly relative sunshine duration data can serve to estimate the local number of morning and afternoon half-day situations in any month and model their year-round expectance. Following this aim all data and figures after Bratislava and Athens CIE IDMP regular measurements can be considered as examples documenting the parameterisation and applicability of the four half-day situation system.

Current saving energy policies are also directed towards utilising renewable energy and in this respect also daylighting can serve to reduce electricity consumption in artificial illumination of interiors. A more precise determination of half-day illumination levels within year–round balance of supplementary electric lighting will enable to control it more effectively. Thus, daylight as natural source can be applied for interior illumination respecting local sunlight and skylight availability.

7. Acknowledgement

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9

Energetic Willow (*Salix viminalis*) – Unconventional Applications

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1. Introduction

Salix viminalis (Common Osier, Basket Willow, Energetic Willow) is a plant belonging to the SRWC group (Short Rotation Woody Crops) (Borjesson et al., 1994; Christersson & Sennerby-Forsse, 1994). Such a qualification points out possible applications resulting from a fast growth and annual yield of biomass. The woody stems of *Salix viminalis* can be cut frequently and serve as burnable biomass. Therefore *Salix viminalis* wood is often called a "green fuel". In general, willows (genus *Salix*) are popular plants since more than 400 species occur in Nature (including *Salix viminalis*). Particularly, Northern Hemisphere is a natural region for different willow species bearing sometimes traditional and very unique names like Sageleaf Willow, Goat Willow, Pussy Willow, Coastal Plain Willow, Kimura, Grey Willow, Sand Dune Willow, Furry Willow, Heartleaf Willow, Del Norte Willow, American Willow, Drummond's Willow, Eastwood's Willow, Mountain Willow, Sierra Willow etc. The variety of willow species partly results from ease of hybrid formation by cross-fertile of particular *Salix* genotypes in a natural process and/or by planned cultivation. Table 1 contains systematic botanic classification of willows.

Kingdom	Plantae
Order	Malpighiales
Family	Salicaceae
Tribe	Salicaceae
Genus	Salix

Table 1. Botanic classification.

The differences between *Salix* species also consists in the morphology of willows i. e. scrubs and trees naturally occur. In practice moist soils and mild climate conditions suits perfectly the demands of willows.

2. Salix viminalis – Conventional applications

2.1 Energetic utilization

In the recent decades among all *Salix* genotypes particularly *Salix viminalis* gained most attention as a agriculturally cultivated plant due to its application as a green fuel. Several positive and negative aspects of such an application are summarized in table 2.

Positive arguments	Negative arguments
High fertility and yield High environmental tolerance Long exploitation of plantations Low labor consumption and advantageous year schedule on labor demand during cultivation Improvement of local economy Reduction of unemployment Diversification of energy resources Low capital consumption during vegetation High energetic effectiveness Reduced consumption of conventional fuels Environment friendly biomass utilization for energetic purposes Exploitation of lie fallows Efficient assimilation of heavy metals Possible cultivation on soils unusable for other crops Possible reclamation of deteriorated lands Constant price increase of fossil fuels Increase of ecological awareness of the society Financial support from EU and local institutions	High cost of plantation lodging Lost of financial fluency due to high cost of the preliminary stage of undertaking Difficult prediction of investment return Lack of integrated bio-energy consumer market High transportation cost from plantation Necessity of fast utilization after harvesting Better cost efficiency of coal originated energy Energy overproduction High cost of biomass agglomerate fabrication High volume of biomass High nitrogen content in fresh harvested biomass High moisture content in fresh harvested biomass Threats resulting form monoculture cultivation on large agriculture areas Unexpected weather and climate changes Damages caused by diseases and pests

Table 2. Selected positive and negative aspects of energetic willow (*Salix viminalis)* cultivation. Particular points in the table selected from the original content. Cited and translated after (Zabrocki & Ignacek, 2008).

Many of the above mentioned arguments result in fact from economic, social and political background. Thus, the cultivation of *Salix viminalis* may definitely find numerous supporters but also opponents. However, positive features of *Salix viminalis* cultivation must be kept in mind since they may help to solve some critical environmental and social issues. In some countries the cultivation and usage of Energetic Willow is at very limited level (Poland). Some sources claim (Bio-energia, 2008) that overall *Salix viminalis* cultivation area does not exceed 6000 hectares. The share of *Salix viminalis* wood burned as a fuel in the total mass of burnable fuels is only ca. 2% high. The situation has not changed significantly in the last period despite of competitive energetic (table 3) and economic (table 4) parameters of the fuel.

Fuel	Heat of combustion [GJ/1000 kg]
LPG	ca. 45
Fuel oil (light fraction)	ca. 42
Fuel oil (heavy fraction)	ca. 40
Black coal	ca. 27
Coke	ca. 25
Dry wood (incl. Energetic Willow)	ca. 19
Dry straw	ca. 15

Table 3. Heat of combustion of selected fuels. The content of the table selected from the original material and translated (Iso-Tech, 2011).

Plant	Plantation no.	Harvest frequency*	Dry biomass price	
			Netto [PLN** / 1000 kg]	Brutto [PLN** / 1000 kg]
Energetic Willow	8	1	367	491
		2	333	458
		3	253	356
Energetic Willow	9	1	346	447
		2	335	444
		3	247	337

*Harvest frequency: 1 – each year, 2 - every 2 years, 3 – every 3 years
**PLN – currency of Poland, 1 EUR = 4 PLN
Source: http://www.bio-energia.pl/

Table 4. Dry biomass prices in Poland. The content of the table selected from the original source and translated (Bio-energia, 2008).

Thus, 1000 kg of dry *Salix viminalis* wood offers amount of energy comparable to 700 kg of black coal of good quality. However, black coal mining is evidently associated with serious irreversible environmental damages what becomes more and more important issue nowadays. This is a next argument for increasing of biomass production and usage for energetic purposes. Energetic utilization of other plants from SRWC group like *Plantanus occidentalis, Liquidambar styraciflua, Pennisetum purpureum, Erianthus arundenaceum, Panicum virgatum, Ricinus communis, Hibiscus cannabinnis, Populus deltoids, Pinus elliottii, EucaIypytus amplifolis, Eucalyptus grandis,* or *Pinus taeda* is a much more rare case in the world scale and particularly in Europe where climate conditions are often the main limiting factor. In Europe, *Salix viminalis* wood seen as renewable source of "green fuel" has a one important competitor i. e. dry straw. Straw is a side product (ca. 20 billion kg per annum in Poland) of grains cultivation i. e. one of the most frequent agricultural activities (Gradziuk, 1999).

2.2 Environment protection - Phytoremediation
Phytoremediation of soil and waters is a task of numerous research projects and technological undertakings. Such attempts base on an unique feature of *Salix viminalis* i. e. the ability to effective uptake, deactivation and accumulation of relatively high amounts of

heavy metals without loosing its vitality. The efficiency of metal ion accumulation is extraordinarily high if compared to other plants and microorganisms. Therefore *Salix viminalis* is often called "hyper-accumulator". This point let to state that *Salix viminalis* is an unique plant among other energetic plants which mainly offer only a high growth rate and mass production but are poor metal ion accumulators.

Memon et al., 2001 citing other authors stated that retention of heavy metals may be accounted to one the below mentioned technologies (Salt et al., 1995; Pilon-Smits & Pilon, 2000):

1. Phytoextraction, in which metal-accumulating plants are used to transport and concentrate metals from soil into the harvestable parts of roots and above-ground shoots (Brown et al., 1994; Kumar et al., 1995).

2. Rhizofiltration, in which plant roots absorb, precipitate and concentrate toxic metals from polluted effluents (Smith & Bradshaw, 1979); Dushenkov et al., 1995).

3. Phytostabilization, in which heavy metal tolerant plants are used to reduce the mobility of heavy metals, thereby reducing the risk of further environmental degradation by leaching into the ground water or by airborne spread (Smith & Bradshaw, 1979; Kumar et al., 1995).

4. Plant assisted bioremediation, in which plant roots in conjunction with their rhizopheric microorganisms are used to remediate soils contaminated with organics (Walton & Anderson, 1992; Anderson et al., 1993).

In the case of *Salix viminalis* the process of metal ion accumulation proceeds through a root system and ion transport involving vascular tissues in stems and differentiated distribution in the whole plant body. Permeation of ions into roots is a typical way of efficient metal ion collection by *Salix viminalis*. This a basis for practical utilization of *Salix viminalis* for purification of various matrixes (soli, water, etc.) being in contact with roots of the plant. Planting of *Salix viminalis* on metal contaminated soils and/or bringing the plant in contact with contaminated waters lead to slow but constant removal of the metal impurities and finally remediation of soil and waters.

According to Baker & Walker, 1990 plants may follow three pathways when they grow on metal contaminated soils.

1. Metal excluders: aerial parts of these plants are free from metal contamination despite of high concentration of them in the soil and in the roots.

2. Metal indicators: such plants accumulate metals in their aerial parts and the concentration of metals depends on the metal content in the soil.

3. Accumulators and hyperaccumulators: These plants concentrate metals in their aerial part but the metal content in the tissues exceeds metal content in the soil. A plant capable to accumulate more than 0.1% of Ni, Co, Cu, Cr or Pb or 1% of Zn (despite of differences in metal content in the soil) in its leaves (dry mass) is called a hyperaccumulator. *Salix viminalis*, according to our earlier studies, may be accounted to the accumulators / hyperaccumulators category. Figs 1 and 2 present (Łukaszewicz et al., 2009) some of our results on the concentration of selected metal ions (Zn^{2+}, Cu^{2+}, Cr^{3+}) in different parts of *Salix viminalis* rods after a certain time of contact with water solutions of the ions.

Table 5 shows that example heavy metal ions (Cu^{2+}) penetrate all important parts of *Salix viminalis*. The ion penetration and the resulting copper accumulation increase with increasing concentration of Cu^{2+} in an artificial soil. Plants were incubated in complete

Knop's medium (Reski & Abel, 1985) containing copper salt at 0, 0.5, 1.0, 1.5, 2.0, 2.5, 3.0 mM stabilized with quartz sand in hydroponic pots. It is also visible that roots and rods (stems) i. e. plant parts responsible for metal ion transportation accumulate copper ions more intensively that new shots and leaves. The latter parts are rather a final location of metal ions and do not participate significantly in the ion transportation. Table 5 informs about biometric changes of the plants exposed to Cu^{2+} infiltration. The plants were still living but shots, leaves and roots underwent a gradual degradation consisting in reduction of mass and/or dimensions. Table 6 (Mleczek et al., 2009) considers the dependence between the kind of metal ion and its accumulation in different tissues. No strict correlation is visible except general tendency to intensive accumulation of cadmium and chromium.
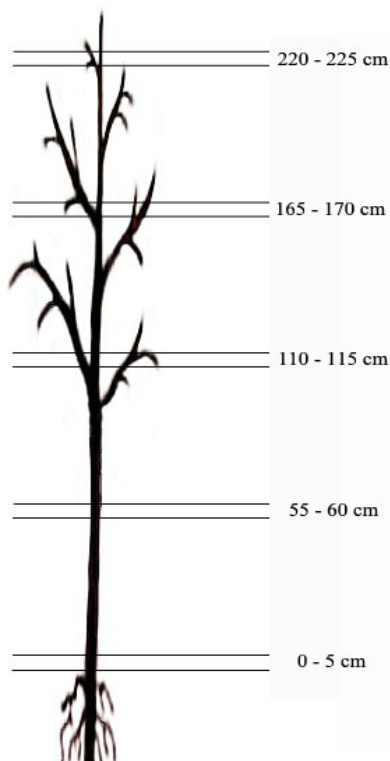
Fig. 1. Sampling wood material from *Salix viminalis* species planted in metal ions solutions. (Łukaszewicz et al., 2009).
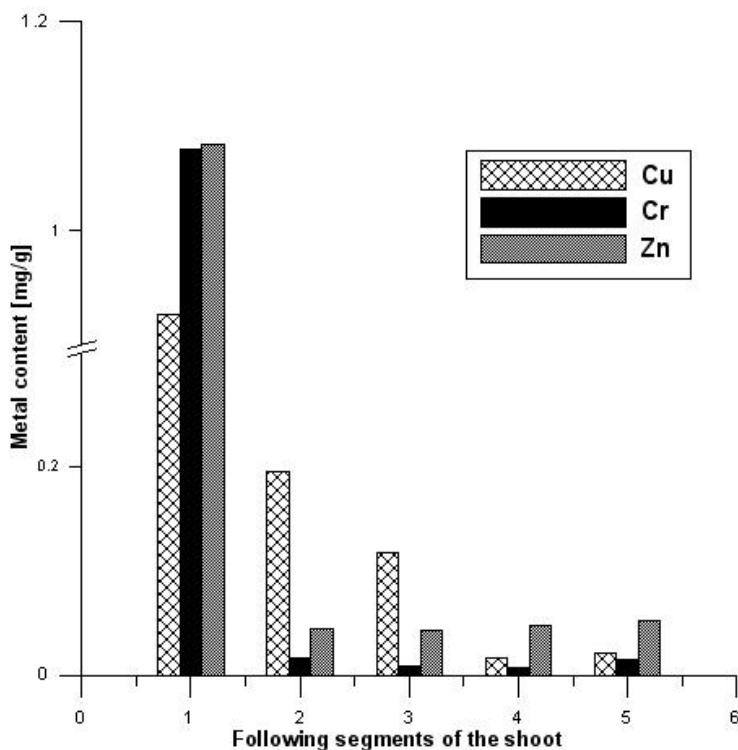
Fig. 2. Metal content in following segments of shoots (distance from rhizosphere: 1.1-5 cm; 2.55-60 cm; 3.110-115 cm; 4.165-170 cm; 5.220-225 cm). (Łukaszewicz et al., 2009).

During the experiment young shoots of *Salix viminalis* after defoliation were put into vessels with water and left until fresh leaves and root sprouted. Selected plants were moved to glass vessels filled with Cu, Cr and Zn salts solutions (0.01 M each). Additionally, chelation agent i. e. EDTA in water solution was added in the amount calculated basing on the assumption that EDTA was capable to form bichelates. According to some authors (Blaylock et al., 1997) plants should be more tolerant to chelated metal ions since after complexation their toxicity is lower. However, there is no common agreement about the positive influence of chelation on the metal ion uptake by *Salix viminalis*. After 7 days the plants were taken form the vessels and appropriate parts of stems (wood samples) were cut and subjected to elemental analysis (fig. 2). It is visible that metal ions enter the aerial part of *Salix viminalis* but the concentration of metals depends on the height above the ground level. Some studies point out differentiated distribution of metal ions in roots, stem, leaves etc. Tables 5 and 6 present such a kind of data (Gąsecka et al., 2010).

Cu addition [mM/dm³]	Cu accumulation (dry weight) [mg/ kg]				Leaves length [cm]	Total leaves surface [cm²]	Shoots length [cm]	Roots length [cm]	Roots biomass [g]
	Leaves	Shoots	Roots	Rods					
0	0.22	0.28	0.48	1.47	6.58	194.9	9.69	9.76	11.57
0.5	0.84	1.69	3.27	3.89	4.24	182.0	8.91	6.18	3.39
1.0	1.65	2.46	5.38	5.25	3.97	181.3	8.77	5.69	2.66
1.5	2.79	2.93	8.84	6.37	3.71	179.0	8.13	4.36	2.37
2.0	3.46	3.56	10.61	7.44	3.65	174.7	7.47	4.34	1.84
2.5	4.22	3.90	13.51	8.17	3.42	174.6	7.55	3.99	1.82
3.0	4.30	4.69	15.38	9.46	3.41	171.8	5.93	3.82	0.82

Table 5. Copper accumulation in *Salix viminalis* L. organs and biomass parameters for subsequent levels of copper addition to the growing medium – mean values (n=3). Selected data cited after (Gąsecka et al., 2010).

Tissue	Decreasing metal accumulation abilities of tissues (from left to Wright)						
Root	Zn	Cd	Pb	Cu	Co	Cr	Ni
Bark	Cu	Cd	Zn	Co	Pb	Cr	Ni
Leaf	Ni	Cr	Co	Zn	Pb	Cu	Cd
Petioles	Cd	Cr	Zn	Cu	Pb	Ni	Co
Shoot (0.1 m)	Cu	Cr	Zn	Cd	Pb	Ni	Co
Shoot (1 m)	Cd	Cr	Cu	Pb	Ni	Zn	Co

Table 6. Heavy metal accumulation in different tissues of *Salix* materials. The table content cited after (Mleczek et al. 2009) with no changes.

High metal ion accumulation is not an exclusive feature of *Salix viminalis*. Other *Salix* genotypes may exhibit high accumulation capacities towards different heavy metal ions (table 7) with particular emphasis on Zn^{2+} accumulation (Mleczek et al., 2010).

Salix genotype		Metal kontent in *Salix* genotypes [mg / kg] (dry mass)						
		Cd	Co	Cr	Cu	Ni	Pb	Zn
Salix purpurea var. Angustifilia Kerner	before	0.86	0.134	0.67	6.54	3.05	1.93	65.72
	after	1.48	0.218	0.94	7.88	8.45	2.15	70.02
Salix purpurea L. Nigra longifolia pendula	before	1.64	0.112	0.99	5.72	3.08	5.62	91.46
	after	1.75	0.240	1.27	6.73	9.28	6.07	96.34
Salix purpurea L. Green Dicks	before	2.19	0.050	2.29	7.94	4.66	2.16	57.19
	after	2.47	0.098	2.51	7.98	7.49	2.51	60.86
Salix purpurea L. Uralensis	before	1.77	0.058	1.91	7.01	4.18	1.11	58.33
	after	2.42	0.122	2.32	7.49	4.86	1.39	60.65
Salix alba L. Kanon	before	1.58	0.050	2.21	4.22	4.25	1.47	97.48
	after	1.87	0.095	3.04	6.47	8.44	1.53	103.21
Salix purpurea var. Schultze Schultze	before	1.87	0.054	0.55	8.12	3.74	1.93	94.28
	after	2.03	0.124	1.02	11.51	5.46	2.29	98.33
Salix fragilis L. Kanon	before	0.89	0.057	2.02	9.35	3.51	0.97	81.48
	after	1.06	0.129	2.47	10.87	7.75	1.27	84.79
Salix petiolaria Rigida	before	1.21	0.093	3.16	5.24	2.28	2.05	62.49
	after	1.58	0.174	3.78	8.89	5.46	2.40	68.92
Salix purpurea 233	before	1.57	0.026	1.61	7.13	1.97	2.88	91.37
	after	1.82	0.049	2.32	10.37	3.24	3.11	98.45
Salix nigra Marsch	before	0.61	0.036	0.59	8.26	6.42	1.42	102.47
	after	0.78	0.048	1.33	10.19	8.45	1.76	112.27
Salix japonica	before	1.51	0.069	2.74	6.79	3.68	2.07	84.25
	after	1.97	0.151	3.54	8.31	7.58	2.30	89.55
Salix purpurea Utilissima	before	0.47	0.037	2.07	4.71	1.19	1.41	37.91
	after	0.92	0.059	3.18	6.95	2.73	1.76	44.51

Table 7. Concentration of heavy metals in young shoots of 12 *Salix* genotypes before and after experiment (hydroponic estimation of heavy metal accumulation). Table cited after (Mleczek et al., 2010) with no changes.

Mechanism of heavy metal intrusion, transportation, deactivation and accumulation has been investigated intensively over many years (Shah & Nongkynrih, 2007; Memon et al., 2001; Lasat, 2001, Clemens, 2006). Fig. 3 illustrates the complex nature of the processes. Shah & Nongkynrih, 2007 recall several basic mechanism of metal ion assimilation among which chelating plays a crucial role. Many substances (chelators) occurring in plant cells contain typical chelating (ligand) atoms like oxygen, nitrogen and sulfur ones. Chelators contribute to metal ion detoxification. Other functional compounds called chaperones specifically deliver metal ions to organelles and metalrequiring. The principal metal chelators in plants are phytochelatins, metallothioneins, organic acids and amino acids. Shah & Nongkynrih, 2007 after some other authors state that phytochelatins are small metal-binding peptides which formation involves glutathione, homoglutathione, hydroxymethyl-glutathione or gamma-glutamylcysteine. Metallothioneins are low molecular mass cysteine (cys)-rich proteins, that

bind metal ions in metal-thiolate clusters. Over 50 metallothioneins has been identified so far in plants. Organic acids and amino acids because of N and O content may chelate intensively various metal ions. Shah & Nongkynrih, 2007 claim that "citrate, malate, and oxalate have been implicated in a range of processes, including differential metal tolerance, metal transport through xylem and vacuolar metal sequestration". Salicylic acid and its derivatives which are definitely present in *Salix viminalis* tissues, has been also identified as chelating agent in some plants. For *Salix viminalis* naturally high concentration of the latter species is probably the key factor providing hyperaccumulating properties of the plant.
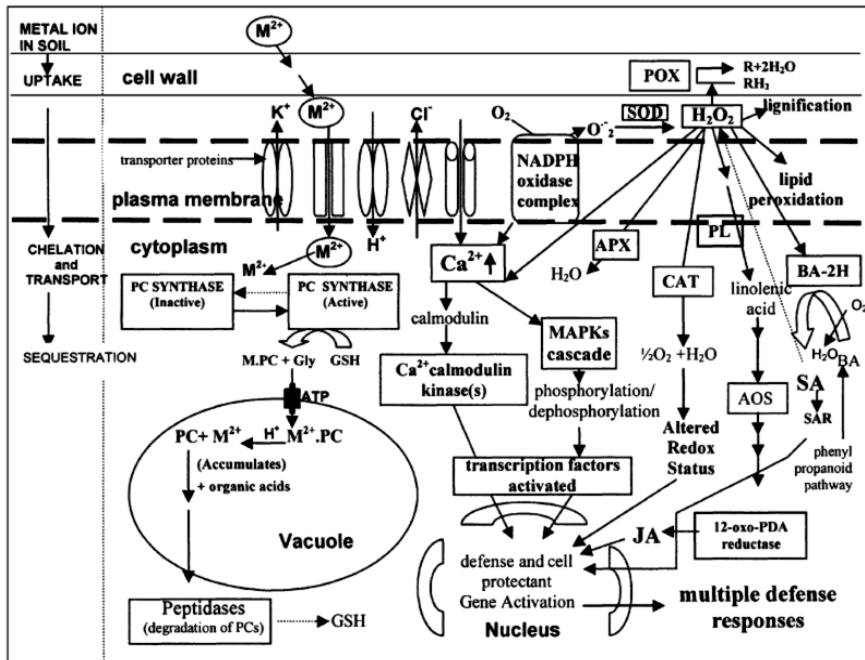
Fig. 3. A model of the mechanisms that occur in plant cell upon exposure to metals: metal ion uptake, chelation, transport, sequestration, signalling and signal transduction. The diagram shows the uptake of metal ions by K+ efflux and transporter proteins, their sequestration by formation of PCs by enzyme PC synthase and GSH in vacuoles, the subsequent degradation of PC-peptides by peptidases to release GSH, the generation of ROI species, the contribution of Ca^{2+} towards activation of Ca^{2+}/calmodulin kinase(s) and MAP kinase(s) cascade leading to defense gene activation in nucleus, the effect of ROI on natural plant defense pathways like octadecanoid pathway (JA) and phenyl propanoid pathway (SA) biosynthesis that lead to defense and cell protectant gene activation is also included to correlate the induced metal stress defense with natural plant defense mechanism. AOS - allene oxide synthase; APX - ascorbate peroxidase; BA - benzoic acid; BA-2H - benzoic acid 2-hydroxylase; CAT - catalase; GSH - glutathione; JA - jasmonic acid; M^{2+} - metal ions; MAPK - mitogen activated protein kinase; 12-oxo PDA reductase - 12-oxo-cis-10,15-phytodienoic acid reductase; PC - phyochelatin; PL - phospholipase; POX - peroxidase; SA - salicylic acid; SOD - superoxide dismutase. The figure and the caption cited with no changes after Shah & Nongkynrih, 2007.

Memon et al., claim that the application of biological metal-accumulators and metal-hyperaccumulators for purification of soils and waters has several positive features like "low cost, generation of a recyclable metal-rich plant residue, applicability to a range of toxic metals and radionuclides, minimal environmental disturbance, elimination of secondary air or water-borne wastes, and public acceptance". The latter statement applies in full to *Salix viminalis*, too. Table 8 proves that Cd removal from soil is extraordinarily high (217 g/ha) if compared to other phytoaccumulators tested in the study (Porębska & Ostrowska, 1999). Also the concentration of the metal in dry *Salix viminalis* wood was very high (22.1 mg/kg) exceeding values found in our study Łukaszewicz et al., 2009.

Plant	Biomass [t / ha]	Metal content [mg / kg] (dry weight)	Metal removal [g / ha]
Thlaspi caerulescens	2.93	12.1	35
Alyssum murale	1.32	33.7	43
Salix viminalis	10.00	22.1	217
Potato – tuber	14.77	3.2	47
Barley – straw	4.95	2.4	12
Barley – grain	3.14	0.70	2
White clover	3.52	1.14	4

Table 8. Estimated removal of Cd with the biomass. Selected data cited and translated after Porębska & Ostrowska, 2009.

3. Unconventional application of *Salix viminalis*

3.1 Fabrication of adsorbents and catalysts

The above described proved efficiency in metal ion accumulation by *Salix viminalis* led to a novel concept of non-energetic use of the plant. In some earlier studies (Łukaszewicz & Wesołowski, 2008) authors have discovered that thermal treatment (oxygen free conditions) of dry *Salix viminalis* wood yields charcoals of a very original and potentially useful pore structure. Usually a two step procedure was applied:

- 1 hour long preliminary carbonization in an inert gas atmosphere at 600 ^{0}C,
- 1 hour long secondary carbonization in an inert gas atmosphere at a desired temperature ranging from 600 to 900 ^{0}C.

The pore structure of such obtained charcoals is characteristic because of a very narrow pore size distribution function (PSD) i. e. only pores of not differentiated dimensions contribute to the total pore volume (figs 4, 5 and 6). The calculated dimensions of pores let to call such fabricated charcoals "nanoporous Carbon Molecular Sieves" (CMS).
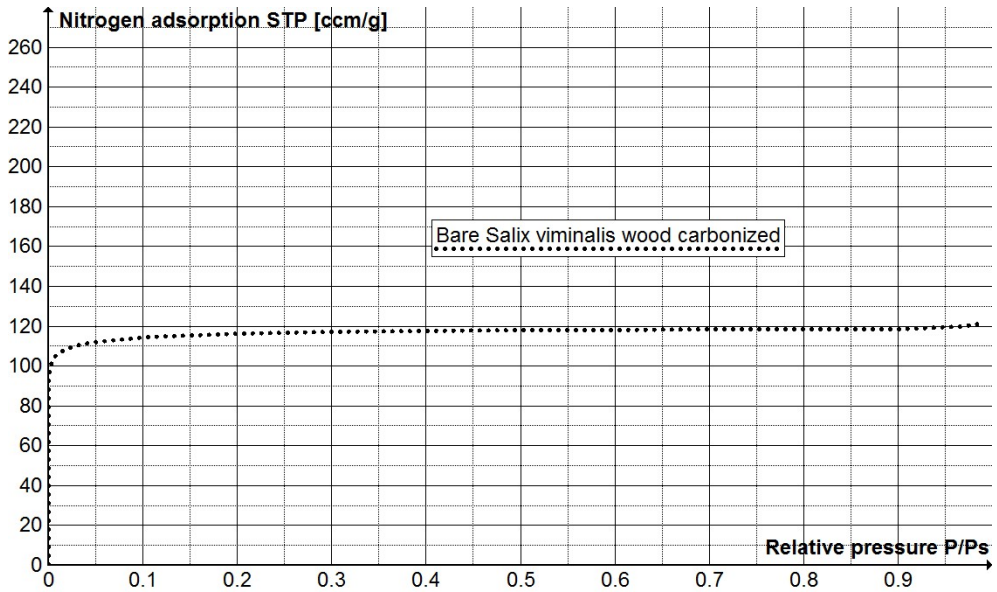
Fig. 4. Nitrogen adsorption isotherm at -196 ^{0}C for bare *Salix viminalis* wood finally carbonized at 700 ^{0}C. I type isotherm characteristic for the presence of nanopores.
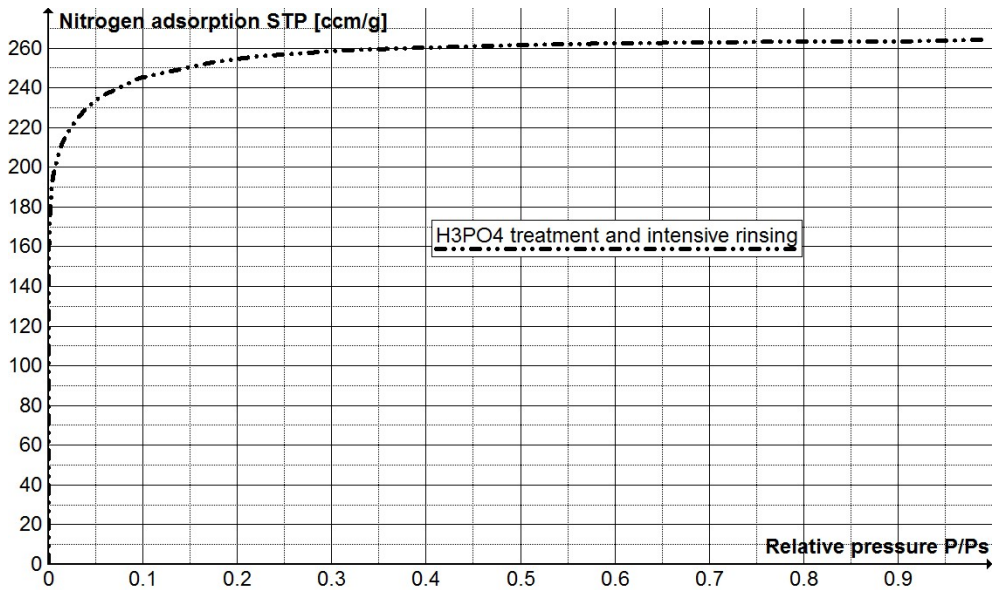
Fig. 5. Nitrogen adsorption isotherm at -196 ^{0}C for activated *Salix viminalis* wood (phosphoric acid treatment) finally carbonized at 700 ^{0}C. I type isotherm characteristic for the presence of nanopores.
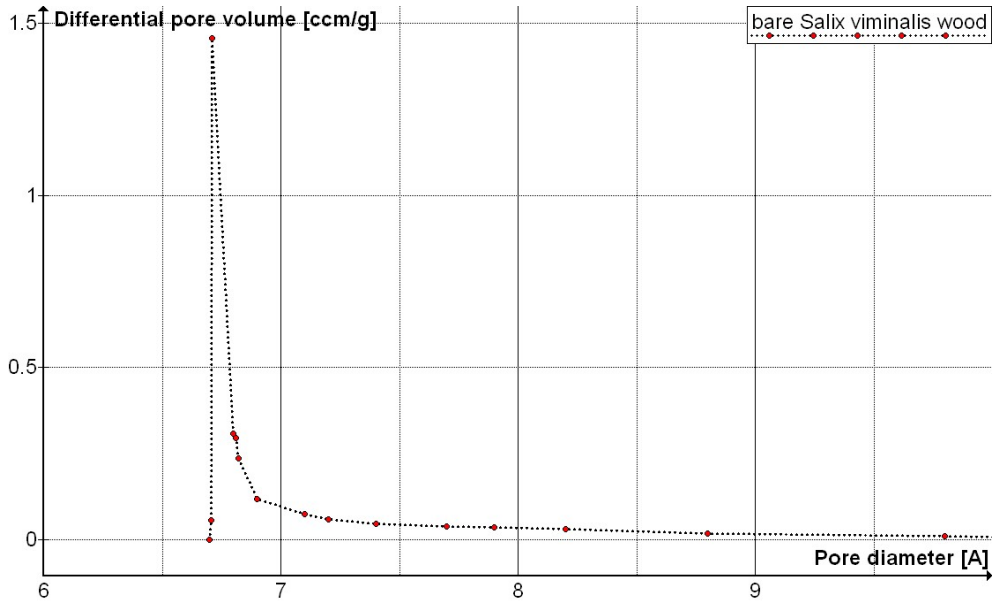
Fig. 6. Pore size distribution function (PSD) determined from low temperature (-196^{0}C) nitrogen adsorption data by means of Hortvath-Kawazoe method (Horvath & Kawazoe, 1983).

The *Salix viminalis* originated CMSs proved their sieving properties in gas mixture separation to single components in chromatographic conditions (Gorska, 2009). For example table 9 contains separation coefficients determined for N_2/CH_4 binary gas mixture over two example Salix viminalis originated CMSs of similar surface area. The separation is of industrial importance since natural gas resources are often contaminated by nitrogen which high content may reduce commercial value of methane. The values are dramatically bigger than 1 at all investigated temperatures i. e. 30, 40, 50, 60 and 70 ^{0}C. It is to emphasize that separation is very efficient at highest temperature of 70 ^{0}C. It is particularly important regarding a potential application of such carbons as and adsorbing bed in a PSA (Pressure Swing Adsorption) installation. In the PSA method, the first step consists in the compression of a gas mixture to be separated in the adsorbing chamber (filled with CMS). Gas compression is an exothermal process leading to the warming of gases and carbon adsorbent what is an undesired phenomenon since separation at high temperature is generally much worse since PSA separation of air is very temperature sensitive (Japan EnviroChemicals Ltd., 2011).

The described fabrication of CMSs does not exploit both unique features of *Salix viminalis* i. e. the unique ability of *Salix viminalis* biomass transformation into a CMS and the *Salix viminalis* ability to heavy metal ion accumulation. Both feature were exploited in the case of a series of hybrid carbon-metal oxide catalysts obtained according to the fabrication procedure proposed recently by Łukaszewicz et al., 2007. The novelty of the method consists in the exploitation of natural phenomenon of metal ion transportation in living plants for the introduction of a metal-based catalytic phase. Metal ions, after introduction to transport-responsible tissues in a living plant (*Salix viminalis*), are transported to the plant cells. The process was efficient since *Salix viminalis* was highly tolerant to the presence of heavy metal ions in its body. Freshly cut ca. 20 cm longs sections of a stem (rootless) of *Salix viminalis* were immersed (vertical alignment) in a water solution containing equimolar quantities of $La(NO_3)_3$ and $Mn(NO_3)_2$ (example concentrations: 0.001M, 0.01M, 0.1M). The stems were fresh enough to preserve intensive metal ion transport resulting in a gradual rise of the solution along the treated stems. A contrast dye was added to the solutions in some experiments to provide eye observation of the capillary rise of solutions along the treated stems. One the other hand, the length of stems was short enough to avoid differentiated distribution of metal ions in the stem what might be expected regarding some former tests (see figs 1 and 2). After the contact with La^{3+} and Mn^{2+} ion solutions, the metal saturated stems were dried, diminished and carbonized (600-800 °C, a two-step procedure) in an inert gas atmosphere (N_2). The first carbonization let to expel volatile species and to transform the wood (lignin-cellulose matrix) into carbon matrix (CMS resembling), consisting mainly of C, O, N and H atoms (Gorska, 2009). The next heat treatment (1 h, N_2 flow) at the temperature of 800 °C did not destroy already developed pore structure (preliminary carbonization) and, what is the most important, it enabled the transformation of introduced metal ions into the corresponding metal clusters. XPS and XRD analysis (Cyganiuk et al., 2010) proved that a complex oxide $LaMnO_3$ was synthesized from introduced ions. SEM and HRTEM investigations proved that the provskite-type oxide is present in such obtained samples in form of inorganic nano-crystallites suspended in carbon matrix, which in general was an amorphous material with few graphite nano-crystallites (figs 7 an 8).

Temp [°C]	Carbon 1 [S_{BET} = 312 ± 9.5 m^2/g]		Carbon 2 [S_{BET} = 358 ± 10.94 m^2/g]	
	Rs	± ΔRs	Rs	± ΔRs
70	3.64	0.31	4.80	0.75
60	3.55	0.24	4.71	0.26
50	3.74	0.62	4.91	0.19
40	3.83	0.53	5.25	3.52
30	4.17	0.34	5.87	0.01

Table 9. Separation factors determined the separation of N_2/CH_4 binary gas mixtures. Separating medium – *Salix viminalis* originated carbons. Specific surface area S_{BET} determined by BET method from low temperature (-196 ^{0}C) nitrogen adsorption. Calculated from data collected by Gorska, 2009.
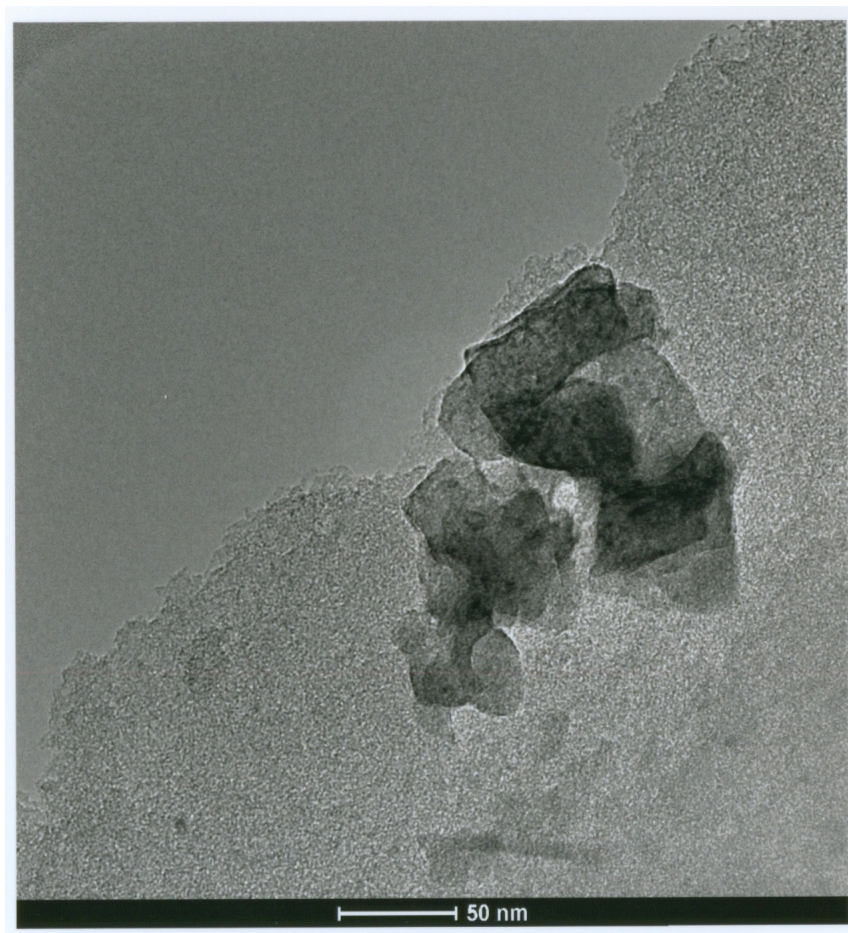
Fig. 7. HRTEM image of a LaMnO$_3$ crystallite embedded in the carbon matrix.
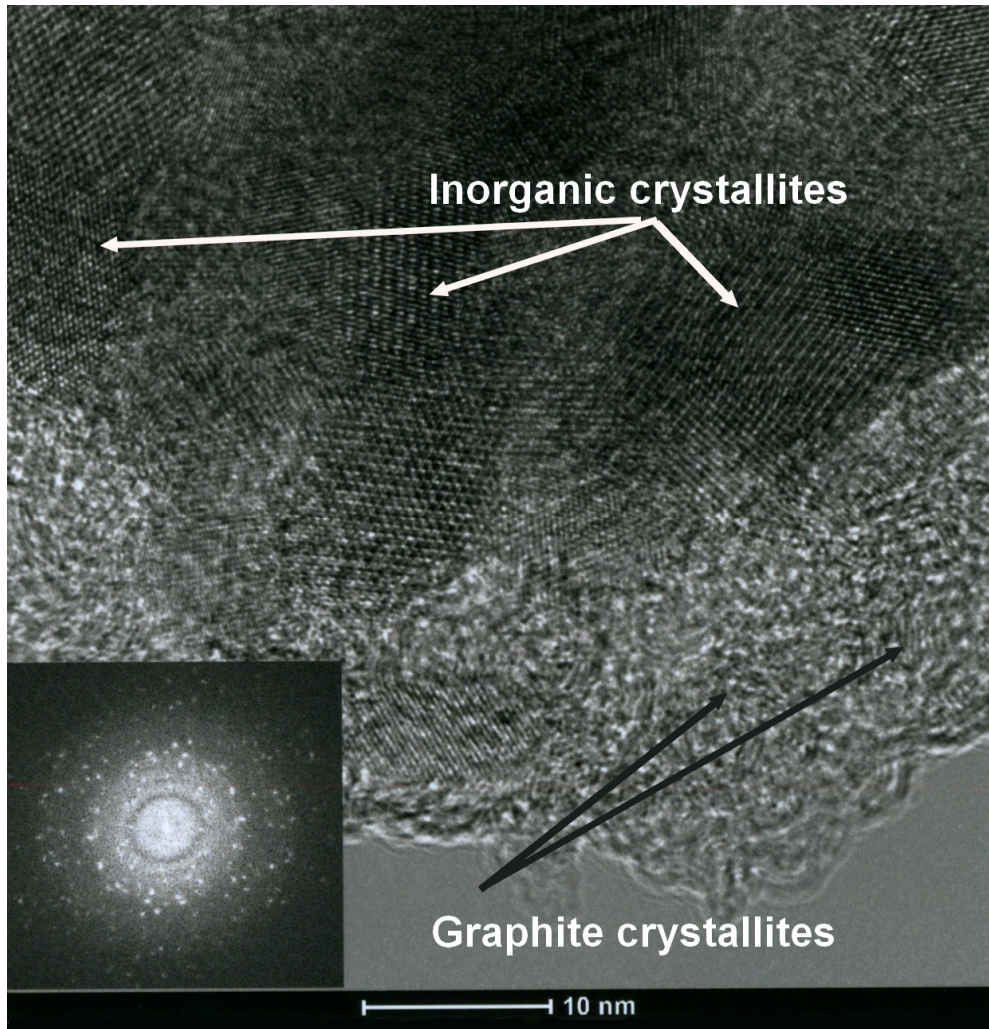
Fig. 8. HRTEM image of a LaMnO$_3$ crystallite embedded in the carbon matrix. Crystalline domains (graphite crystallites) visible in the amorphous carbon matrix.
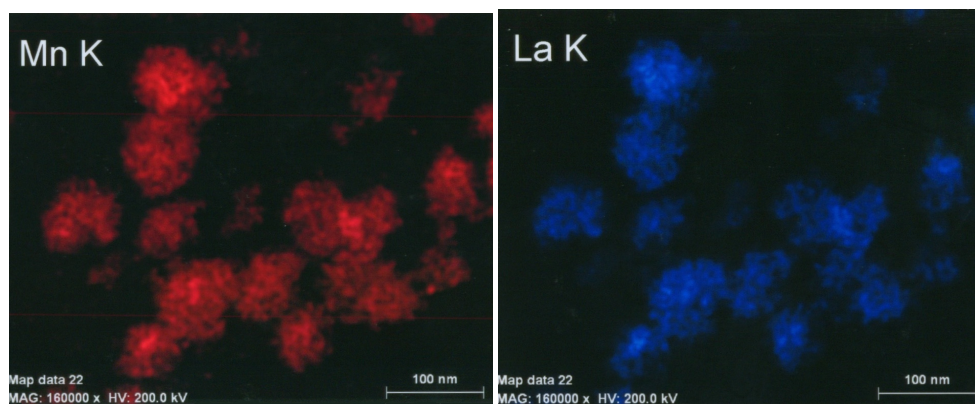
Fig. 9. Identical distribution of Mn (left) and La (right) atoms in hybrid C/LaMnO$_3$ catalyst.
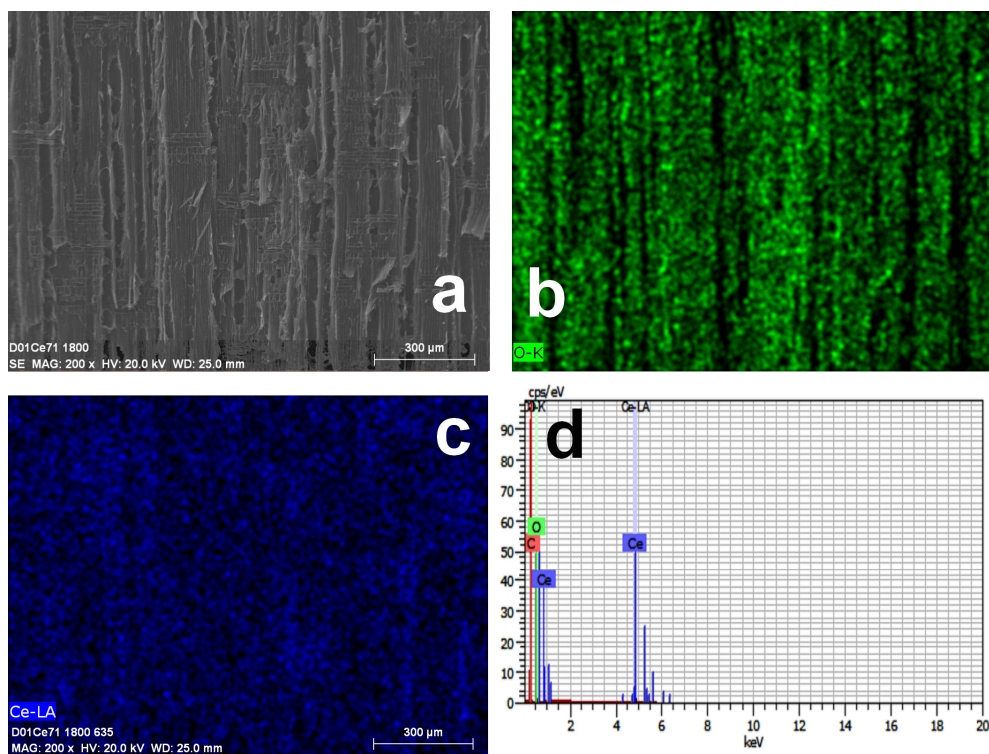
Fig. 10. SEM and SEM-EDS/EDX analysis of hybrid C/Ce catalysts obtained from *Salix viminalis*: a – SEM micrograph, b –distribution of oxygen atoms determined by SEM-EDS/EDX, c - distribution of cerium atoms determined by SEM-EDS/EDX, d – elemental analysis of the hybrid material.
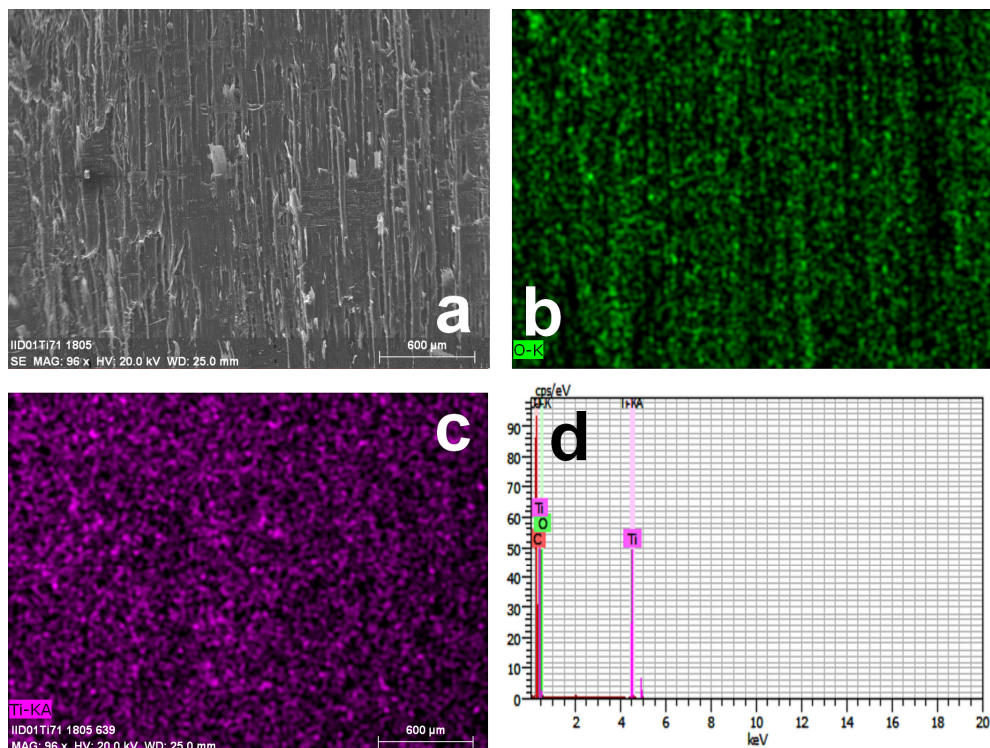
Fig. 11. SEM and SEM-EDS/EDX analysis of hybrid C/Ti catalysts obtained from *Salix viminalis*: a – SEM micrograph, b –distribution of oxygen atoms determined by SEM-EDS/EDX, c - distribution of titanium atoms determined by SEM-EDS/EDX, d – elemental analysis of the hybrid material.

Such obtained hybrid materials were tested as catalysts for n-butanol conversion to a 4-heptanone according to the reaction:

$$2\ RCH_2OH \rightarrow 2\ RCHO \rightarrow RCOR$$
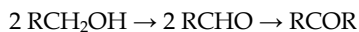
The catalysts exhibited very good catalytic performance despite very low concentration of the active component i. e. a perovskite-type oxide $LaMnO_3$ (atomic content below 1%). The noticed high activity i. e. yield and selectivity (Cyganiuk et al., 2010) resulted from very high dispersion of the active phase understood as:
- - reduced size of $LaMnO_3$ crystallites (10-100 nm),
- - uniform distribution of both metals in the carbon matrix (fig. 9).

Similarly, titanium and cerium based hybrid materials were obtained by exploitation of metal ion transportation in living parts of Salix viminalis (ca. 20 cm long stem sections). Figs 10 and 11 depict uniform distribution of Ce and Ti atoms in a carbon matrixes. Their occurrence is accompanied by oxygen atoms however the latter are a usual constituent of carbon matrixes and can not be exclusively associated with Ce and Ti in the form of metal oxides. Elemental analysis data definitely prove (figs 10 and 11) that Ce and Ti are present in investigated hybrid

samples and their presence result only from the performed fabrication procedure. The elements are relatively rare and have not been found in the samples of non-impregnated but carbonized *Salix viminalis* wood. Also in this case the atomic content of the metals is very low i. e. definitely below 1% despite of the concentration of impregnating solution. Thus, the proposed exploitation of metal ion transport in living parts of *Salix viminalis* ensures rather low level of impregnation but of very high dispersion. The Ti and Ce containing hybrid materials were tested as catalysts, too. Both materials despite of the same properties of carbon component of them, exhibited dramatically different catalytic activity:

-   Ti/C hybrids towards dehyration of n-alcohols (n-butanol conversion to butane, ca. 55% selectivity at 460 ^{0}C),
-   Ce/C hybrids towards ketonization of n-alcohols (n-butanol conversion to heptanone-4, ca. 75% selectivity at 460 ^{0}C).

The differences must by attributed to different catalytic properties of the active components of the hybrid materials i. e. to Ce and Ti derivatives (mixed oxides) which presence was proved by XRD, XPS and HRTEM measurements.

In summary, the proposed hybrid catalysts fabrication method is basing on two important and exclusive features of *Salix viminalis*:

-   high vitality preserving some living functions like metal ion transportation in fragments of a complete plant (single rod cut into 20 cm long pieces),
-   high tolerance of still living parts of *Salix viminalis* to heavy metal ions which enter the plant structure. We assume that toxic influence of the heavy metal ions is considerably reduced in the plant cells otherwise transportation of metal ions could be severely disrupted and finally terminated. During impregnation in most *Salix viminalis* samples (sections of rod) no visible morphological changes were observed and the 20 cm long sections retained their original olive-green color characteristic for its bark. Visible bulge and shrinkage did not occur.

The originality of the above presented concept let to submit patent applications (Łukaszewicz et al., 2006; Łukaszewicz et al., 2007).

3.2 Dry distillation of *Salix viminalis* wood

Fabrication of charcoals from *Salix viminalis* consists in the a heat treatment of the biomass in oxygen free conditions. In fact this process can be also called dry distillation w wood. However, usually distillation is run aiming at the collection of volatile products which evolve during heat treatment. Looking at charcoal fabrication (described above) from such a point view authors has decided to cool down (liquefaction) volatiles leaving heating zone of stove along with the stream of inert gas (nitrogen) passing through the stove. The condensate in form of a dark brown viscous liquid was collected in a glass beaker and subsequently subjected to several analysis. We assumed that the condensate is a mixture of numerous organic compound as in the case of wood tar obtained by dry distillation of other sorts of wood i. e. pine (Egenberg et al., 2002).

At the beginning we assumed that the collected tar must contain phenols and polyphenols which are created during thermolysis of lignin (de Wild et al., 2010). *Salix viminalis* wood contains ca. 20-24 % (by weight) of lignin in dry mass of wood (Mleczek et al., 2010). The distillate called biooil was subjected to some separation measures like extraction to isolate several fractions containing polyphenols. Polyphenols are a precious group of compounds mainly because of their antioxidant properties.

3.3 Polyphenols and other antioxidants

Free radicals play important role in the functioning of human organism (Grajek, 2007). However, their presence may be the reason of oxidative stress. The stress often results from disrupted balance between peroxidants and antioxidants in an organism. It is proven that high activity of free radicals and prolonged influence of oxidative stress are responsible for pathogenesis of nearly 100 diseases (Wolski, 2007) including Alzheimer and Parkinson diseases (Bartosz, 2008; Fitak & Grzegorczyk-Jaźwińska, 1999). During ageing oxidative damages in cells become more frequent with parallel reduction the activity of antioxidative enzymes. The situation becomes worse due to UV irradiation, environmental pollution, permanent mental stress and bad nutrition habits. Oxygen being the base of human existence is mainly available in it triplet form O_2^{**}. The electron configuration results in moderate chemical activity in contrast to other forms like $(O_2^*)^-$, HO_2^* and OH^*. The latter form is considered as the most reactive. Proper enzymes ensure control over 98-99% of all oxygen in a human body. However, the remaining amount of oxygen may undergo transformation (Fenton reaction, Haber-Weiss reaction) into the most reactive forms i. e. oxygen derivatives being free radicals. Daily up to 10 thousand DNA oxygen-related damages occur in a human body. The damages may be repaired by some specific enzymes but the introduction of antioxidants should reduce the threat. Therefore everyday diet has to be supplemented by natural antioxidants. Antioxidation properties of polyphenols may involve the three general mechanisms:

- direct expunge of reactive form of oxygen and nitrogen by two possible pathways: Single Electron Transfer (SET) or Hydrogen Atom Transfer (HAT). In such processes a polyphenol molecule transforms into a phenoxyl radical which after reaction with a next oxygen radical stabilizes as chinone like structure (fig. 12)
- chalation of transition metal ions (particularly copper and iron) which participate in the reactions leading to the formation of reactive radicals like the Fenton reaction involving Fe^{2+} ions and yielding dangerous hydroxyl radical OH,
- increasing of concentration of endogenous antioxidants and/or inhibition of enzymes stimulating the formation of free radicals.

Such positive chemical features of polyphenols turns peoples attention towards intensive search for sources of them and the development of methods of polyphenols separation from their natural matrixes for further enrichment of some products like pharmaceuticals, food, cosmetics etc. This way of thinking involves investigations on appropriate plants i. e. candidates for a subsequent chemical treatment like polyphenol extraction. According to some extended studies (Makowska-Wąs & Janeczko, 2004) polyphenols occur in many plants and plant originated products like herbs, needles of coniferous plants, algae, green tea leaves, eucalyptus wood, byproducts of olive, wine, yeast production. It is obvious that chemical exploitation of one source plant yields a limited number of polyphenols and search for other polyphenols needs a selection and a proper treatment of another source plants. It has to be stated that the polyphenol content in source plants is very differentiated but also very low. Table 10 informs about the antioxidant activity determined for 100 g of example fruits and vegetables. The highest activity is noticed for pure vitamins and synthetic antioxidants. However, the mentioned products owe their antioxidative activity not only due to the presence of polyphenols since other type of antioxidants may be present, too.
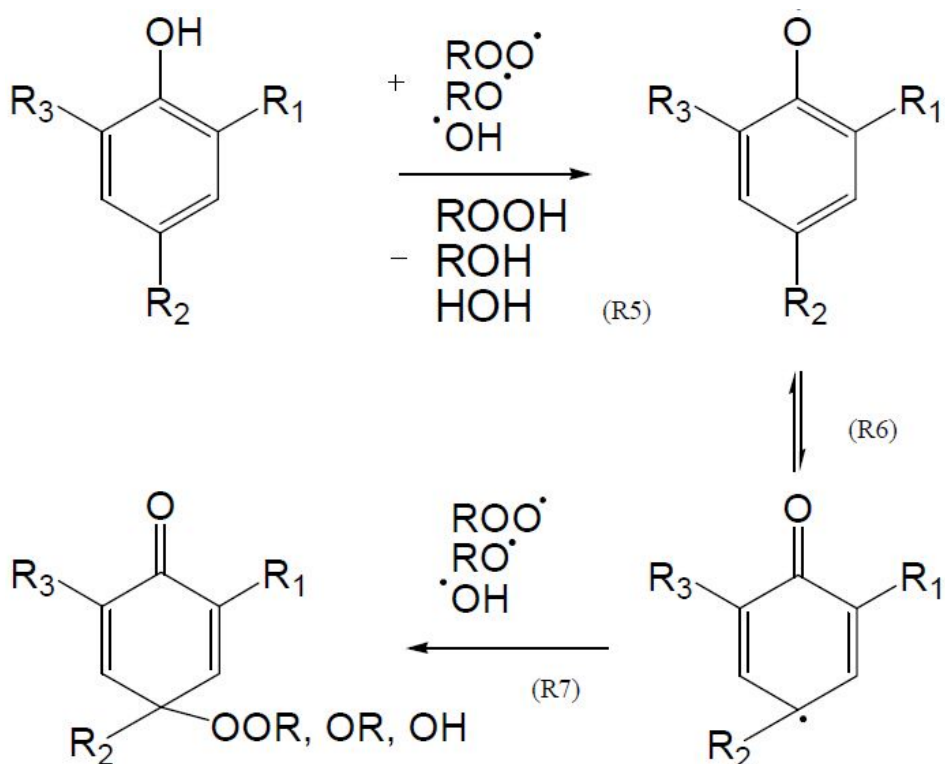
Fig. 12. Oxygen based free radical reaction with a polyphenol.

Obviously the above list is not closed and other natural and synthetic products may be addend and therefore search for other effective products is fully justified. Authors attention has turned towards chemical processing of some easily accessible and renewal resources. Our primary idea was to involve chemical processing not limited to the separation of already existing polyphenols (a passive approach) but also on treatments that transform original matter of low polyphenol content into a new product of high polyphenol concentration (active approach). Such a concept focused our attention on *Salix viminalis* again due to its inexpensiveness, renewal cultivation and high content of lignin which thermal treatment releases polyphenols. As the matter of fact *Salix viminalis* as a living plant contains some amounts of different polypneols like flavonoides (flavanols, flavones, flavonones, flawonone dimers, chalcones), phenolic acids, lignans, catechin and its derivatives as well as tannins (procyanidins, prodelfinidins) being derivatives of flavan-3-ols. Particular *Salix* species differ much regarding the total content of polypheneols (Nyman & Julkunen-Tiitto, 2005) and their type (Landucci et al., 2003).

For example *Salix caprea* contains variety of flavonoids and the lack of lignans (Pohjamo et al., 2002). Contrastly, for *Salix viminalis* characteristic are relatively low concentrations of flavonoids (Harborne & Baxter, 1999), moderate concentrations of lignans (Pohjamo et al., 2003) and high concentrations of tannins (Nikitina & Orazov, 2001).
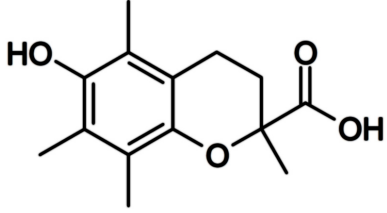
Food produkt	Antioxidant activity [TE/100 g]
Red Grapes	1350
Red Cabbage	1000
Broccoli Flowers	500
Spinach	500
Green Grapes	400
Tomato	300
Green Beans	175
Green Cabbage	150
Lima Beans	1055
Red Beans	11459
Blueberries	3300
Raisins	5900
Wheat Bran	4620
Wheat Flour (refined)	600
Substance	**Antioxidant activity [TE/100 g]**
Ascorbate	442 000
Trilox	400 000
Witamin E	201 000
BHT	395 000
TE – TRILOX Equivalent	TRILOX

Table 10. Antioxidant activity of selected food products, vitamins and synthetic antioxidants. Selected points cited after (Prakash et al., 2010).

The concentration of polyphenols in *Salix viminalis* depends also on the season of the year. t maximal concentration of flavonoids is reached during blossom while tannins concentration is highest in Autumn (Nikitina & Orazov, 2001). Long exposure of *Salix viminalis* to sunshine (UV radiation) additionally increases the content of compounds capable to neutralization of free radicals (flavonoids, phenolic acids, proantocyanidynes) and reduces the content of salicylic acid and its derivatives (Tegelberg & Julkunen-Titto, 2001). Thus, a proper cultivation of *Salix viminalis* and well planned collection of polyphenols by extractive methods may result in a better efficiency of the whole attempt. However, as mentioned earlier, the total contents of polyphenols is relatively low and therefore the mass of isolated antioxidants in relation to the mass of raw material is dramatically low. Thus, the contemporary chemical technology should not only rely on the Nature's productivity but also search for more effective methods of polyphenols fabrication instead of collection. The heat-treatment of *Salix vimanlis* wood yields three basic products (charcoal, biooil, biogas) but yield of each depends on heating rate as depicted in fig. 13).

As mentioned biooil formation is a result of lignin pyrolysis. Lignin is biopolymer (fig. 14) consisting of some characteristic units i. e. p-cumarol alcohol, coniferyl alcohol, synapine alcohol (fig. 15.) bonded by various organic bridges. Thus, the bonds may break at different point yielding a huge number of organic compounds including polyphenols. Volatile products evolve during heat-treatment with unequal intensity (fig. 16). The most intensive collection of liquid condensate is possible in the temperature range of 260-380 °C).
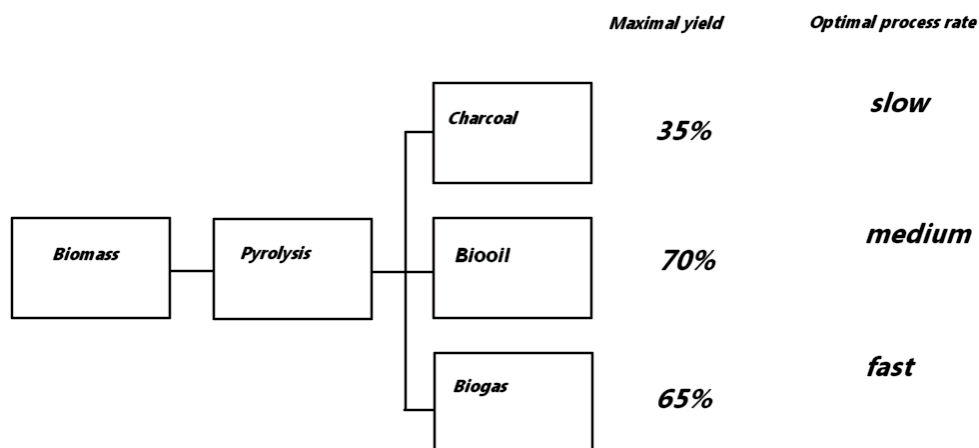
Fig. 13. Typical products of biomass pyrolysis. The influence of process conditions (heating rate, temperature) on yield of particular products.
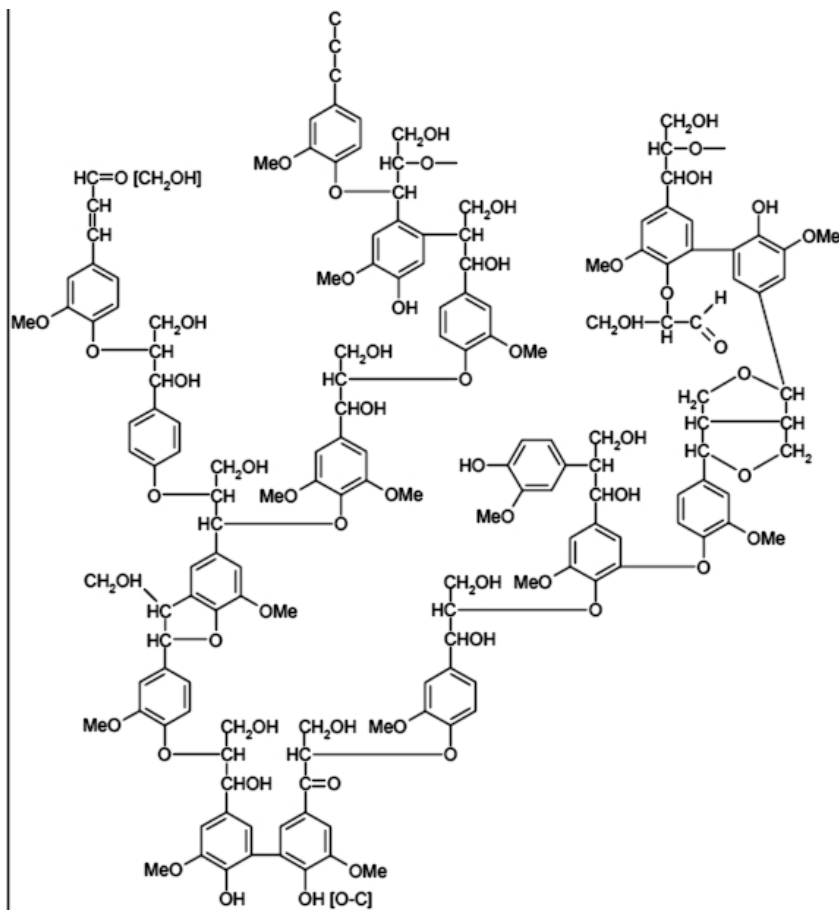
Fig. 14. Pattern structure of lignin.
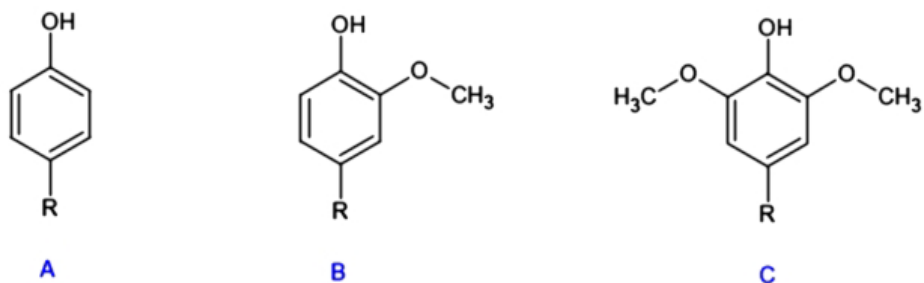
R= -H, -CH₃, -C₂H₃, -C₂H₅, -C₃H₅, -C₃H₇, -COCH₃, -C₃H₄OH, -CHO

Fig. 15. Structures of three phenolic alcohols being monomers in lignin: A – p-cumarol alcohol, B – coniferyl alcohol, C – synapine alcohol.
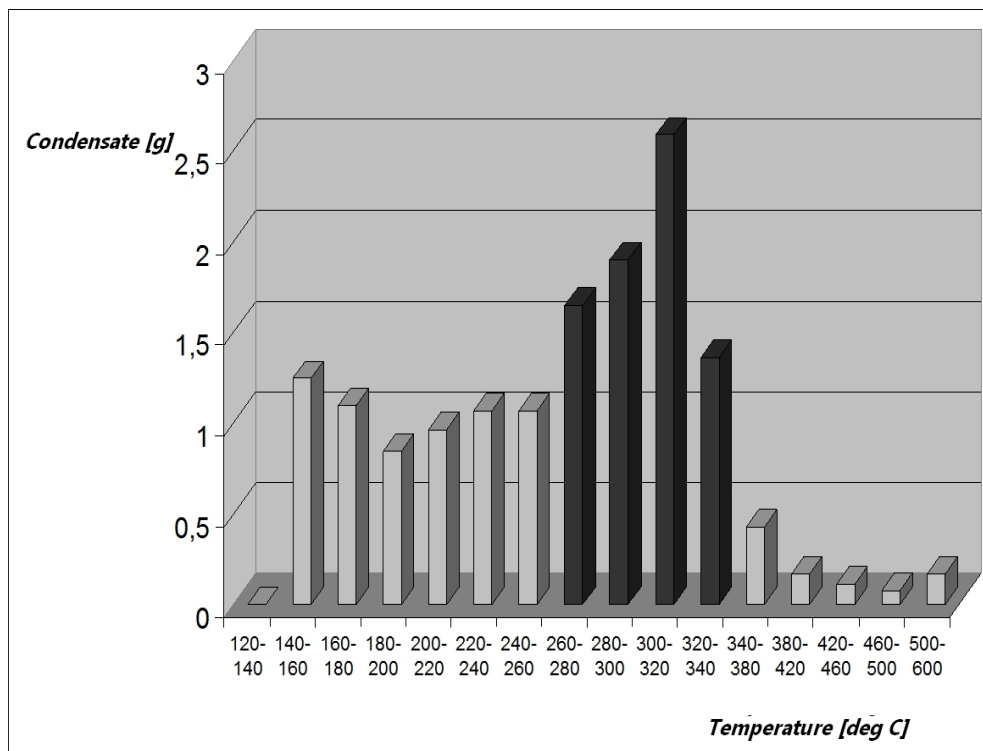
Fig. 16. The intensity of liquid condensate yield (biooil) at different temperatures.

The such collected fraction was considered as a raw biooil subsequently subjected to separation (extraction, chromatography) procedures and chemical characterization. Several instrumental methods were applied: gas chromatography GC-MS (Autosystem XL - MS Turbomass), nuclear magnetic resonance ^{1}H and ^{13}C NMR (700 MHz Bruker Avance) and infrared spectroscopy FT-IR (Perkin Elmer Spectrum 2000). Additionally the isolated fractions were tested as antioxidants according to ASTM 4871 standard (www.astm.org/Standards/D5770.htm, 2011). The latter procedure consists in the oxidation of a standard substance DBS (dibuthyl sebacate) in liquid phase at relatively severe conditions (150 ^{0}C, constant flow of air 100 cm^3/min). The oxidation may proceed in the presence (1000 ppm) of different protective antioxidants including separated fractions of raw biooil of *Salix viminalis* origin (dry distillation) and some commercially distributed antioxidants like BHT (2,6-di-tert-buthyl-p-cresol, buthyl hydroxy toluene, buthylated hydroxy toluene). BHT is widely used for the protection and stabilization of cosmetics and food products. The most promising results were achieved so far for two extracts called A and B (ethyl ether and dichloromethane extracts respectively).

The results of a complex analysis (GC-MS, NMR, FTIR, UV-VIS) of both extracts confirm that:

-      each extract contains ca. 50 different compounds which may exhibit antioxidative properties,

- most of the potential antioxidats are in fact derivatives of three organic structures (cumarol alcohol, coniferyl alcohol, synapine alcohol) which are claimed to be units of a the biopolymer occurring in *Salix viminalis* wood i. e. lignin (see text above); the compounds are released from the wood sample due to thermolysis of the biopolymer - lignin,
- the extract B contains more furan derivatives while the extract A contains more oxygen heterocyclic compounds.

The determination of the composition of the two preliminary extracts A and B has a certain chemical value but more important is to confirm if the extract theoretically consisting of antioxidant species can exhibit efficient antioxidant activity, what is the main motivation for this research. The absence of such activity could question the whole research attempt which from early beginning was focused on a practical aspects i. e. on the applicability of all products of the dry *Salix viminalis* wood pyrolysis. The preliminary hypothesis was confirmed by the performed controlled oxidation tests (fig. 17). It is visible that the addition of 1000 ppm of a commercial antioxidant i. e. BHT protects the test substance DBS for ca. 50 hours. After this time one observes increasing concentration of some oxidation products in the reaction chamber. In the same experimental conditions pure DBS undergoes instant oxidation without any significant protection time. The addition of the biooil extract B in the same proportion of 1000 ppm extends threefold the protection time. Thus, DBS was protected nearly for one week despite sever experimental conditions. It has to be stated that the protection times for much lower temperatures like room temperature must by very long.
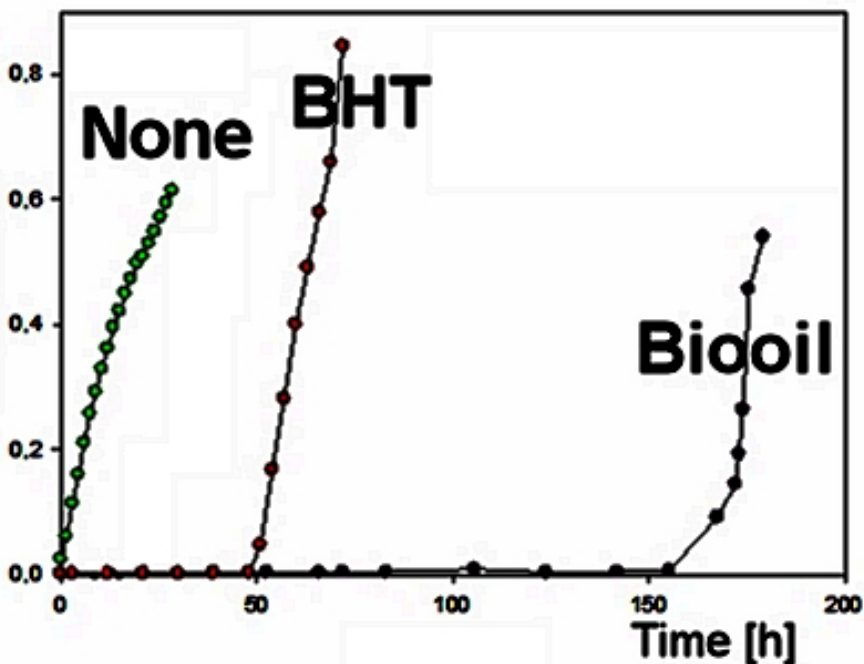
Fig. 17. Restraining of DBS oxidation by means of extract B and BHT.

4. Summary

The performer research program prove that *Salix viminalis* is a precious raw material for chemical treatment and it could not be seen only as a fuel for energetic utilization. Its practical value increases regarding that it is easily accessible as agriculture product. It grows fast with a good yield. *Salix viminalis* cultivation has a positive influence on the environment since their high mass productivity per hectare is definitely associated with CO_2 absorption from the atmosphere. The proposed elaboration method is nearly complete since all major products of the wood thermolysis i. e. solid (active carbon of CMS properties) and liquid (biooil containing antioxidants) may find a wide application in practice.

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Biomass Energy Conversion

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1. Introduction

The use of biomass as a source of energy varies in different countries and depends in part on the country's level of development. In many developing countries, biomass provides most of the basic energy needs, mostly as fuelwood, animal wastes or crop residues while in developed countries only a fraction of their energy requirement comes from agriculture and agro-industrial wastes. In the United States for example, biomass conversion amounts to about 3.25% of the energy supply (EIA, 2002 and Haq, 2002) while in Bhutan, the share of biomass energy in total energy use accounts for about 87% (Victor, and Victor, 2002).

Biomass resources could play a significant role in meeting the future energy requirements. However, the approach in their utilization should be carefully analyzed in view of diverse cultural, socio-economic and technological factors in a given locality. Agricultural and agro-industrial wastes can provide an inexpensive source of energy and effective low sulphur fuel. It could be processed into other fuels thereby reducing environmental hazards (e.g. biomass from sewage). Also, there is relative ease with which it could be gathered and generated. However, the conversion of light energy into biomass by plants is relatively of small percentage and there is relatively low concentration of biomass per unit area of land and water. The additional land for biomass production is getting scarce, and the high moisture content of fresh biomass makes collection and transport expensive. Thus, biomass energy conversion could be relatively inefficient. Moreover, extensive utilization of these resources may compete with the demand for these as food. These are some of the issues concerning the extensive utilization of biomass resources.

In view of the depleting forest and agricultural resources for energy use, attention should be focused on new and emerging technologies for their efficient conversion. There are a number of sources of energy for both rural or agricultural and urban or industrial residues. There is a need to diversify the traditional resources for energy to meet the demands. These include, among others: (1) planting high energy value crops, fast growing trees, sugar and starchy crops, aquatic plants, oil and hydrocarbon crops, and (2) getting energy from municipal sewage and solid wastes. Some common properties of biomass resources will be reviewed to gain perspective of biomass as a source of energy compared with traditional fossil fuel sources.

The primary advantage in the use of biomass as an energy resource is that it is a renewable feedstock and does not contribute to global warming.

2. Biomass properties and characterization

The important biomass properties include the following: (a) heating value, (b) proximate analysis and (c) ultimate analysis. Any biomass conversion process begins with knowing its energy content in units of MJ/kg and compared with traditional resources like coal. Further, biomass resources may be describe based on its proximate analysis whereby its moisture content (MC) is reported, followed by the volatile combustible matter (VCM) contents, fixed carbon (FC) and ash. Finally, the ultimate analysis is important to illustrate the biomass composition in relation to the top five elements it contains as follows: (a) carbon (C), (b) hydrogen (H) (c) oxygen (O), (d) nitrogen (N) and (e) sulphur (S) content. Other characterization would include describing its compositional contents such as lignin, cellulose and hemi-celluloses , carbohydrates and fat contents.

When biomass is converted thermally in the presence of excess amounts of air, (i.e. combustion) the total energy released in the form of heat is termed its heating value or calorific value. The heating value of biomass is reported in units of kJ/kg. Gasoline used as fuel for running internal combustion engines has a reported heating value of about 47 MJ/kg and diesel has heating value of about 45 MJ/kg. Biomass on the other hand may have heating values ranging from 15 – 25 MJ/kg.

2.1 Heating value and ultimate analysis of biomass

Heating value of biomass is usually measured using a bomb calorimeter. Table 1 shows the ultimate analyses and heating value of some fossil fuels and common biomass. In the absence of equipment for measuring heating values of biomass, two most common equations are used. These are the Dulong equation (Gupta and Manhas, 2008) and the Boie equation (Annamalai, et al., 1987) shown in equations (1) and (2).

Material	Elements (% dry weight)						Heating Values
	C	H	N	S	O	Ash	MJ/kg
Pittsburgh seam coal	75.5	5.0	1.2	3.1	4.9	10.3	31.7
Utah coal	77.9	6.0	1.5	0.6	9.9	4.1	32.9
Wyoming Elkol coal	71.5	5.3	1.2	0.9	16.9	4.2	29.5
Lignite	64.0	4.2	0.9	1.3	19.2	10.4	24.9
Charcoal	80.3	3.1	0.2	0.0	13.0	3.4	57.4
Douglas fir	52.3	6.3	0.1	0.0	40.5	0.8	21.3
Pine bark	52.3	5.8	0.2	0.0	38.8	2.9	20.4
Redwood	53.5	5.9	0.1	0.0	40.3	0.2	21.0
Rice hulls	38.5	5.7	0.5	0.0	39.8	15.5	15.4
Rice straw	39.2	5.1	0.6	0.1	35.8	19.2	15.2
Sawdust	49.7	6.2	0.7	0.2	42.5	0.7	20.0
Paper	43.4	5.8	0.3	0.2	44.3	6.0	17.6
Feedlot manure (fresh)	45.4	5.4	1.0	0.3	32.0	15.9	17.4
Municipal solid waste	47.6	6.0	1.2	0.3	32.9	12.0	19.9
Corn cobs	46.2	7.6	1.2	0.3	42.3	2.4	26.3
Sorghum stalks	40.0	5.2	1.4	0.2	40.7	12.5	15.4
Cotton gin trash (CGT)	42.0	5.4	1.4	0.0	36.7	14.5	15.5

Table 1. Ultimate analysis data and heating values for selected solid and biomass fuels (from LePori and Soltes, 1985, with permission).

The Dulong equation is given by the following equation (1),

$$HV (kJ/kg) = 33,823*C + 144,250*(H-O/8) + 9,419*S \tag{1}$$

where C, H, O, N and S are the elemental mass fractions in the material.

Example. From the ultimate analysis data shown in Table 1, estimate the heating value in MJ/kg of douglas fir.

Solution.
1. Substituting the mass fractions of the elements into the equation, we have
   HV (kJ/kg) = 33,823*(0.523) + 144,250 (0.063-((0.405)/8)) + 9,419*(0)
2. Thus, the heating value is calculated as
   HV (kJ/kg) = 17,689 + 1,785 + 0 = 19,474 kJ/kg (19.5 MJ/kg).

Note that the heating value from the table is given as 21.3 MJ/kg, an 8.45% difference. The Dulong equation is valid when the oxygen content of the biomass is less than 10%. In this example, the oxygen content of douglas fir is 40.5% and way above 10% , hence a large difference.

The Boie equation is given by the following equation (2),

$$HV (kJ/kg) = 35,160*C + 116,225*H - 11,090*O + 6,280*N + 10,465*S \tag{2}$$

where C, H, O, N and S are the elemental mass fractions in the material.

2.2 Proximate analysis of biomass

The proximate analysis is a good indicator of biomass quality for further conversion and processing. Proximate analysis is important for thermal conversion processes since the process require relatively dry biomass (normally less than 10% moisture). If gaseous combustible fuel from biomass is to be produced, the feedstock with the highest volatile matter content is ideal to use. For slagging and fouling issues, the feedstock with the lowest ash content is an excellent choice. The fixed carbon is used to relate the heating value of the product and co-products. Table 2 shows some proximate analysis data for some biomass resources.

Material	Proximate Analysis (% weight, wet basis)				Proximate Analysis (% weight, dry basis)		
	MC	VCM	FC	Ash	VCM	FC	Ash
Corn cob (Stout, 1985)	15.0	76.60	7.00	1.40	90.12	8.23	1.65
Stover (Stout, 1985)	35.0	54.60	7.15	3.25	84.00	11.00	5.00
CGT	9.01	64.78	14.36	11.85	71.20	15.78	13.02
Switchgrass	10.31	73.24	13.01	3.44	81.67	14.51	3.82
Sorghum	22.11	55.62	11.25	11.02	71.40	14.45	14.15
Woodchips	21.05	67.46	10.07	1.42	85.44	12.76	1.80

Table 2. Proximate analysis data for selected biomass.

3. Biomass conversion processes

The development of conversion technologies for the utilization of biomass resources for energy is growing at a fast pace. Most developing countries find it hard to catch up because

the level of technology is beyond their manpower as well as their manufacturing and technological capability. Added to this is the unavailability of local materials and parts for the fabrication of these conversion units. Figure 1 shows the different methods for converting biomass into convenient fuel. Biomass conversion into heat energy is still the most efficient process but not all of energy requirement is in the form of heat. Biomass resources need to be converted into chemical, electrical or mechanical energy in order to have widespread use. These take the form of solid fuel like charcoal, liquid fuel like ethanol or gaseous fuel like methane. These fuels can be used in a wide range of energy conversion devices to satisfy the diverse energy needs. In general, conversion technologies for biomass utilization may either be based on bio-chemical or thermo-chemical conversion processes. Each process will be described separately.
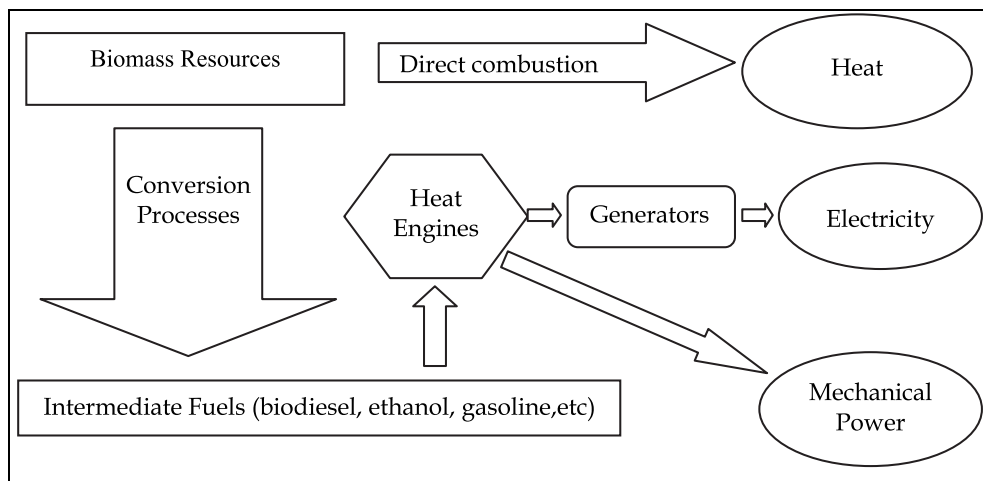
Fig. 1. Methods of using biomass for energy.

3.1 Bio-chemical conversion processes
The two most important biochemical conversion processes are the anaerobic digestion and fermentation processes.

3.1.1 Anaerobic digestion
Anaerobic digestion is the treatment of biomass with naturally occurring microorganisms in the absence of air (oxygen) to produce a combustible gaseous fuel comprising primarily of methane (CH_4) and carbon dioxide (CO_2) and traces of other gases such as nitrogen (N_2) and hydrogen sulphide (H_2S). The gaseous mixtures is commonly termed "biogas". Virtually all nitrogen (N), phosphorus (P) and potassium (K) remain in the digested biomass.
The entire process takes place in three basic steps as shown in Figure 2. The first step is the conversion of complex organic solids into soluble compounds by enzymatic hydrolysis. The soluble organic material formed is then converted into mainly short-chain acids and alcohols during the acidogenesis step. In the methanogenesis step, the products of the second step are converted into gases by different species of strictly anaerobic bacteria. The percentage of methane in the final mixture has been reported to vary between 50 to 80%. A

typical mixture consists of 65% methane and 35% CO_2 with traces of other gases. The methane producing bacteria (called methanogenic bacteria) generally require a pH range for growth of 6.4 to 7.2. The acid producing bacteria can withstand low pH. In doing their work, the acid producing bacteria lower the pH and accumulate acids and salts of organic acids. If the methane-forming organisms do not rapidly convert these products, the conditions become adverse to methane formers. This is why the first type of reactors developed for conversion of biomass wastes into methane have long retention times seeking equilibrium between acid and methane formers.

Municipal wastes and livestock manures are the most suitable materials for anaerobic digestion. In the US, numerous landfill facilities now recover methane and use it for power generation. Aquatic biomass such as water hyacinth or micro-algae can be digested and may become valuable sources of energy in the future. Anaerobic digestion of organic wastes may constitute an effective device for pollution control with simultaneous energy generation and nutrient conservation. A major advantage of anaerobic digestion is that it utilizes biomass with high water contents of as high as 99%. Another advantage is the availability of conversion systems in smaller units. Also the residue has fertilizer value and can be used in crop production. The primary disadvantage of anaerobic digestion of diluted wastes is the large quantity of sludge that must be disposed of after the digestion process including the wastewater and the cost of biogas storage. In cold climates, a significant fraction of the gas produced may be used to maintain the reactor operating temperature. Otherwise, microorganisms that thrive on lower or moderate temperatures should be used.
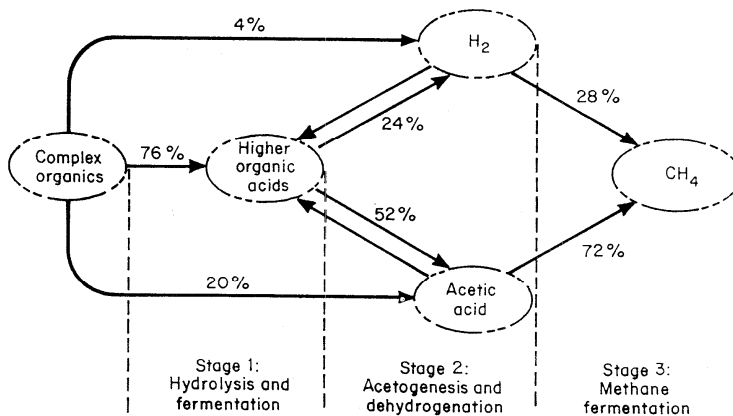
(Source: American Chemical Society)

Fig. 2. Steps in anaerobic digestion process with energy flow represented as % chemical oxygen demand (COD).

3.1.1.1 The first generation biogas reactors

Three main types of biogas facilities have been successfully developed in Asia for widespread biogas production in households and industrial use. These are the "Chinese Digester" of fixed dome type, the "Indian Gobar Gas Plant" of floating gas holder type and the rectangular commercial size biogas digesters developed in Taiwan. These are what we may call the first generation biogas reactors. Shown in Figure 3 is the common Chinese digester design. These

designs have eliminated the use of a floating gas holder and incorporated local materials for construction (brick or concrete). Biogas is pressurized in the dome and can be easily used for cooking and lighting. Figure 4 shows the "Indian Gobar Gas Plant" with floating gas holder.
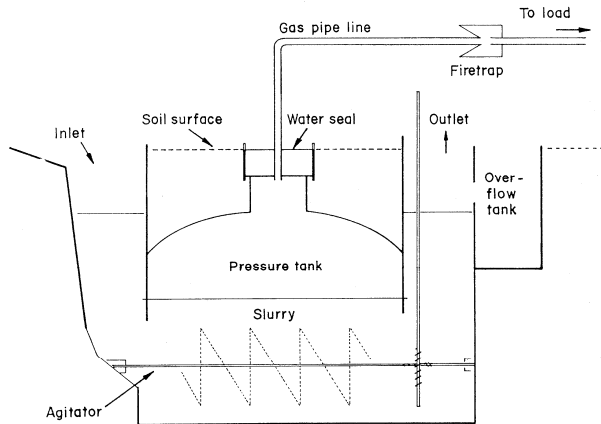
Fig. 3. The "Chinese Digester" of the dome type.
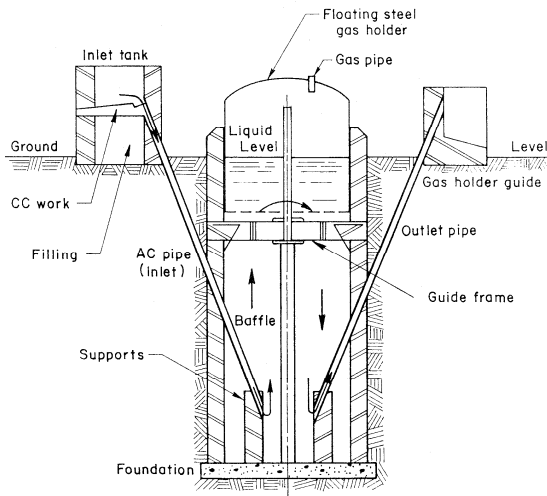
Fig. 4. The "Indian Gobar Gas Plant" schematic showing cross-sectional design.

The Indian design uses concrete inlet and outlet tanks and reactor. The steel cover acts as the floating gasholder. These digesters have no pumps, motors, mixing devices or other moving parts and digestion takes place at ambient temperature. As fresh material is added each day, digested slurry is displaced through an outlet pipe. The digesters contain a baffle in the center which ensures proper utilization of the entire digester volume and prevents short circuiting of fresh biomass material to the outlet pipe.

Figure 5 is an example of a rectangular biogas digester used in commercial swine facilities in Taiwan. Similar reactors have been built and used in the Philippines for commercial swine facilities (Maramba, 1978). The gas holder is designed and constructed separately.
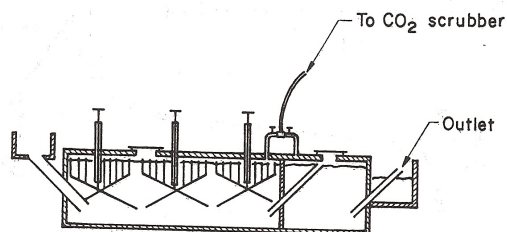
Fig. 5. The Taiwan rectangular digester design with a separate gas holder.

While the above designs have been operated successfully, the reactors are still considered World War II technologies. The main disadvantage is the long retention times of between 30 to 60 days. Thus, for large scale units, they require larger reactor volumes which make the initial cost and area requirements quite high. Their main advantage is the fact that these units have less maintenance and operational costs and they are less prone to breakdowns due to variations in the quantity and quality of feed. They are resistant to shock loadings and minimal process parameters are monitored for efficient operation. The only operating procedure made is the daily mixing of the slurry.

3.1.1.2 The second generation biogas digesters

There are now new technologies which we may call the second generation biogas digesters. These high rate bio-reactors were originally designed for low strength liquid wastes but the progress has been remarkable and most units can now be used for even the high strength wastes with high quantities of suspended solids like those of livestock manure.

Callander, et al., (1983), have made an extensive review of the development of the high rate digester technology. The improvements of such digesters can be largely attributed to better understanding of the microbiology of the methane production process. The most popular high rate anaerobic digesters originated from many conventional wastewater treatment plants that utilizes the anaerobic contact process (Figure 6) followed by the anaerobic clarigester. Perhaps the design that has caused widespread attention is the development of the upflow anaerobic sludge blanket (UASB) developed in Netherlands (Letingga, et al., 1980). Many commercial high rate digesters are now based on this design. Other reactors include the anaerobic filters (Young, et. al., 1969), the expanded bed fixed film reactor, and the stationary fixed film reactor.

As researchers began to understand the microbiology of the processes, they began to realize the varied nature and characteristics of the microorganisms used in the conversion. Thus recent designs call for the separation of two types of microorganisms in the reactors. Some new reactors are designed whereby acid forming bacteria are separated from the methane producing bacteria. With this design, the acid formers are now independent from the methane formers and therefore each group of microorganisms can do its job without harming the population of the other types of microorganisms.

The retention times have been reduced for most of the high rate biogas digesters and thus reducing the size of the digesters. However, there are corresponding need for a modest

laboratory for microbial analysis, system pH control and monitoring of other parameters such as buffering capacity, solids retention times, alkalinity and the like.
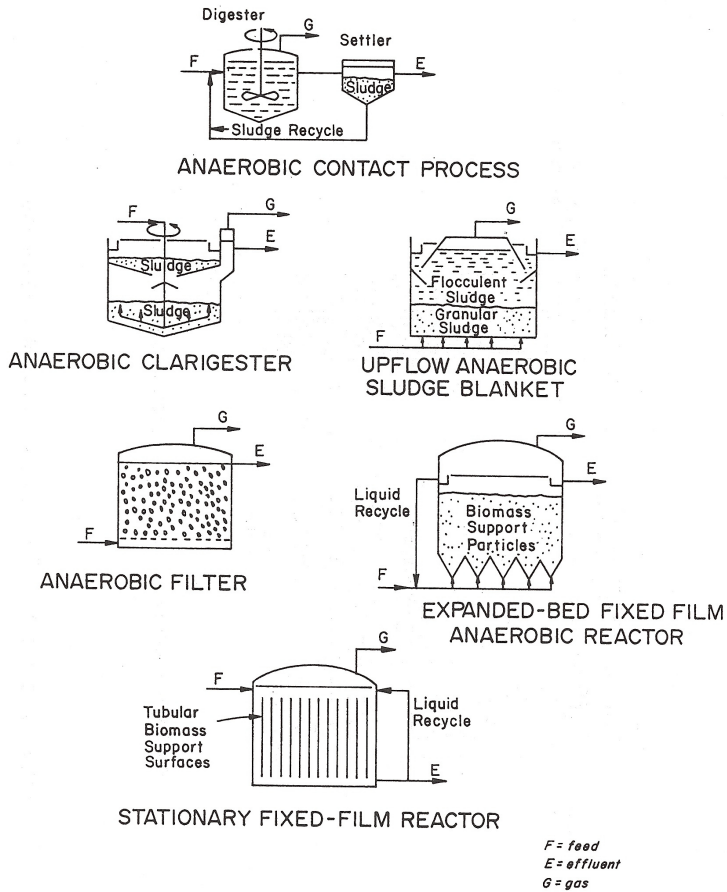
Fig. 6. Some examples of second generation biogas digesters.

3.1.2 Ethanol fermentation

Ethyl alcohol can be produced from a variety of sugar containing materials by fermentation with yeasts. Strains of *Saccharomyces cerevisiae* are usually selected to carry on the fermentation that converts glucose ($C_6H_{12}O_6$) into ethyl alcohol (C_2H_5OH) and carbon dioxide (CO_2). In the batch process the substrate is diluted to a sugar content of about 20% by weight, acidified to ph 4-5, 8-10%, the liquid is distilled, fractionated and rectified. One gallon of alcohol (3.79 liters, 21257 kcal) is obtained from 2.5 gallons of cane molasses or the equivalent of 5.85 kg of sugar (21,842 kcal). So there is almost no energy loss in the fermentation process.

When a starchy material, such a corn, grain sorghum or barley, is used as substrate, the starch must be converted into fermentable sugars before yeast fermentation. The

decomposition of large organic molecules requires the catalytic action of certain enzymes also produced by microorganisms. The most popular microbe is the *Aspegillus niger*.

Crops mentioned as potential substrate for the production of alcohol include sugarcane, sorghum, cassava, and sugar beets. The two main by-products of then fermentation are CO_2 and the spent materials, which will contain the non-fermentable fraction of the substrate, the non-fermented sugars and the yeast cells. The two most important reasons for the high costs for ethanol production are: the batch nature of the process and the end-product (ethanol) inhibition of the yeast.

Continuous fermentation has been found successful on a laboratory scale. One way of avoiding end product inhibition is operation under vacuum so that ethanol is removed as it is formed. More researches are underway. Figure 7 shows a schematic diagram for the production of high percent ethanol from cassava (NRC, 1983).
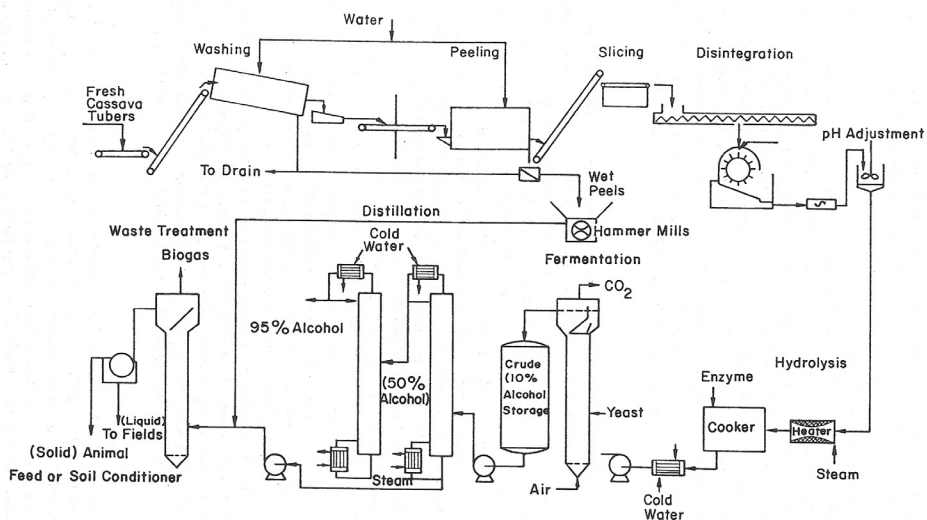
Fig. 7. Schematic of ethanol production from cassava.

If the feedstock is high in cellulosic components, these must be hydrolyzed also by a different sets of enzymes to break down the long chain cellulose structure into shorter chain compounds. In our laboratory facilities, we made use of enzymes produced by *Trichoderma reesi*. Commercially, genetically modified *T. reesi* may be sourced from Genencor International (Palo Alto, California, USA).

3.2 Thermo-chemical conversion processes

Biomass wastes can be easily converted into other forms of energy at high temperatures, They break down to form smaller and less complex molecules both liquid and gaseous including some solid products. Combustion represents a complete oxidation to carbon dioxide (CO_2) and water (H_2O). By controlling the process using a combination of temperature, pressures and various catalysts, and through limiting the oxygen supply, partial breakdown can be achieved to yield a variety of useful fuels. The main thermo-chemical conversion approaches are as follows: pyrolysis/charcoal production, gasification

and combustion. The advantages of thermo-chemical conversion processes include the following:
a. Rapid completion of reactions
b. Large volume reduction of biomass
c. Range of liquid, solid and gaseous products are produced
d. Some processes do not require additional heat to complete the process

3.2.1 Pyrolysis

Pyrolysis or destructive distillation is an irreversible chemical change caused by the action of heat in the absence of oxygen. Pyrolysis of biomass leads to gases, liquids and solid residues. The important components of pyrolysis gas in most cases are hydrogen, carbon monoxide, carbon dioxide, methane and lesser quantities of other hydrocarbons (C_2H_4, C_2H_6, etc.). The liquid consists of methanol, acetic acid, acetone, water and tar. The solid residue consists of carbon and ash. Thus pyrolysis can be used to convert biomass into valuable chemicals and industrial feedstock.

In a typical pyrolysis process the feed material goes through the following operations: (a) primary shredding (b) drying the shredded material (c) removal of organics (d) further shredding to fine size (e) pyrolysis (f) cooling of the products to condense the liquids and (g) storage of the products.

Different types of pyrolytic reactors include vertical shaft reactors, horizontal beds. Among these, the simplest and generally cheapest is the vertical shaft type. Fluidized bed reactors are relatively a recent development. Figure 8 shows a rotary kiln pyrolysis reactor. The unit is cylindrical, slightly inclined and rotates slowly which causes the biomass to move through the kiln to the discharge end.

Numerous technologies have now been developed for the production of bio-oil and char using the pyrolysis process, Many of the reactors developed are improvements on the traditional reactors used in rural areas of developing countries that include simple pit kilns or drum type reactors. The energy efficiency of charcoal production using these methods is only the order of 17-29% while theoretically, efficiencies as high as 40% could be achieved.
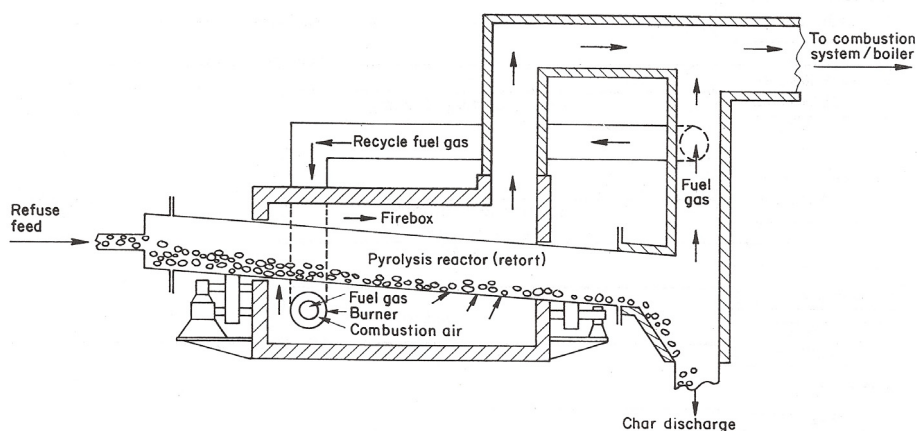
Fig. 8. Schematic of the rotary kiln pyrolysis reactor.

3.2.2 Gasification

Gasification is the thermo-chemical process of converting biomass waste into a low medium energy gas utilizing sub-stoichiometric amounts of oxidant (Coovattanachai, 1991). The simplest form of gasification is air gasification in which biomass is subjected to partial combustion with a limited supply of air. Air gasifiers are simple, cheap and reliable. Their chief drawback is that the gas produced is diluted with nitrogen and hence has low calorific value. The gas produced is uneconomical to distribute; it must be used on-site for process heat. In oxygen gasification, pure oxygen is used so that the gas produced is of high energy content. The chief disadvantage of oxygen gasification is that it requires an oxygen plant and thus increases the total cost of gasification. The schematic diagram of the processes occurring is a gasifier is shown in Figure 9 including the temperature profile at each important step in the process.
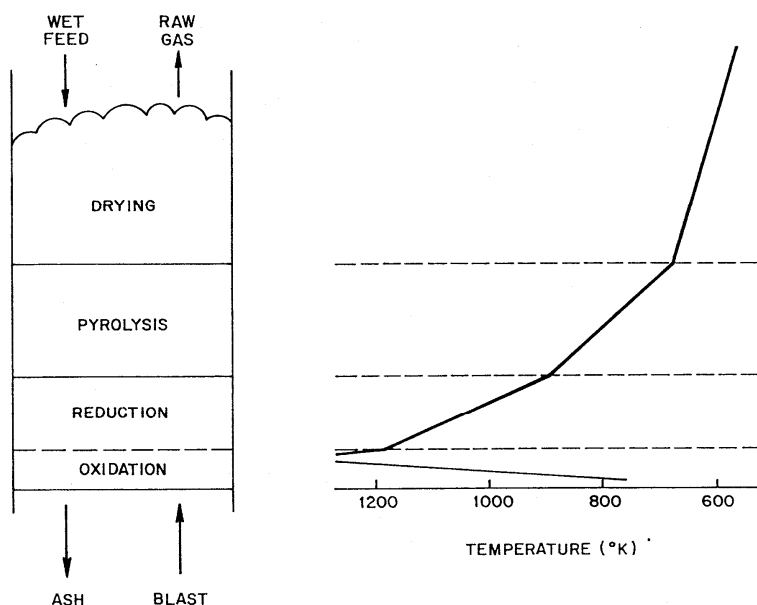
Fig. 9. Schematic diagram of processes occurring in a gasifier and the temperature profile.

The simplest air gasifier is the updraft gasifier shown in Figure 10. Air is introduced at the bottom of the bed of biomass near the hearth zone. The gas produced is usually at a low temperature. The sensible heat of the gas is used to dry and preheat the biomass before it reaches the reduction zone. Products from the distillation and drying zones consist mainly of water vapor, tar and oil vapors and are not passed through the hot bed. They therefore leave the reactor uncracked and will later condense at temperatures between 125°C – 400°C.

Because the tar vapors leaving an updraft gas producer seriously interfere with the operation of internal combustion engines, the downdraft gasifiers (Barret, et. al., 1985) are more extensively used. The air is introduced into a downward flowing bed of solid fuel and the gas outlet is at the bottom as shown in Figure 11. The tarry oils and vapors given off in

the distillation zone are cracked and reduced to non-condensible gaseous products while passing through the oxidation (hearth) zone. Downdraft gasifiers have a reduced cross-sectional area above which the air is introduced. The throat ensures a homogeneous layer of hot carbon through which the distillation gases must pass.
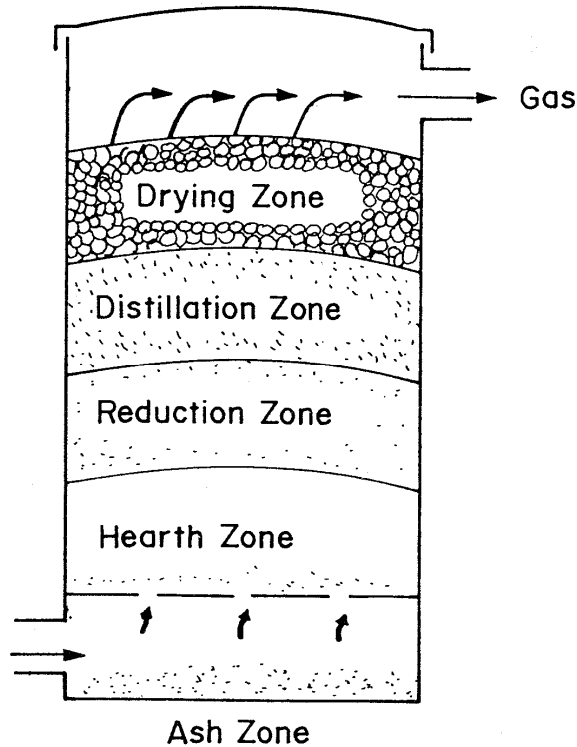
Fig. 10. Schematic diagram of an updraft gasifier.

The crossdraft gasifier is also a fixed bed gasifier where the feed material could be moved by gravity while the flow of air is at an angle against the feed flow. The usual flow of air is perpendicular to the flow of biomass. They have almost the same performance as the updraft and downdraft gasifiers.

A fluidized bed gasifier (LePori and Soltes, 1985) consists of a fluidized bed of inert particles in which biomass is fed. The gas stream generally carries with it the char particles out of the bed. These particles are separated from the gas by means of cyclones. Fluidized beds can gasify much higher amounts of biomass area per unit of time compared to the other types of gasifiers. The precise composition of the gas from the gasifiers depends on the type of biomass used, the temperature and rate of reaction. Typically, if wood is used as the feed, the gas composition is shown in Table 3. The heat content is about 5500 kJ/m^3. The synthesis gas quality for the Texas A&M University fluidized bed gasifier is shown in Table 4 (Lepori, 1985). A schematic of a fluidized bed gasifier is shown in Figure 12.
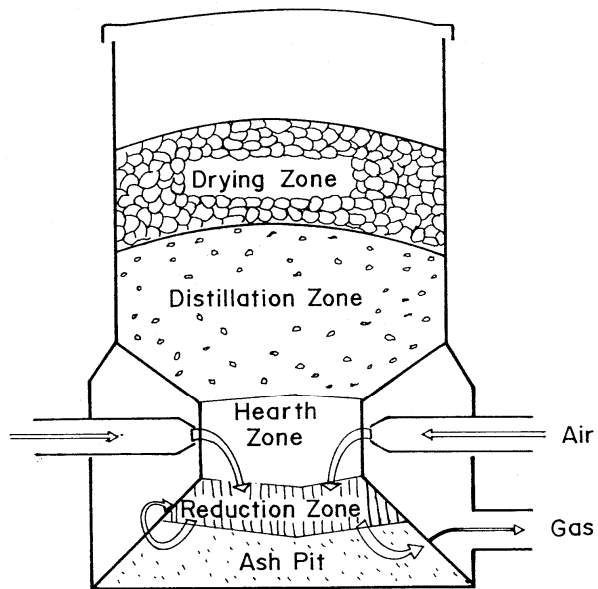
Fig. 11. Schematic diagram of a downdraft draft gasifier.
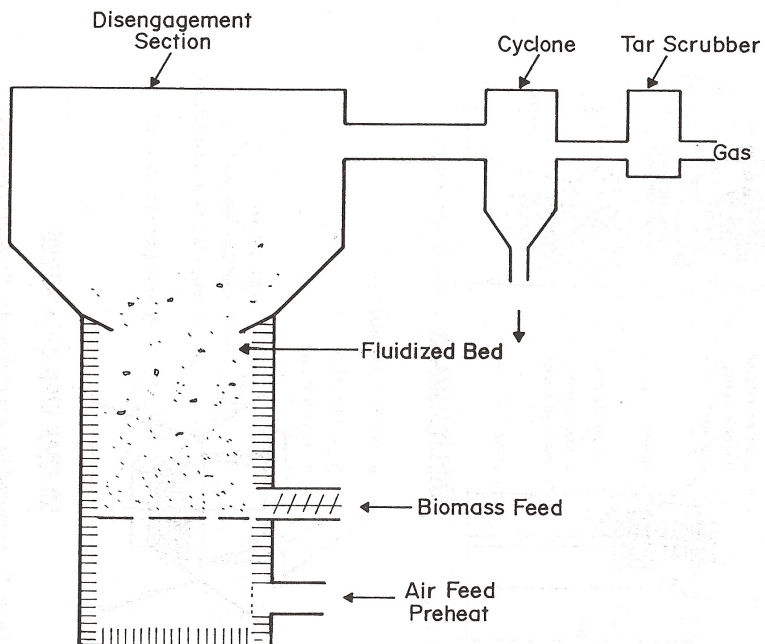
Fig. 12. Schematic diagram of a fluidized bed gasifier.

Type of Gas	Percent Composition
1. Carbon dioxide (CO_2)	10%
2. Carbon monoxide (CO)	20-22%
3. Hydrogen (H_2)	12-15%
4. Methane (CH_4)	2-3%
5. Nitrogen (N_2)	50-53%

Table 3. Typical gas composition of a fluidized bed gasifier using wood as feedstock.

Type of Gas	Percent Composition
1. Carbon dioxide (CO_2)	18.25%
2. Carbon monoxide (CO)	13.44%
3. Hydrogen (H_2)	14.68%
4. Methane (CH_4)	3.21%
5. Nitrogen (N_2)	47.31%
6. Ethylene (C_2H_4)	1.83%
7. Ethane (C_2H_6)	0.36%

Table 4. Typical gas composition of the TAMU fluidized bed gasifier.

3.2.3 Biomass combustion

One of the most common methods of biomass conversion is by direct combustion or burning. The simplest units include numerous cookstoves already developed in rural areas of developing countries. Much improved and continuous flow designs include the Spreader-Stoker system (similar to that shown in Figure 13) used in many refuse derived fuels (RDF) facility for converting solid wastes, and the fluidized bed combustion units (similar to that shown in Figure 12). The number component parts of this system is listed below:

1. Refuse charging hopper
2. Refuse charging throat
3. Charging ram
4. Grates
5. Roller bearings
6. Hydraulic power cylinders and control valves
7. Vertical drop-off
8. Overfire air jets
9. Combustion air
10. Automatic sifting removal system

In a spreader-stoker system, the fuel is introduced into the firebox above a grate. Smaller particles will tend to burn in suspension and larger pieces will fall onto the grate. Most units, if properly designed, can handle biomass with moisture content as high as 50-55%. Moisture contained in the fuel is driven off partially when the fuel is in suspension and partially on the grate. The feed system should provide an even thin layer of fuel on the grate.

In a fluidized bed combustor (FBC), the fuel particle burns in a fluidized bed of inert particles utilizing oxygen from the air. Advantages of fluidized bed combustion include: (1) high heat transfer rate, (2) increased combustion intensity compared to conventional combustors and, (3)

absence of fouling and deposits on heat transfer surfaces. The schematic diagram of a fluidized bed combustor is similar to that of a fluidized bed gasifier. The only difference is the use of excess air for combustion processes and starved air for gasification processes.

So far FBC has been used mostly for coals. A number of wastes, e.g. wastes from coal mining and municipal wastes, are also sometimes incinerated in fluidized beds. It has been suggested that certain quick-maturing varieties of wood could be combusted in fluidized beds for generation of steam. There is indeed a global search for suitable varieties of wood for this purpose and FBC is likely to play an important role in supplying energy requirements in certain countries in the future.
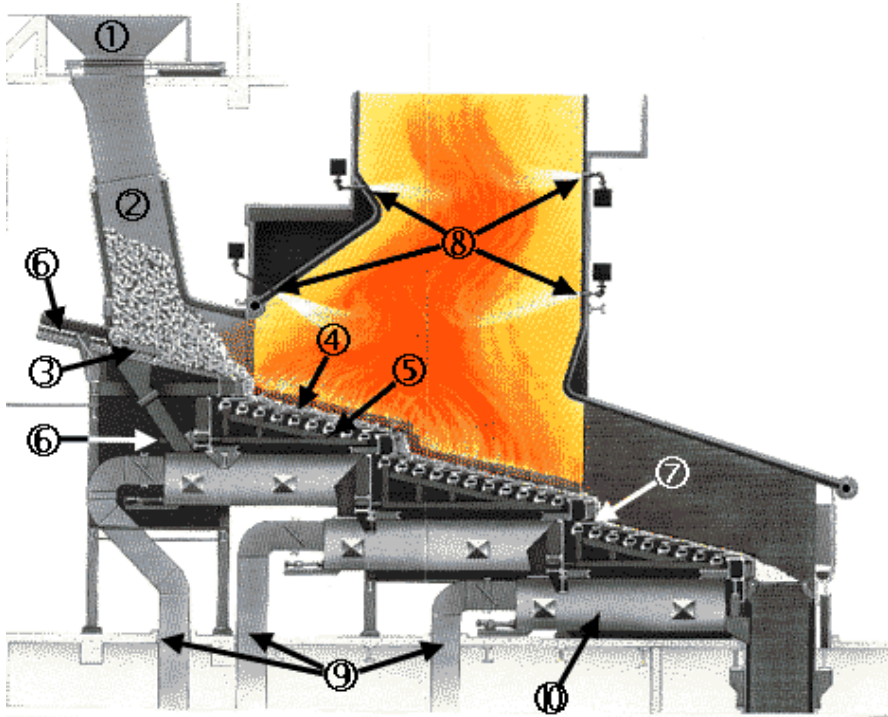
Fig. 13. Schematic diagram of a reciprocating grate combustor (Courtesy of Detroit Reciprogate Stocker).

Granular biomass fuels, e.g. paddy husk and chips of wood up to 2cm x 2cm x 2cm in size have been successfully combusted in fluidized beds of sand particles. Conventional combustion of paddy husk is slow and inefficient. Nearly complete combustion and high combustion intensities of paddy husk can be achieved in a fluidized bed combustor. The same combustor can also be used for burning wood. Combustion intensities up to about 500 Kg/hr-m^2 have been achieved in fluidized bed combustors using biomass fuels.

A number of thermo-chemical conversion processes exist for converting biomass into liquid fuels. These can be crudely divided into direct liquefaction and indirect liquefaction (in which the biomass is gasified as a preliminary step) processes. While all these techniques are relatively sophisticated and will generally be suitable for large scale conversion facilities,

they do represent an important energy option for the future because the heavy premium that liquid fuels carry.

The steam produced from heat of combustion of biomass may power a steam turbine to produce electricity. However, because of the high ash contents of most biomass resources, direct combustion of these biomass resources is not practical and efficient due to slagging and fouling problems. Because of these problems, some biomass with high ash are often mixed with low ash biomass such as coal, also termed co-firing.

3.2.4 Biomass co-firing

Co-firing refers to mixing biomass and fossil fuels in conventional power plants. Significant reductions in sulfur dioxide (SO_2 – an air pollutant released when coal is burned) emissions are achieved using co-firing systems in power plants that use coal as input fuel. Small-scale studies at Texas A&M University show that co-firing of manure with coal may also reduce nitrogen oxides (NOx- contribute to air pollution) emissions from coal (Carlin, 2009). Manure contains ammonia (NH_3). Upon co-firing manure and coal, NH_3 is released from manure and combines with NOx to produce harmless N and water.

Biomass co-firing has the potential to cut emissions from coal powered plants without significantly increasing the cost of infrasructure investments (Neville, 2011). Research shows that when implemented at relatively low biomass-to-coal ratios, energy consuption, solid waste generation and emissions are all reduced. However, mixing biomass and coal (especially manure) does create some challenges that must be address.

There are three types of co-firing systems adopted around the world as follows:
a. Direct co-firing
b. Indirect co-firing , and
c. Separate biomass co-firing.

Direct co-firing is the simplest of the three and the most common option especially if the biomass have very similar characteristics with coal. In this process, more than one type of fuel is injected into the furnace at the same time. Indirect co-firing involves converting the biomass into gaseous form before firing. The last type has a separate boiler for the co-fired fuel.

It was reported that the carbon life cycle and energy balance when co-firing 15% biomass with coal is carbon neutral or better (Eisenstat, et al., 2009). In this research, carbon emissions are reduced by 18%.

4. Conclusion

From the above discussions we observe a rapid development of technologies for the conversion of biomass into heat energy and fuels. Countries should take advantage of these rapidly developing technologies. However, as more conversion technologies are developed, the biomass resource base may be the next constraint. Thus, methods to diversify the biomass resource base have to be made in conjunction with the use of emerging technologies for conversion. The sources of biomass have to be broadened from the traditional crop residues, livestock manure and fuel wood to culturing energy crops such as aquatic biomass (e.g. algae) while recovering the energy from municipal solid wastes and sewage.

Attempt has to be made to make use of more efficient equipment and technologies for energy utilization. In anaerobic digestion for example, many countries are still utilizing age old first generation anaerobic reactors while high rate biogas reactors are already gaining

popularity. In the implementation of new and emerging technologies, lessons learned from past experiences must be taken into consideration. Many of these technologies require highly qualified and skilful manpower, more advanced monitoring techniques and equipment and materials that many developing countries may not have. The government of each country should have an active role to support the developing of such technologies including massive information campaign and training and improvement of local expertise in the use of advanced materials and process equipment for biomass conversion into energy and fuels.

Finally, to reverse the trend in the depletion of agriculture and forestry resources, massive reforestation program must be made together with developing technologies for harvesting, pre-processing and storage of biomass. This should be implemented together with infrastructure development for efficient transport of biomass to where it is needed or develop technologies that will be brought to where biomass resources are abundant.

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Air Gasification of Malaysia Agricultural Waste in a Fluidized Bed Gasifier: Hydrogen Production Performance

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1. Introduction

Recently, biomass gasification technology to produce hydrogen-rich fuel gas is highly interesting possibilities for biomass utilization as sustainable energy (McKendry, 2002). Hydrogen production from biomass gasification has many advantages as secondary renewable energy source as it is the universe's most abundant element, clean fuel has the potential to serve as renewable gaseous and liquid fuel for transportation vehicles. As a fuel, hydrogen is considered to be very clean as it releases no carbon or sulfur emissions upon combustion. The energy contained in hydrogen on a mass basis (120 MJ/kg) is much higher than coal (35 MJ/kg), gasoline (47 MJ/kg) and natural gas (49.9 MJ/kg). Additionally, the most important advantage for all the living beings is that when it is burned, hydrogen produces non toxic exhaust emissions. Clearly, the emissions from hydrogen combustion contain no carbon monoxide (CO), carbon dioxide (CO_2) and unburned hydrocarbons (Veziroglu et al., 2005). Using biomass as an energy source can reduce the greenhouse gas emission that causes global warming which is a negative effect of using fossil fuels as an energy source.

In Malaysia, more than 2 million tonnes of agricultural wastes are produced annually and potentially an attractive feedstock for producing energy as the usage contributes little or no net carbon dioxide to the atmosphere. Major agricultural products are oil palms, sawlogs, paddy and tropical fruits. The palm oil sector is the biggest producer and hence the major contributor to the agricultural residues generation in Malaysia. The oil-palm solid wastes (including shell, fibre and Empty Fruit Bunch (EFB)) are abandoned materials produced during palm oil milling process. For every ton of oil-palm fruit bunch being fed to the palm-oil refining process, about 0.07 tons of palm shell, 0.146 tons of palm fiber and 0.2 tons of EFB are produced as the solid wastes. Bagasse which is the matted cellulose fibre residue from sugar cane that has been processed in a sugar mill were produced about 3×10^5T per year in 1999. Despite the decreasing acreage, coconut still plays an important role in the

socio-economic position of the Malaysian rural population that involves 80,000 households. About 63% of coconut production, coconut fronds and shells represent the largest amount as residues (about 8%) (Ninth Malaysia Plan 2006-2010). Table 1 summarize the estimations of the current and potential selected agicultural wastes (biomass) utilizations in annual energy productivity in Malaysia.

Thermo-chemical conversion processes, including gasification, pyrolysis and combustion have been proven the best available technology to convert these renewable materials into valuables fuel (hydrogen) and fine chemical feedstock. However gasification process offers technologically more attractive and useful options for medium and large scale applications due to presence of non–oxidation conditions and lower green house gases emission. Fluidized bed gasifier is proven to be a versatile technology capable of burning practically any wastes combination with low emissions. The significant advantages of fluidized bed gasifier over conventional gasifiers include their compact furnaces, simple designs, effective gasification of wide variety of fuels, relatively uniform temperatures and ability to reduce emissions of carbon dioxide, nitrogen oxides and sulfur dioxides.

Crops/ Activities	Energy productivity (boe/ha/year)	Current Annual Amount Used for Energy Purposes		Current Annual Energy Potential of Utilised Biomass (million boe)	
Oil Palms	88.7	Fruit shells Fruit fibres Effluents	23.609 13.630 0.022	Pruned fronds EFB Effluents Replanting wastes	77.665 11.444 2.928 12.94
Rubber trees	29.5	Wood	4.967	Wood Effluents	3.707 0.210
Paddy plants	11.54			Rice husks Rice straws	1.025 2.541
Coconut trees	28.21	Fronds Shells	1.578 0.785	Fronds	0.164
Cocoa trees	80.33	N.A.	N.A.	Pruning wastes Pod husks Replanting wastes	16.850 0.085 0.630
Sugarcane	54.9	Bagasse	0.421	Leaves and tops	0.298
Logging	-	-		Residues	19.060
Timber processing	-	Sawdust & waste	3.733	Tree bark and sawdust	1.0

Table 1. Estimates of the energy productivity and biomass production and utilization (Ninth Malaysia Plan 2006-2010)

1.1 Hydrogen fuel

Technology development for conversion of waste feedstock to hydrogen has an economical potential. Depletion of fossil fuel source such as oil, gas and coal is going to become the biggest problem in the near future. Therefore, hydrogen fuel from the biomass waste is the best supersede for fossil fuels. Hydrogen is not widely used today but it has a great potential as an energy carrier such as fuel cell that can be applied to power cars and factories and also for home usages in the future. In comparison with fossil fuels, 9.5 kg of hydrogen produce energy equivalent to that produced by 25 kg of gasoline (Mirza et al., 2009).

Hydrogen has the highest energy content of any common fuel by weight (about three times more than gasoline). Hydrogen is an odorless, tasteless, colorless and non-poisonous gas. It is a renewable resource found in all growing things. Hydrogen is an important raw material for chemical, petroleum and agro-based industries. The demand for hydrogen in the hydrotreating and hydrocracking of crude petroleum is steadily increasing (Min et al., 2005). Hydrogen is catalytically combined with various intermediate processing streams and is used in conjunction with catalytic cracking operations to convert heavy and unsaturated compounds to lighter and more stable compounds. Large quantities of hydrogen were used to purify gases such as argon that contain trace amounts of oxygen. Furthermore, in the food and beverages industry, hydrogen was used for hydrogenation of unsaturated fatty acids in animal and vegetable oils, to produce solid fat and other food products. While in manufacturing of semi conducting layers in integrated circuits, hydrogen were used as a carrier gas. The pharmaceutical industries use hydrogen to make vitamins and other pharmaceutical products. Hydrogen is mixed with inert gases to obtain a reducing atmosphere that is required for many applications in the metallurgical industry such as heat treating steel and welding (Delgado et al., 1997 and Dupont et al., 2008).

In 2005, the overall U.S. hydrogen market is estimated at \$798.1 million and it is expected to rise to \$1,605.3 million for U.S. and \$740 million for European in 2010 (Keizai, 2005). However, hydrogen production is not enough to uphold this value. The hydrogen technology had been intensively studied to find a variety of hydrogen source with different treatment processes because hydrogen has great potential as an environmentally clean energy fuel and as a way to reduce reliance on imported energy sources. In Asian region, the biomass from agriculture sector is the largest source of hydrogen production. Many experts predict that hydrogen will eventually power tomorrow's industries and thereby may replace coal, oil and natural gas. However, it will not happen until a strong framework of hydrogen production, storage, transport and delivery is developed.

1.2 Biomass gasification

According to Xiao et al. (2007), it is generally reported by different authors that the process of biomass gasification occurs through main three steps. At the first step in the initial heating and pyrolysis, biomass is converted to gas, char and tar. Homogeneous gas-phase reaction resulted in higher production of gaseous. High bed temperature during this phase allowed further cracking of tar and char to gases. Second step is tar-cracking step that favours high temperature reactions and more light hydrocarbons gases such as Hydrogen (H_2), carbon monoxide (CO), carbon dioxide (CO_2) and methane (CH_4). Third step is char gasification step that is enhanced by the boudouard reaction.

The gasification mechanism of biomass particles might be described by the following reactions:

$$Biomass \rightarrow Gas + Tars + Char \qquad (1)$$

The Combustion reactions:

$$C + \tfrac{1}{2} O_2 \rightarrow CO \text{ -111 MJ/Kmol} \qquad (2)$$

$$CO + \tfrac{1}{2} O_2 \rightarrow CO_2 \text{ -283 MJ/Kmol} \qquad (3)$$

$$H_2 + \tfrac{1}{2} O_2 \rightarrow H_2O \text{ -242 MJ/Kmol} \qquad (4)$$

The Boudouard reaction:

$$C + CO_2 \rightleftarrows 2CO \text{ +172 MJ/Kmol} \qquad (5)$$

The Water gas reaction:

$$C + H_2O \rightleftarrows CO + H_2 \text{ +131 MJ/Kmol} \qquad (6)$$
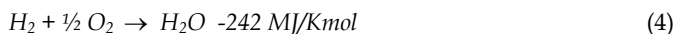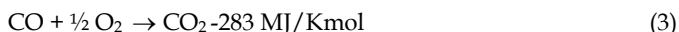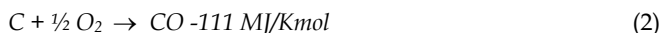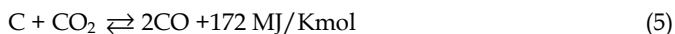
The Methanation reaction:

$$C + 2H_2 \rightleftarrows CH_4 \text{ -75 MJ/Kmol} \qquad (7)$$

The Water gas shift (CO shift) reaction:

$$CO + H_2O \rightleftarrows CO_2 + H_2 \text{ -41 MJ/Kmol} \qquad (8)$$
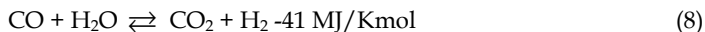
The gasification performance for optimized gas producer quality (yield, composition, production of CO, H_2, CO_2 and CH_4 and energy content) depends upon feedstock origin, gasifier design and operating parameters such as temperatures, static bed height, fluidizing velocity, equivalence ratio, oxidants, catalyst and others which are summarized in Table 2.

In summary, most of performed researches have explored the effect of different gasifying agent (air or steam) and applied different types of catalysts on gasification or pyrolysis process. Temperature and equivalence ratio of biomass with fuel (either air or steam) is the most significant parameter to contribute to the hydrogen production. However, less emphasis has been given to experimental investigation on the optimization of pyrolysis and gasification processes integration for the conversion of low value biomass into hydrogen and value-added products, which is the focus of this paper.

2. Materials and experimental

2.1 Raw materials

Three types of agricultural residues were investigated in this research namely palm kernel shell, coconut shell and bagasse as they are abundantly available in the agriculture sector in Malaysia. The samples were open air dried for 2 to 3 days to remove moisture and to ease crushing. Both of these samples were pulverized into powder and were sieved into specific particle size of (0.1-0.3 mm). Sieving was accomplished by shaking the ground biomass samples in a Endecotts Shaker Model (EFL2 MK3) for 30 minutes and dried in a vacuum oven at 80°C overnight and were kept in a tightly screw cap bottle. Table 3 summarized fuel properties investigated in this research.

	Raw materials	Gasifier design	Gasification performance	References
1	Wood sawdust	Integrated gasifier	Efficiencies: > 87.1% LHV: of 5000 kJ/Nm³.	Cao et al. (2006)
2	Pine wood block	down draft gasifier	Fuel gas yield: (0.82-0.94) Nm3/kg biomass, Hydrogen yield: (21.18- 35.39) g/kg biomass LHV : (4.76-5.44) MJ/Nm³	Pengmei et al. (2007)
3	Hazelnut shell	applied air-blown gasification	Hydrogen yield: 24 g/kg hazelnut shells.	Midilli et al. (2001)
4	Biomass	two-step process	Hydrogen content : 60% Hydrogen yield : 65 g/kg biomass	Zhao et al. (2010)
5	Palm kernel	Fluidized bed gasifier	Hydrogen yield : 67 mol % LHV : 1.482 - 5578 MJ/Nm³	Wan Ab Karim Ghani et al.,(2009)
6	Biomass	downdraft gasifier	LHV: 9.55 MJ/Nm³ H2 yield : 52.19-63.31%	LV et al. (2007)
7	Woody biomass	Fixed bed	The product gas composition: a)cellulose : 35.5% mol CO, 27% mol CO_2 and 28.7% mol H_2. b) Xylan and lignin were approximately 25% mol CO, 36% mol CO_2 and 32% mol H_2.	Hanaoka et al. (2005)
8	Biomass	Fixed bed	H2 concentration: air- 59% mol steam – 87% (increasing trend from 600 to 1050K)	Florin and Harris (2007)
9	Biomass	updraft gasifier	H2 composition: 22.3 mol% (air) and 83% mol % (steam)	Lucas et al. (2004)
10	Biomass	catalytic fluidized bed	Hydrogen yield: 28.7% Conversion efficiencies79%.	Miccio et al. (2009)

Table 2. Selected review on biomass gasification performance for hydrogen production.

	Palm Kernel shell	Coconut shell	Bagasse
Proximate Analysis (wt% wet basis)			
Volatile matter	30.53	51.10	43
Fixed carbon	48.5	26.4	32.40
Ash	8.97	12.50	10.20
Moisture	12	10	14.40
Ultimate Analysis (wt% dry basis)			
Hydrogen	5.52	5.40	5.30
Carbon	51.63	50.20	43.80
Oxygen	40.91	43.40	47.10
Nitrogen	1.89	1.46	1.20
Sulfur	0.05	0.06	0.03
Cellulose	20.80	28.60	30
Hemicellulose	22.70	28.60	23
Lignin	50.70	24.40	22
Bulk Density (kg/m³)	733	661	111
HHV (MJ/kg)	24.97	21.50	16.70

Table 3. Proximate and Ultimate Analysis of Feedstock Sample

2.2 Experimental set up and procedures

The schematic diagram of the experimental facility used in this study is shown in Figure 1. The reactor was made of stainless steel pipe and the total high of reactor is 850 mm with an internal diameter of 50 mm, directly heated via electrical furnace equipped with Temperatures Indicator Controller (TIC) and thermocouples that those installed in two different zones of reactor, screw feeder, condenser, gas cleaning, gas drying and sampling section, gas chromatograph (GC).
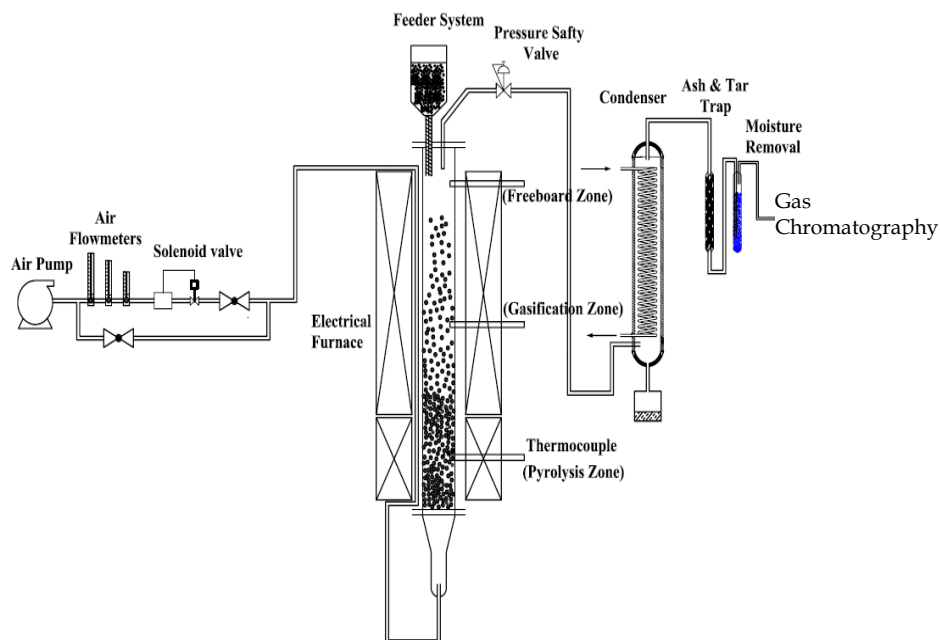
Fig. 1. Schematics diagram of biomass air gasification in fluidized bed reactor

Prior each experiment, the reactor was charged with 20 g of silica beads as the bed material to obtain a better temperature distribution, to stabilize the fluidization and to prevention coking inside the reactor. The solenoid valve (S.V) was turned on and a pre-heated air flow passed through the bed and the reactor when the temperatures in the bed (pyrolysis zone) and in the gasification zone reached the desired temperature. The feeder was turned on once the temperatures of these two parts stabilized. Typically, each test took about 20 to 25 minutes to stabilize and measurements were taken at intervals of 2 minutes. During each experiment, the air stream and the biomass feedstock were introduced from bottom and top of the gasifier, respectively. The clean gas was then sent to a water cooler to separate the condensed and un-condensed tars and steam. Sampling gas bags were employed to collect the product gas leaving the cooler for off line gas analysis.

3. Results and discussion

The gasification performance mainly will be evaluated based on the gas production quality (hydrogen yield and carbon conversion efficiency) and quantity (gas composition). Furthermore, the ash and oil yield will also be determined and quantified.

3.1 Effect of gasification temperature
The product yields (hydrogen, ash and oil) and detail gas composition of studied biomass at different gasification temperature are summarized in Table 4 and Figure 2, respectively. In this study, reactor temperature is increase from 700 to 1100 °C in 50°C and at constant feeding rate (0.78 kg/h) and equivalence ratio(ER)(0.26).

Reactor Temperature (°C)	750	800	850	900	950	1000	1100
a) Palm kernel shell							
Hydrogen yield	14.08	16.8	22.88	23.44	26.7	28.56	31.04
(g H_2/kg biomass, wet basis)							
LHV (MJ/kgNm³)	25.776	29.964	25.451	24.954	24.439	21.3	18.3
Ash (w/w)	0.174	0.158	0.142	0.136	0.12	0.114	0.1
Oil (w/w)	0.1	0.13	0.164	0.144	0.29	0.16	0.1
b) Coconut shell							
Hydrogen yield	18.93	19.8	20.64	22.37	23.7	25	25.44
(g H_2/kg biomass, wet basis)							
LHV (MJ/kgNm³)	24.68	26.328	25.872	25.489	23.274	20.936	20.247
Ash (w/w)	0.183	0.167	0.156	0.132	0.128	0.122	0.114
Oil (w/w)	0.06	0.078	0.11	0.11	0.12	0.07	0.05
c) Bagasse							
Hydrogen yield	11.6	13.1	13.47	17.44	19	21.4	23
(g H_2/kg biomass, wet basis)							
LHV (MJ/kgNm³)	23.245	26.74	26.224	25.674	25.152	24.53	21.653
Ash (w/w)	0.178	0.143	0.122	0.1	0.092	0.088	0.083
Oil (w/w)	0.052	0.052	0.064	0.084	0.072	0.052	0.03

Table 4. Summary of results for effect of gasification temperature on hydrogen production

In general, higher temperature favoured production gas as compared to ash and oil. Hydrogen yield increased as the temperature increased from 750 to 1000°C with the value of 14 to 31 mol%, 18 to 25.44 mol% and 11 to 23 mol% for palm kernel shell, coconut shell and bagasse, respectively. Palm kernel shell gave the highest H_2 compared to other samples due to the highest lignin content in their structure (Worasuwanarak et. al., 2007 and Dawson and Boopathy, 2008). Meanwhile, the product gas low heating value (LHV) showed a maximum value, 30, 23, 23 and 27 MJ/KgNm³ for palm kernel, coconut shell and bagasse, respectively. Ash and oil products yield ranging 0.10-0.29 % and 0.02-0.29%, respectively. These phenomena would be due to various reasons namely (i) higher production of gases in initial pyrolysis step whose rate is faster at higher temperature (Franco et al., 2003); (ii) higher gas production caused by endothermic char gasification reactions, which are favored at high temperature in pyrolysis zone, (iii) elevated temperature in gasification zone is favourable for tar and heavy hydrocarbons cracking that result to higher gas production (Tavasoli et al., 2009).
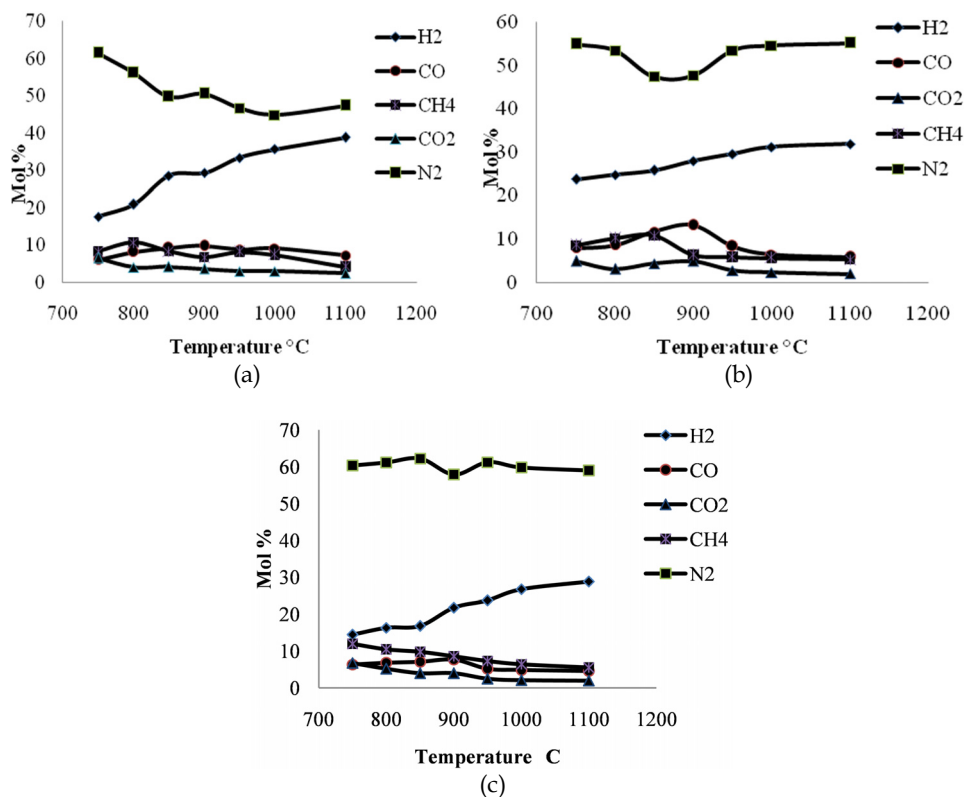
Fig. 2. Comparison gas composition for (a) palm kernel shell, (b) coconut shell and (c) bagasse at different temperature

Figure 2 illustrates that hydrogen mol fraction significantly increased while the content of other produced gas particularly methane (CH_4) showed an opposite trend for all studied samples. This is in accordance with Le Chatelier's principle; higher temperatures favour the reactants in exothermic reactions and favour the products in endothermic reactions. The H_2 formation is favoured by increasing of the gasification temperature, which could be due to the combination effect of exothermal character of water-gas shift reaction (Eqn. 8) which occur and predominate between 500-600°C and the water-gas reaction (Eqn. 6) which becomes significant at the temperature from 1000 to 1100°C and upward (Midilli et. al., 2001). The water shift reaction occurred in any gasification process due to the presence of water inside of fuel and water vapour in side of air. Water vapour and carbon dioxide promote hydrogen production in biomass gasification process (Cao et. al, 2006). Furthermore, increasing of gasification temperature also increases thermal cracking of tar and heavy hydrocarbons into gaseous components (Babu, 1995). At the same time, the gas production also increased due to cracking of liquid fraction developed in this range of temperature (300-500°C). These observations are in accordance with Encinar et al. (1996), Fagbemi et al. (2001), Zanzi et al. (2002) and Chen et al. (2003) where they found that the pyrolysis temperature below 600°C should be favoured for overall hydrogen production.

On the contrary, different trend were observed for other produced gaseous. Methane (CH_4) increased to 0.7%, 10.8% and 9.83% for palm kernel shell, coconut shell and bagasse, respectively when temperature rises from 750°C to 850°C but decreased gradually with temperature decreases. This can be explained as contribution of methanation reaction (Eqn. 7) during the gasification process. This was an expected result because as explained above most H_2 production reactions are endothermic and content of CH_4 decreases because temperature strengthens steam methane reforming reaction (McKendry, 2002, Lucas et al., 2004) and Pengmei et al., 2007). Furthermore, increasing of temperature contributes to decreases in CO_2 but increased CO. The content of CO was mainly determined by Bourdouard reaction (Eqn. 5) where the boudouard reaction only produces CO at high temperature around 800-900°C (Encinar et al., 2001 and Mathieu and Dubuisson, 2002). Moreover, Tavasoli at el. (2009) reported that decreasing the concentration of CH_4 and heavy hydrocarbons with increasing of the rise in temperature in gasification process results in higher conversion of biomass and exhausting of major energy that is the reason for decline in value of LHV, because produced gases contain less quantities of CH_4 due to contribution in stem reforming reaction.

3.2 Effect of equivalence ratio (ER)

The Equivalence Ratio (ER) varied from 0.23 to 0.27 through changing airflow rate at three constant temperatures (900°C, 950°C and 1000°C) at constant feeding rate (0.78 kg/hr) to find the optimum condition for hydrogen production. Table 5 summarize the obtained results and shows that the maximum molar fraction of hydrogen at 1000°C reached to (44.6% at ER: 0.23), (36.65% at ER: 0.23) and (36.38% at ER: 0.22) for palm kernel shell, coconut shell and bagasse, respectively.

Equivalence Ratio (ER)	0.23	0.24	0.25	0.26	0.27
a) palm kernel shell					
i) 900°C	20.48	22	26	23.44	20
ii) 950°C	25.28	30.2	27.44	26.7	21.6
iii) 1000°C	35.68	32.24	30.1	28.6	24.65
b) coconut shell					
i) 900°C	23.5	25.4	24.9	22.37	19.4
ii) 950°C	27.8	26.6	25.4	23.7	20.6
iii) 1000°C	29.32	28.9	26.8	25	21.05
c) Bagasse					
i) 900°C	22	23	24.52	22.26	19.86
ii) 950°C	21.9	28.1	26.8	23.72	21
iii) 1000°C	23.7	29.1	27.74	25.22	23.1

Table 5. Summary of results for effect of equivalence ratio on hydrogen yield (gH2/kg biomass

Figure 3 shows the gas composition for palm kernel shell gasification (selected sample for optimization study) at different temperature. Hydrogen yield were observed to increase first and decreased as ER increased. The obtained results are in accordance with other researchers where they found that increasing temperature in air gasification contributed to increasing of the hydrogen release (Midilli et al., 2001; Gonzalez et al., 2008; Lucas et al., 2004). In addition, they observed that increasing of the flow rate of air will decrease hydrocarbon contents due to partial combustion which subsequently contributed to decrease in tar and gaseous hydrocarbons. However, high flow rate of air will decrease the lower heating value (LHV) of the gasification gas (Pinto et al., 2003 and Lv et al., 2004). This phenomenon can be discussed by the following explanations.
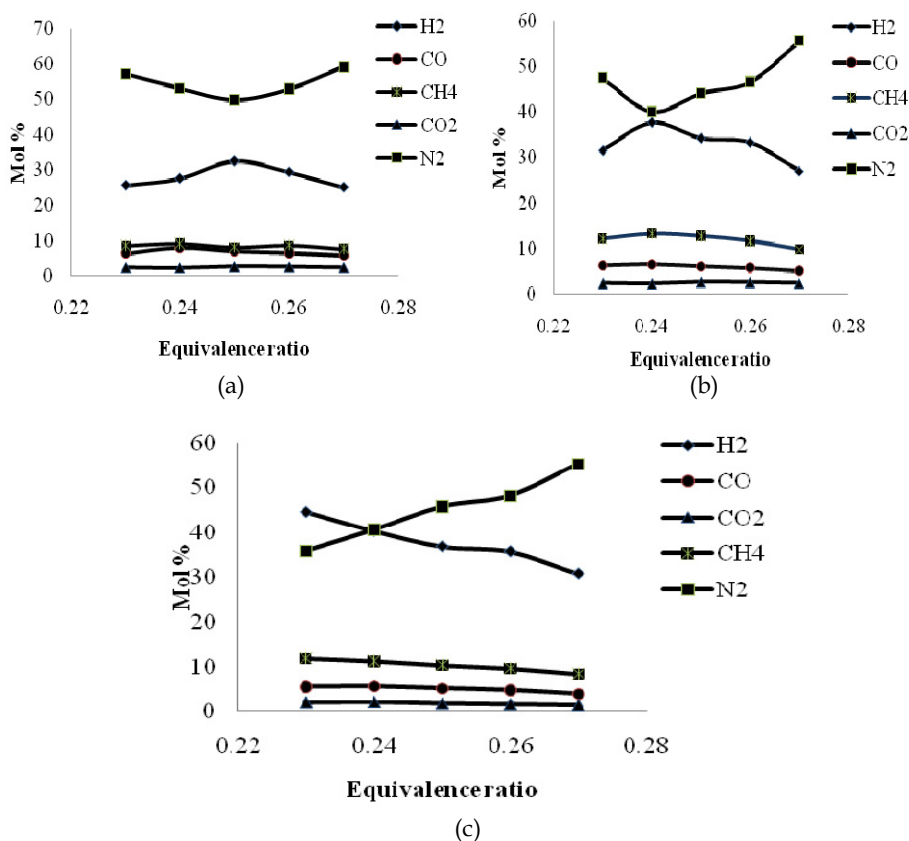
Fig. 3. Comparison gas composition at temperature (a) 900°C (b) 950°C and (c) 1000°C in different ER at optimized condition of palm kernel shell gasification

At highest temperature 1000°C, low ER was suitable with compare to 900°C and 850°C. At low ER the combustion reactions in Eqn. 2 was dominated when compared to the combustion reaction in Eqn. 3 because of lack of oxygen. This is further verified by Wan Ab karim Ghani et. al. (2009) and Pengmei et. al. (2004) that explained that ER not only represents the oxygen quantity introduced to the reactor but also affects the gasification

temperature under the condition of auto thermal operation. Higher equivalence ratio caused gas quality to degrade because of more oxidization reaction. In addition, the usage of air as oxidants contributed to higher ER which introduced large percentage of nitrogen into the system and diluted the combustible constituents in fuel gas (Pengmei et. al., 2007). On other hand, small ER will cause of lower oxygen be available for complete the gasification reactions which is not favourable for process. Therefore the gas composition is affected by the two contradictory factors of ER.

3.3 Effect of feeding rate
Various feeding rate ranging from 0.20 to 1.21 kg/hr were tested for palm kernel shell to determine the time required for complete reactions of gasification of biomass and suitable feeding rate of reactor by considering of value of reactor and minimum fluidization velocity of biomass particles. Figure 4 shows that with increasing of the feeding rate, the hydrogen yield increased and reached to the maximum value of 29.1%. It was found that higher feeding rates did not have great influence neither on net gas production nor on the hydrogen yield. This is explained by the fact that the higher feeding rate attributed to less residence time per volume air which will caused less oxygen be in contact with the biomass particles (W.A.W.A.K. Ghani et. al., 2009). Thus, decreasing of temperature at pyrolysis and consequently gasification process will be occurred and hence the biomass samples will remain raw or partially gasified.
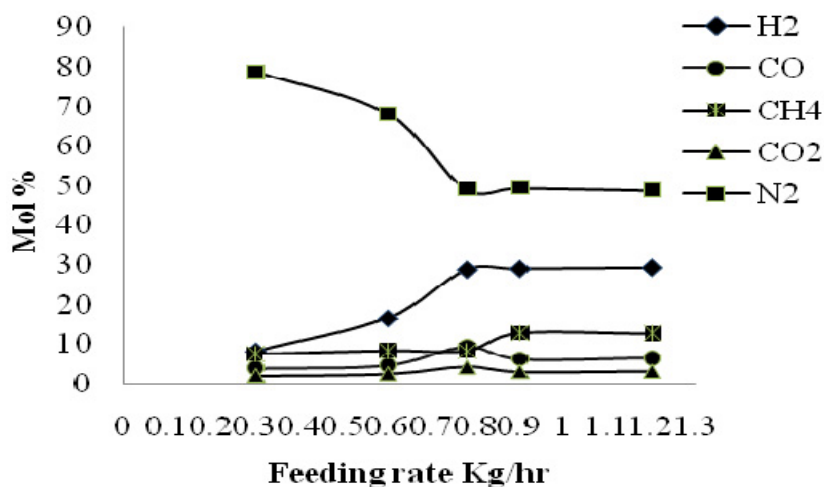
Fig. 4. Effect of feeding rate on gas composition at optimized condition of palm kernel shell gasification

3.4 Effect of biomass particle size
Figure 5 illustrates the hydrogen production performance for palm kernel shell at difference particle size (0.1, 2 and 5 mm). It was observed that with decreasing the particles size, the produced hydrogen and hydrogen yield decreased with the maximum value of 22.2% which belong to the smallest particle size. Lv et al. (2004) reported that pyrolysis process of small particles mainly controlled by reaction kinetics. Thus, as the size of biomass particles

increase, the production gas resultant inside the particles is more difficult to diffuse out and process is mainly controlled by gas diffusion. On other hand, larger particles are not only difficult to be entrained by fluidizing gas, but also produce fewer smaller particles after gasification reaction. This results in a reduction in fine particle entrainment, and hence decreases the amount of volatile matter and unburned char (Leung et al., 2003).
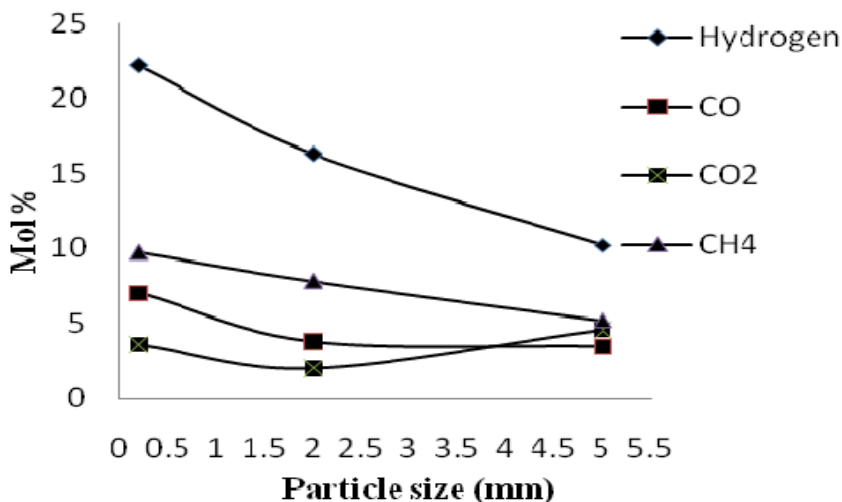
Fig. 5. Effect of particle size on gas composition at optimized condition of palm kernel shell gasification

3.5 Carbon conversion efficiency
The carbon conversion efficiency in this study were calculated based on the below equation (Eqn. 9).

$$\text{Carbon conversion efficiency} = (a/b) \times 100 \, \% \qquad (9)$$

Where:
    a = Total reacted carbon in the system (kg)
    b = Total carbon fed to the system (kg).

In this study, the maximum carbon conversion efficiency reached up to (89%), (88.6%) and (94.5%) for palm kernel shell, coconut shell and bagasse, respectively at 1100°C under the air/biomass ratio (1.12 Nm^3/Kg). These variations were observed as resulted from the biomass properties (see Table 2). As expected bagasse with the lowest carbon content and lowest density should be burned completely under given fluidizing velocity. As for other samples, the unburned carbon out of the gasifier might attributed by the sort residence time of biomass particles to further react either with O_2 and CO_2 and H_2O at the same fluidizing conditions. This phenomenon is explained by Cao et al. (2006) that the carbon conversion also has relation with air/biomass ratio where they founded the maximum carbon conversion occurs at air/biomass ratio about 2.5 Nm^3/kg. They reported that carbon conversion increased rapidly with increasing of the air/biomass ratio and decreased gradually with further air/biomass ratio increased. This is due to the fact that higher gas

velocity had contributed to longer residence time for carbon to complete the reaction with O_2 or with CO, CO_2 and H_2O and consequently decreasing in the carbon conversion efficiency.

4. Conclusion

Air gasification of agricultural wastes was successfully performed in a lab scale fluidized bed gasifier, producing producer gas mainly hydrogen which could replaced fossil fuel in the near future. Among the gasification parameters tested, the gasification temperature and equivalence ratio appeared to have the most pronounced effect on the hydrogen performance. Hydrogen production is favoured by an increasing temperature and hydrogen yield is enhanced as the water gas shift reaction goes to the completion with reducing of CO and CO2 in the product gas. The influence of equivalence ratio on the performance of a gasifier could be regarded as the effect of reactor temperature as the reactor was found to be ER dependent. As a higher equivalence (ER) had complex effects on tests results and there existed an optimal value for this factor, which was different according to different operating parameters. The feeding rate and biomass particle size would only show minor effect during the gasification process. In view of laboratory scale, the optimum conditions for hydrogen production in air gasification for studied biomass feedstock can be summarised as the following; a) temperature of gasification zone (950-1000°C); b) Equivalence ratio 0.23 and c) feeding rate at 0.70 kg/hr and d) Particle size (1-3 mm). The obtained results deduced to the conclusion that agricultural wastes are potential candidate for hydrogen production as an alternative renewable energy source and partially reduced the landfill problems of agricultural residues.

5. Acknowledgment

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Extraction and Optimization of Oil from Moringa Oleifera Seed as an Alternative Feedstock for the Production of Biodiesel

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1. Introduction

Energy production for industrial and domestic purpose has primarily been based upon the combustion of fossil fuels, such as oil and coal and it has been reported that these resources are finite and pose significant environmental impact from their combustion (Carraretto et al., 2004; Abdulkareem & Odigure, 2002; Odigure & Abdulkareem, 2001). It has been predicted that coal will be a viable energy resource for 90-200years, while the world oil supply is reaching its peak due to over dependence on oil consumption (Odigure et al., 2003). This was blame on the inability of energy sector to balance the oil supply with the increasing demand by various sectors including domestic consumption (Abdulkareem, 2005). Like any other commodity, fossil fuel price is also influence by shortage or oversupply and it has been reported that the change in demand as well as supply by the OPEC and non OPEC nations will greatly affects the price of the oil for many years (Abdulkareem, 2005). In other to meet up with the energy demand worldwide, government and oil sector embarks on the programme of new oil discoveries, and it has been reported that searching for new oil is a loss to the companies. For instance, about ten major oil companies spent $8 billion on searching for new oil; results of their search only produce commercial discoveries of oil worth approximately $4 billion. Consequently, the oil companies now consider searching for new oil not economical and unable to replace their rapidly depleting resources (Abdulkareem & Odigure, 2006; Abdulkareem & Odigure, 2010; Ahmmad et al., 2011; Udaeta et al., 2007). Apart from the price instability of the fossil fuel which is the major sources of energy, environmental pollution is also a major problem emanated from over dependence on fossil fuel. Combustion of fossil fuel is harmful to human health and the environment, and there is an increasing campaign for cleaner burning

fuel in order to safeguard the environment and protect man from the inhalation of genotoxic substances (Perez-Roa et al., 2006; Adeniyi et al., 2007; Abdulkareem et al., 2010). For instance, the exhaust from petroleum products, especially diesel is known to be toxic and carcinogenous in nature, since they contain polycyclic aromatic hydrocarbons (Ahmmad et al., 2011). Though, there is no energy source that is completely environmentally safe, hence it is important to use the available energy sources wisely to minimize environmental hazard and optimize the efficiency with which it is produced (Bernard & Wolfgang, 2009; Abdulkareem et al., 2011). The environmental impacts of using fossil fuel and other non-renewable fuels, such as coal and uranium, present a major obstacle to the continued use of such resources to meet our energy needs. The conventional petroleum-based fuels such as gasoline or diesel, as well as natural gas and coal, all contain carbon. When these fuels are burnt, their carbon recombines with oxygen from the air to form carbon dioxide which is the primary greenhouse gas that causes global warming. In the same vein, combustion of fossil fuels at the high temperature and pressures reached inside an internal combustion engine (what powers most vehicles) or in an electric power plant produces other toxic emissions (Abdulkareem et al., 2011). Carbon monoxide, oxides of nitrogen, oxides of sulphur, volatile organic chemicals, and fine particles are all components of air pollution attributable to the refining and combustion of fossil fuels. When released into the atmosphere, many of these compounds cause acid rain or react with sunlight to create ground level smog. Vast ecosystem damage, increase lung disease and cancer are the ultimate price inhabitant pay for consuming these fossil fuels (Abdulkareem & Odigure, 2006). The concern for price instability due to over dependence on the fossil and increasingly awareness on the environmental impact of combustion of fossil fuel have called for the alternative source of energy and proper utilization of existing energy sources. Biofuel which is described as the natural and renewable domestic fuel are now considered promising and economical alternative and sustainable energy sources (Shireen & Debabrate, 2008; Khunrong et al., 2011; Eevere et al., 2011). Biodiesel made from vegetable oil, has been reported to burns clearly, which result in a significant reduction for the types of pollutants that contribute to smog and global warming. Some of the advantages of the biodiesel over the fossil fuel diesel include cost of production, it has been reported that once the technology of biofuel is readily available, the cost of biofuel will be much less than that of fossil fuel (Ahmmad et al., 2011; Durosoy et al., 2011). This was blame on the fact that increases in word population will lead to an increment in demand for oil which will results in increase in price beyond the expectation level (Nashawi et al., 2010). While fossil fuel is described as limited resources since it is produce from a specific material, biofuel can be manufactured from a variety of material (Vera & Langlois, 2007). Other problem associated with fossil fuel is the non-biodegradability; the situation that makes it difficult to clean when spillage is experienced. While the biofuel are easily biodegradable and safer to handle than the fossil fuel, this makes spill of biofuel to be less hazardous and less expensive to clean up. Biodiesel also had a high flash point which makes it less explosive at moderate temperature, hence biodiesel is safer to transport and store (Hamamci et al., 2011). There is also wide spread of efforts to investigate an economical additives that can be blended with biodiesel to enhace its application in a colder climates which is the major detractor at moment. On the suitability of the biodiesel in a diesel engine, it has been reported that the first diesel engine which was invented by Rudolf Diesel in 1892, was originally designed to run on unrefined biodiesel.This provide an indiaction that diesel engine can easily adapt to biofuel with little

 modification (Agarwal and Das, 2001). Biodiesel is therefore, produced by the process known as transesterification, which is a chemical reaction for conversion of oil to biodiesel (El-Sabagh et al., 2011; Adeniyi et al., 2007). In this process the oil is chemically reacted with alcohol like methanol or ethanol in the presence of catalyst like sodium hydroxide or potassium hydroxide. After the chemical reaction, various components of the oil break down to form new compounds known as triglycerides. The triglycerides are converted into alkyl esters, which is the chemical name of biodiesel. If methanol is used in the chemical reaction, methyl esters are formed, while when ethanol is used, ethyl esters are formed. Both of these compounds are biodiesel fuels with different chemical combination (Silas, 2008). While the glycerin, that has been separated during transesterification process is released as a by-product of the chemical reaction. Glycerin will either sink to the bottom of reaction vessel or come to the surface depending on its phase. It can be easily separated by the centrifuges. This whole process is called transesterification. The feedstock (oil) therefore play a major role in the production of biodiesel (Ayhan, 2008).

Biodiesel as an alternative sources of energy, can be produced from biological or biomass material including corn, cellulose, sugar cane, edible oils such as vegetable oil, soybean, palm oil etc. Biodiesel Fuel can also be produced from a variety of non edible oil including rapeseed, mustard flax, sunflower, canola, hemp, Jatropha and waste vegetable oils (Aghan, 2005; Adeniyi et al., 2007; Helwani et al., 2009; Hossain and Boyce, 2009; Abdulkareem et al., 2010). This fuel sources are said to reduce engine wear and produce less harmful emissions. In different part of the world, depending on availability, biodiesel has been produced from different plants. This was first done as an academic exercise, but today commercialization of this production process and product is on-going. For instance Freedman et al, (1984) reported the use of fish oil, soy oil, rape seed oil, cotton seed oil, sun flower, safflower, peanut and line seed oil for the production of methyl esters. According to Barminas et al, (2001) categories of suitable agricultural products for bio-fuel production include seeds, nuts, fruits, leaves, and root and stem etc. It has also been reported that algae farming provide yields 4-5 times more biodiesel per acre than crops like soybeans, but the technology of producing biodiesel from algae is very expensive hence the possibility of achieving commercialization of biodiesel from algae might not happen any moment soon. The European standard specification EN 14214 in 2004, therefore defined biodiesel as fatty acid methyl esters (FAME) from any kind of feedstock (Canakci, 2007; Chhetri *et al*., 2008; Refaat *et al*., 2008). Therefore, from an economic point of view; the production of biodiesel is very feedstock sensitive. The cost of biodiesel has been estimated based on assumption regarding production volume, feedstock and chemical technology (Canakci and van Gerpen, 2001; Zhang *et al*., 2003b; Kulkarni and Dalai, 2006) and feedstock cost comprises a very substantial portion of overall biodiesel cost. Though, the production from various feed stocks had been investigated, however, each of the feedstock has its own problems. For instance, the production of biofuel from waste oil has been described to be economical and readily available, however the inherent difficulties of processing and gathering remain the major factor that militate against its usage as a feedstock in the production of biodiesel (Whang et al 2003(a&b)). Edible sources like soybeans, sunflower seeds and cotton seeds etc. which are easily available and can be gathered and processed easily need to be closely monitored and controlled in other not to create larger global problems of deforestation, hunger and poverty while trying to solve the problem of energy crises. Critics of biofuel fear that the uses of food (edible oil) as a feed feedstock in the production of biodiesel could result into food crisis. It has been reported that to produce 5% of the total diesel consumption in United State of America

from biodiesel, will require approximately 60 % of the crop produced in United State, the action consider being unethical by the critics. Despite the wide acceptance of biofuel as alternative energy source to supplement or replace fossil fuel. The latest research and development in the production of biodiesel is aimed at producing the biofuel from non edible oil like Jatropha Curcas, sunflower etc. Employing non edible oil as a feedstock in the production of biodiesel will actually help in solving the strain relationship between the energy sectors and critics of production of biodiesel from edible oil which was considered unethical. This present study is therefore focus on the optimization of extraction of oil from moringa oleifera seed kernel which is non edible oil especially in Nigeria where it is abundantly available, as an alternative feedstock in the production of biodiesel. Moringa Oleifera (Zogale) seed kernel contains about 45% oil by weight. The oil can be use for cosmetic making, lubrication and consumption. Beside its industrial use as a fine lubricant, the fatty acid profile of the oil with its high content of oleic acid make it an oil with potential for further industrial application (Michelle, 1994). Moringa oleifera seeds are available in abudant in Minna and utilizing the oil from the seed to produced biodiesel will not constituite any enviromental hazard.

1.1 War of energy and food security

Food security refers to the availability of food and one's access to it, a household is therefore, considered food-secure when its occupants do not live in hunger or fear of starvation. According to FAO, 2008, food security exists when all people, at all times, have physical, social and economic access to sufficient, safe and nutritious food to meet their dietary needs and food preferences for an active and healthy life. Hence, the stages of food insecurity range from food secure situations to full-scale famine. Generally, the food insecurity can be categorized as either chronic or transitory. In chronic food insecurity situation, the societies exposed to a high degree of vulnerability to famine and hunger. The situation is similar to undernourishment and is related to poverty, which is existing mainly in poor countries (Ayalew, 1988). Many countries experience perpetual food shortages and distribution problems, which resulted in chronic and often widespread hunger amongst significant numbers of people. Worldwide around 852 million people are chronically hungry due to extreme poverty, while up to 2 billion people lack food security intermittently due to varying degrees of poverty (FAO, 2003). According to CNN report (2009), six million children die of hunger every year - 17,000 every day. It has been reported that as of late 2007, export restrictions and panic buying, US Dollar depreciation, (HM Government, 2010) increased farming for use in biofuel (Smith and Edwards, 2011), world oil prices at more than $100 a barrel (The Monitor's view, 2008), global population growth, (Randerson, 2008) climate change (Vidal, 2007), loss of agricultural land to residential and industrial development (Dancy, 2008) and growing consumer demand in China and India (Walt, 2008) are claimed to have pushed up the price of grains (Brown, 2008). The issue of food security is therefore a complex objective pursued with shelter, safety, health and self-esteem in a world where individual households, face diverse complex and different livelihood opportunities (Smit *et al.*, 1993). Hence, the proper understanding of food security requires explicit recognition of complexity and diversity, and that it necessarily privileges the subjective perceptions of the food insecure themselves (World Bank, 1986).

Energy security is a term used to describe an association between national security and the availability of natural resources for energy consumption. Though, access to cheap energy has become essential to the functioning of modern economies, however, the uneven

distribution of energy supplies among countries has led to significant vulnerabilities. It has been reported that energy security resulted into the political instability of several energy producing countries, the manipulation of energy supplies, the competition over energy sources, attacks on supply infrastructure, as well as accidents, natural disasters, the funding to foreign dictators, rising terrorism, and dominant countries reliance to the foreign oil supply (Wesley, 2007). The world wide over dependence on the oil and the peaking limits of oil production, it is obvious that economics and societies will begin to feel the decline in the resources that we have dependent upon. Hence, the issue of energy security has become one of the leading issues in the world today as oil and other resources have become as vital to the world's people. The looming end of the era of cheap oil is going to put the energy security of most industrialized countries in jeopardy and the same is true in the case of food since many of the imports which are not sustainable even at this very moment, may become far too expensive to afford. It is therefore, important that both of these issues are extremely serious and need to be dealt with and addressed immediately.

Food security is probably on a more serious level than energy security even though both have to be considered side by side. The high prices of food today are mostly driven by elevating demand due to rapid population growth among other conventional factors such as urbanization and industrialization, economic growth and food consumption, and land use changes and water scarcity (Khan *et al*., 2009). Today there are almost 219,000 additional people to feed at the global table every night, this unfortunate scenario is the consequenc of the current competition between food and energy. Most developed nations are now converting food products into energy sources, for instance, the United States is now converting massive quantities of grains into fuel for cars, even with increasing grain consumption. This massive capacity to convert grain into fuel means that the price of grain is now tied to the price of oil. The same phenomenon is also happening in Brazil, where distills ethanol from sugar cane, ranks second in production after the United States, while the European Union's goal of getting 10 percent of its transport energy from renewable, mostly biofuel, by 2020 is also diverting land from food crops (Eaves and Eaves, 2007).

1.2 Application of optimization in solvent extraction

Principles of optimization find applications in the fields of science, engineering, and business. Optimization is therefore concerned with selecting the best among the entire set by efficient quantitative methods (Onifade, 2002). It has been reported that the recent development in chemical and process engineering industry has undergone significant changes during the past few years due to the increased cost of energy, increasingly stringent environmental regulations, and global competition in product pricing and quality (Onifade, 2002). One of the most important engineering tools for addressing these issues is optimization of the technique involved. Effective optimization techniques are now available in software for personal computers, a capability that did not exist some years ago. To achieve effective application of optimization in the chemical and process industries, there is the need for proper understanding of both the theory and application by engineers and scientists who find optimization as the decision making process which is the exasperating and difficult. In this present study, optimization technique is employ to determine the best conditions at which oil can be extracted from moringa oleifera seed by solvent extraction method.

The process of solvent extraction of oil , includes diffusion of a solvent into oil-bearing cells of vegetable oil seeds resulting in a solution of the oil in solvent. Various solvents can be used for extraction. However, after extensive research and consideration of various factors, such as commercial economics, edibility of the various products obtained from extraction, physical properties of the solvent especially its low boiling point, volatility, toxicity, viscosity etc. Hence, the selection of the equipment for an extraction process is influenced by the factors, which are responsible for limiting the extraction rate. Thus if the diffusion of the solute through the pores of the residual solid is the controlling factors, the material should be of small size so that the distance the solute has to travel is small. On the other hand, if the diffusion of the solute from the surface of the particle to the bulk of the solution is the controlling factor, then a high degree of agitation is required for optimum leaching of the seed, thus particle size, temperature, agitation and solvent are the major factors influencing solvent extraction techniques. These factors are therefore combined during experimental design which resulted into what is described as factorial experimental design for the purpose of optimizing the process and to investigate the interaction between the various factors that influence the rate of extraction.

The method of factorial experimental design forces data to be orthogonal which allows one to determine the relative importance of each input variable and thus to develop a parametric model that includes only the most important variables and effects. It also represents efficient method of experimentation to determine the best operating condition for each variable factor that influences the process. In factorial experimental design, experiments are systematically planned and conducted in such a way that all the variable factors are changed simultaneously rather than one at a time, for the purpose of reducing the number of experiments. Due to the orthogonal nature of a factorial design method, statistical tests are effective in discriminating among the effects of different natural variations such as the unit operations, operators, batches and other environmental factors. The standard factorial design therefore requires 2^k tests, where k represents the number of input variables to be investigated. It is also important for the user of factorial design to decide the extent to which each of the variable input should be changed from its original value. To take this decision, the user needs to take into account the sensitivity of the process response to a change in a given input variable, as well as the typical operating range of the process. The experimental design range should therefore be chosen in other to avoid the possibility of the response of the resulting measurements not to generate errors that are far greater than the typical real values. To achieve this in experimental factorial design, variance (ANOVA) or regression analysis can be use to analyzed the experimental results effectively, which is relatively easy to determine the major effect of a variable factor. The factorial design therefore,becomes an important tool in the solvent extraction techniques.

2. Moringa oleifera

Moringa oleifera popularly called Zogale in the northern part of Nigeria is the most widely cultivated variety of the genus Moringa and belong to the family of Moringaceae. Moringa oleifera is a nutritious vegetable tree with a variety of potential uses. The moringa oleifera tree shown in Figure 2.1 is slender with drooping branch that grows to approximately 10 m in height. To maintain the pod and leaves within the arms reach, the tree is normally cut to one meter or less.

Fig. 2.1. Moringa oleifera tree

The Moringa tree grows mainly in semi-arid tropical and subtropical areas, but grows best in dry sandy soil; it tolerates poor soil, including coastal areas. It is a fast-growing, drought-resistant tree that is native to the southern foothills of the Himalayas, and possibly Africa and the Middle East. The tree has its origin from the Southern Indian State of Tamilnadu. Today, it is widely cultivated in Africa, Central and South America, Sri Lanka, India, Mexico, Malaysia and the Philippines. It grows up to 4m in height and develops to flowering and fruiting within one year of its cultivation. Moringa oleifera is considered as one of the world's most useful trees, this is because almost every part of the tree can be used for food, or has some other beneficial property. Hence it is commonly called the *'Wonder Tree'*. In the tropics, it is used as foliage for livestock. The immature green pods, called "drumsticks" are probably the most valued and widely used part of the tree. They are commonly consumed in India, and are generally prepared in a similar fashion to green beans and have a slight asparagus taste (Rajangam *et al, 2000*).

The Moringa seeds (Figure 2.2) yield 38–45% edible oil (called Ben oil, from the high concentration of Behenic acid contained in the oil) that can be used in cooking, cosmetics and lubrication. Unfortunately, the oil from moringa oleifera seed is not popular edible oil in Nigeria; hence extraction of oil for the purpose of biodiesel production will not pose any food shortage threat which is a major factor against the production of biodiesel from vegetable oil.

Fig. 2.2. Moringa oleifera (a) Dried pods (b) Seed kernel with husks (c) seed kernel without husk

The refined oil is clear, odourless and resists rancidity like any other botanical oil. The seed cake remaining after the oil extraction can be used as fertilizer or as flocculants to treat turbid water. The leaves are highly nutritious, being a significant source of beta-carotene, Vitamin C, protein, iron and potassium; it is consumed mostly among the Hausas in Northern Nigeria. In addition to being used fresh as a substitute for spinach, the leaves are commonly dried and processed into powder and used in soups and sauces.

3. Methodology

3.1 Material and equipment

This study focus on the extraction of oil from moringa oleifera seed by means of solvent extraction and production of bio-ethanol from rice husk using alkali as the hydrolising agent and zymomonas for fermentation. The entire chemicals used in this study are of analytical grade (98-99.5%). They include hexane, ethanol, iodine, sodium hydroxide, calcium oxide, potasium iodide and potasium hydroxide. The equipments used are mortar and pestle, sieve, electronic weighing balance, thimble, measuring cylinder, stop watch, pH meter,

electric oven and distillation column. The moringa oleifera seeds and rice husk used in this study were collected in Bosso Estate, Minna, Niger State, Nigeria.

3.2 The 2^k factorial experimental design

When several factors are of interest in an experiment a factorial method of analysis is used in order to study the effect of individual factor and its interaction with other factors to economize the experimental resources (Azeez, 2005;Zhang and Huang, 2011; Wang et al., 2011). In this study, three factors namely temperature, particle size and resident time are of interest while agitation was kept constant. This gives rise to three-factor factorial experiment; the factors are tested at high and low levels. When three factors are tested at two levels as applicable in this study, it is denoted by 2^3 factorial; thus there exist eight (2^3) treatment combinations as shown in Table 3.1. The table indicates how the individual effect and interactions are calculated. It was assumed that A,B and C are the fixed factors where there are 'a' levels of A, 'b' levels of B and 'c' levels of C arranged in the factorial experiment. Generally there will be abc…..n total observations if there are n replicates of the complete experiment. The analysis variance is shown in Table 3.2.

Treatment combination	Factorial Effect							
I	I	A	B	C	AB	AC	BC	ABC
A	+	-	-	-	+	+	+	-
B	+	+	-	-	-	-	+	+
Ab	+	-	+	-	-	+	-	+
C	+	-	-	+	+	-	-	+
Ac	+	+	-	+	-	+	-	-
Bc	+	-	+	+	-	-	+	-
Abc	+	+	+	+	+	+	+	+

Table 3.1. Design matrix for a 2^3 Factorial Design

Consider a three factors experiment, with underlying model as shown in Equation1, before the model equation can be fitted, it is important to conduct some statistical tests such as G-test, T-test and F-test, which involves calculation of these statistical parameters with the aid of certain formulae shown in Equations 2-4 and compare them with those given in the statistical tables. G-test is used to check if the output has the maximum accuracy of replication. T-test is used to check the significance of regression coefficient, and F-test is used to test for the adequacy of the model. Equations 2-4 represent the formulae to calculate G-test, T-test and F-test respectively.

Sources of Variation	Sum of Squares	Degree of Freedom	Mean Square	Expected Mean Squares	F_o
A	SS_A	$(a-1)$	MS_A	$\delta^2 + (bcn\ \Sigma\ \tau^2_i)/\ (a-1)$	MS_A/MS_E
B	SS_B	$(b-1)$	MS_B	$\delta^2 + (can\ \Sigma\ \beta^2_j)/(b-1)$	MS_B/MS_E
C	SS_C	$(c-1)$	MS_C	$\delta^2 + (abn\ \Sigma\ \gamma^2_k)/(c-1)$	MS_C/MS_E
AB	SS_{AB}	$(a-1)(b-1)$	MS_{AB}	$\delta^2 + (cn\Sigma\Sigma(\tau\beta)^2_{ij})/(a-1)(b-1)$	MS_{AB}/MS_E
AC	SS_{AC}	$(a-1)(c-1)$	MS_{AC}	$\delta^2 + (bn\Sigma\Sigma(\tau\gamma)^2_{ik})/(a-1)(c-1)$	MS_{AC}/MS_E
BC	SS_{BC}	$(b-1)(c-1)$	MS_{BC}	$\delta^2 + (an\Sigma\Sigma(\beta\gamma)^2_{jk})/(b-1)(c-1)$	MS_{BC}/MS_E
ABC	SS_{ABC}	$(a-1)(b-1)(c-1)$	MS_{ABC}	$\delta^2 + (n\Sigma\Sigma\Sigma(\tau\beta\gamma)^2_{ijk})/(a-1)(b-1)(c-1)$	MS_{ABC}/MS_E
Error	SS_E	$abc(n-1)$	MS_E	δ^2	
Total	SS_T				

Table 3.2. Variance (ANOVA) analysis

$$Y_{ijkl} = \mu + \tau_i + \beta_j + \gamma_k + (\tau\beta)_{ij} + (\tau\gamma)_{ik} + (\beta\gamma)_{jk} + (\tau\beta v)_{ijk} + E_{ijk} \tag{1}$$

$i = 1,2,---a$
$j = 1,2,---b$
$k = 1,2,---c$
$l = 1,2,---n$
Where μ is the overall mean effect,
     τ_i is the effect of the ith level of factor A
     β_j is the effect of jth level of factor B
     γ_k is the effect of kth level of factor C
     $(\tau\beta)_{ij}$ is the effect of the interaction between A and C
     $(\beta\gamma)_{ik}$ is the effect of the interaction between B and C
     $(\tau\beta v)_{ijk}$ is the effect of the interaction between A, B and C
E_{ijkl} is the random error component having a normal distribution with zero and variance δ^2

$$G_{-cal} = \frac{Su^2_{max}}{\Sigma\ Su^2} \tag{2}$$

$$T_{-cal} = \frac{|b_j|}{Sb} \tag{3}$$

$$Sb = \frac{\sqrt{(Su^2)}}{\sqrt{(N.r)}}$$

$$F_{-cal} = \frac{S^2_a d}{su^2} \tag{4}$$

$$S^2_a d = \frac{r}{N-\lambda}\Sigma(Y - Y_{cal})^2$$

$$Su^2 = \frac{1}{r-1}\Sigma(Y_r - Y_i)$$

Where

$S^2_a d$ = the dispersion of adequacy

Su^2 = sum of dispersion

bj = coefficient of equation variable

λ = insignificant coefficient = 2

r = number of replicates for a particular run = 2

N = number of runs =8

Y = experimental yield

Y_{cal} = response yield calculated using the appropriate model equation

Y_r = response yield of a replicate

Y_i = average response yield of the replicate for a run

3.3 Production of bio-ethanol from rice husk

Prior to the production of bio-ethanol, the rice was treated to confirm the presence of starch. Paddy rice was milled sieved and the residue was collected and weighed. $2cm^3$ of sample was measured from the bulk sample and transferred into the test tube. Potassium iodide reagent was then added drop wise into the sample in the test tube and stirred until colour was changed from yellow to black, which confirm the presence of starch. 500g of the husk was collected and soaked in $750cm^3$ of water for a period of 24 hours after which it was filtered with the aid of a filter cloth, $600cm^3$ of the filtrate was collected and made up to $1000cm^3$ with boiled water, the mixture was stirred continuously to avoid formation of lumps, it was then allowed to cool and on cooling, a thick-jelly mass was formed, gelatinized mixture was then poured into a $2000cm^3$ flask for hydrolysis. $200cm^3$ of 0.5m potassium hydroxide was added to the sample and immersed in the water bath for hydrolysis and the temperature was maintained at 75oC for 60 minutes. $100cm^3$ of 50% ethanoic acid was then added to serve as a terminator of the hydrolysis reaction after which the mixture was set aside to cool. $4cm^3$ of hydrolyzed sample, , few drops of Fehling's solution was added in a conical flask and heated, colour change was observed and recorded, sample changes to brick red precipitate, which confirm the presence of simple sugars.

3.3.1 Fermentation of hydrolysed rice husk

Zymomonas mobilis "Local strain" was isolated from palm wine using standard solid medium. Media constituents include 5.0g of yeast extract, 20g of agar and $1000cm^3$ of distilled water with pH 6.8. Medium was treated with actidione (cycloheximide) to inhibit *Zymomonas mobilis* growth before autoclaving at 121oC for 15 minutes. *Zymomonas mobilis* was then inoculated into the medium and incubated an aerobically at 3oC for 24 hours. Working close to the flame (creating aseptic environment), *Zymomonas mobilis* was introduced into the conical flask containing the substrate, the flask were then shaken (agitation process) and the mouths of the conical flasks were flamed before corking back and incubating at room temperature, they were shaken at various intervals in order to produce a homogenous paste and even distribution of the organisms in the substrates. After fermentation process, the substrates were then filtered using filter cloth and collected in a conical flask, in order to separate the desired product (the filtrate) from the residue. The filtrates were then distilled at 78.3oC using alcohol distillation apparatus, round bottom flask containing the filtrate was placed in the heating mantle and the mouth fixed to the condenser, a beaker for distillate collection was placed at the end of the set up, rubber pipes

or hose were connected to the condenser to supply water from the tap for cooling the condenser to supply water from the tap for cooling the condenser and letting out water out of the condenser simultaneously. Temperature on the heating mantle was set to the standard temperature for the production of ethanol which is 78.3oC, as the filtrate was heated, the vapour rose and entered into the condenser, tap water was passed into and out of the condenser using the rubber pipes and this condenses the vapor from the heated filtrate, condensed vapour was collected into the beaker at the other end of the distillation set up as the distillate (bio-ethanol), this process was repeated for other samples. The distillate was further purified by the use of calcium oxide (lime), a basic oxide, when added to the ethanol, absorbed the water to form calcium hydroxide, an alkaline solution; calcium hydroxide formed was separated from ethanol by further distillation which leaves absolute ethanol. One cm^3 of alcohol was treated with iodine and sodium hydroxide, the colour change was observed and recorded, yellow precipitate was formed, which confirm that ethanol is present. The produced bio-ethanol was characterized to determine the density, flash point, pour point.

4. Results and discussion of results

4.1 Results and statistical analysis of experimental results

Tables 4.1 and 4.2 present the results on the extraction of oil from moringa oleifera seed with hexane and ethanol as the solvent respectively at different temperature, particle size and resident time. Results obtained as presented indicate that there are thirty two experimental runs with two replicates each for sixteen samples. It can be seen from the results that the extraction time, temperature, particle size and type of extraction solvent affects the rate of extraction of oil from oleifera moringa seed. Ethanol plays a major role in the production of biodiesel from oil, achieve a suistainable production of biodiesel therefore, it is important to employ a cheap and suistanable method of ethanol production. In this work the production of bioethanol from agricultural waste (rice waste) was also conducted and the results obtained are presented in Tables 4.3 and 4.4.

Results presented reveals that at the extraction conditions combination with all samples at low levels, the oil yield was 37.78% and 37.35% for the replicate using n-hexane. Ethanol yielded 19.90% and 20.25% for the replicate. While For treatment combination where the temperature was high (65oC) while particle size and extraction time were low (500µm and 6hr respectively) n-hexane yielded 38.58% and 38.37% for the replicate. Ethanol at a high temperature of 75oC and particle size (500µm and extraction time of 6hrs yielded 20.82% and 21.23% for the replicate. Similarly For treatment combination where the temperature was low (55oC) while particle size high (710µm) and extraction time low (6hr) n-hexane yielded 43.17% and 43.26% for the replicate. Ethanol at a low temperature of 65oC, particle size high (710µm) and extraction time low (6hrs) yielded 38.71% and 38.65% for the replicate. While for extraction combination where the temperature was (55oC) and particle size (500µm) are low, extraction time was high (7hrs) n-hexane yielded 42.22% and 41.98% for the replicate. Ethanol at a low temperature and particle size (65oC and 500µm respectively) and extraction time high (7hrs) yielded 22.16% and 21.96% for the replicate. Also for the extraction conditions combination where the temperature and particle size were high (65oC and 710µm respectively) and extraction time were low (6hr) n-hexane yielded 43.01% and 42.95% for the replicate. Ethanol at a high temperature and particle size of (75oC and 710µm respectively) and low extraction time of 6hrs yielded 35.32% and 35.68% for the replicate. Results

presented also shows that, for the extraction combination where the temperature was high (65°C), low particle size (500µm) and high extraction time (7hrs) n-hexane yielded 42.81% and 42.25% for the replicate. Ethanol at a high temperature of 75°C, low particle size (500µm) and high extraction time of 7hrs yielded 26.67% and 26.14% for the replicate. It could be observed from the Tables of result that, for treatment combination where the temperature was low (55°C) while particle size and extraction time were high (710µm and 7hrs respectively) n-hexane yielded 41.38% and 41.35% for the replicate. Ethanol at a low temperature of 65°C, high particle size and extraction time (710µm and 7hrs respectively) yielded 28.84% and 28.24% for the replicate. Finally, for extraction condition combination where all the parameters are high temperature (65°C), particle size and extraction time were (710µm and 7hr respectively) n-hexane yielded 42.03% and 42.52% for the replicate. Ethanol at a high temperature of 75°C, particle size and extraction time (710µm and 7hrs respectively) yielded 24.75% and 25.03% for the replicate

S/N	wt of oil extracted (g)	% wt of oil extracted	Temp (°C)	Particle Size (µm)	Resident Time (hr)
Solvent = Hexane					
1	4.22	42.03	65	710	7
2	4.15	41.38	55	710	7
3	4.23	42.22	55	500	7
4	4.29	42.81	65	500	7
5	3.87	38.58	65	500	6
6	3.79	37.78	55	500	6
7	4.31	43.01	65	710	6
8	4.33	43.17	55	710	6
Solvent = Ethanol					
1	2.48	24.75	75	710	7
2	3.76	28.84	65	710	7
3	2.22	22.16	65	500	7
4	2.67	26.67	75	500	7
5	2.09	20.82	75	500	6
6	2.00	19.90	65	500	6
7	3.55	35.32	75	710	6
8	3.89	38.71	65	710	6

Table 4.1. Oil yield at various conditions from the first run with hexane and ethanol as the solvent

S/N	wt of oil extracted (g)	% wt of oil extracted	Temp (°C)	Particle Size (μm)	Resident Time (hr)
Solvent = Hexane					
1	4.27	42.52	65	710	7
2	4.14	41.35	55	710	7
3	4.21	41.98	55	500	7
4	4.23	42.25	65	500	7
5	3.83	38.15	65	500	6
6	3.70	36.92	55	500	6
7	4.30	42.95	65	710	6
8	4.34	43.26	55	710	6
Solvent = Ethanol					
1	2.57	25.65	75	710	7
2	3.71	27.05	65	710	7
3	2.35	23.45	65	500	7
4	2.77	27.65	75	500	7
5	2.18	21.74	75	500	6
6	2.44	20.34	65	500	6
7	3.45	34.28	75	710	6
8	3.92	38.96	65	710	6

Table 4.2. Oil yield at various conditions from the second run with hexane and ethanol as the solvent

Substrate	Volume of hydrolysate (cm³)	Volume of ethanol (cm3)	% Ethanol concentration
Rice husk	350	25	7.143
	300	35	11.667
	250	37.5	14.880
	150	43	28.667

Table 4.3. Ethanol production using Zymomonas mobilis from distillation process

Properties	Commercial grade ethanol	Bio-ethanol produced from rice husk
Appearance	Clear, colourless liquid	Clear, colourless liquid
Boiling point (°C)	78.15	78.3
Density (g/cm³)	0.789	0.787
Viscosity	1.20	1.34
Flammability	Flammable	Flammable
Flash point (°C)	13	14.5
Refractive index	1.3614-1.3618	1.3626

Table 4.4. Properties of produced ethanol compared to commercial ethanol

4.1.1 Statistical analysis of experimental results

Statistical analyses were conducted with the aim of developing a model to represent the relationship between the factors investigated and the yield of oil from the moringa oleifera seeds with hexane and ethanol as the extraction solvent. Table 4.4 shows an estimation of upper and lower levels of the three factors (temperature, particle size and time). While Tables 4.5 and 4.6 indicates factorial experimental design results with n-hexane and ethanol as the extraction solvent respectively.

The average effect of a factor which is described as the change in response produced by a change in the level of factor response produced by a change in the level of factor averaged over the levels of other factors. This has been calculated and subsequently tabulated in Table 4.7 for n-hexane and ethanol.

Level of Factor	Code	A Temperature (°C)		B Particle Size (μm)	C Time (hrs)
		Hexane	Ethanol		
High level	+1	65	75	710	7
Low level	-1	55	65	500	6

Table 4.4. Factors and their coded levels

Treatment combination		Design factor			First yield Y_1	Second yield Y_2	Average yield Y_{av}
Run		A	B	C			
1	I	-1	-1	-1	37.78	36.92	37.35
2	A	+1	-1	-1	38.58	38.15	38.37
3	B	-1	+1	-1	43.17	43.26	43.22
4	C	-1	-1	+1	42.22	41.98	42.10
5	Ab	+1	+1	-1	43.01	42.95	42.98
6	Ac	+1	-1	+1	42.81	42.25	42.53
7	Bc	-1	+1	+1	41.38	41.35	41.37
8	Abc	+1	+1	+1	42.03	42.52	42.28

Table 4.5. 2^3 Factorial experimental design results using n-hexane as extraction solvent

Treatment combination		Design factor			First yield Y_1	Second yield Y_2	Average yield Y_{av}
Run		A	B	C			
1	I	-1	-1	-1	19.90	20.25	20.08
2	A	+1	-1	-1	20.82	21.25	21.04
3	B	-1	+1	-1	38.71	38.65	38.65
4	C	-1	-1	+1	22.16	21.96	22.06
5	Ab	+1	+1	-1	35.32	35.68	35.50
6	Ac	+1	-1	+1	26.67	26.14	26.41
7	Bc	-1	+1	+1	28.84	28.24	28.54
8	Abc	+1	+1	+1	24.75	25.03	24.89

Table 4.6. 2^3 Factorial experimental design results using ethanol as extraction solvent

Factors and interactions	Main effects (n- hexane)	Main effects (Ethanol)
A	0.5300	-0.3813
B	2.4975	9.5213
C	1.5900	-3.3488
Ab	-0.1925	-3.0338
Ac	0.1400	0.7288
Bc	-2.8675	-7.0263
Abc	0.4325	-0.8750

Table 4.7. Effects and interactions for solvent extraction of oil using n-hexane and ethanol

Variance (ANOVA) analysis, which enables one to examine the magnitude and direction of the factors' effect and determine which variable are likely to be important was also conducted and the results are presented in Table 4.8 and 4.9 respectively for n-hexane and methanol as the extraction solvent. Variance analysis also helps to determine the statistical significance of the regression coefficients (β_i). The level of significance was assumed to be 5% (α = 0.05), which implies that there are about five chances in hundred that reject the hypothesis when it should be accepted: i.e. 95% confidence that right decision is made. Therefore the critical value for each of the F-ratio F {α ,dfr, abc(n -1)}i.e. F(0.05,1,8 is equal to 5.32 from statistical table is equal to 5.32 from statistical table. The F-ratios were compared with this critical value (5.32) and the null hypothesis using Fcal > F(0.05,1,8) = 5.32. The magnitude of the effects when n-Hexane was used as the extraction solvent indicates that particle size (factor B) is dominant and has a high significant followed by the extraction time (factor C) and the effect of factor A, extraction temperature which is relatively low.

Sources of variation	Sum of square	Degree of freedom	Mean square	Expected mean square	F_o
A	1.1236	1	1.1236	39.5575	2.2940
B	22.5150	1	22.5150	41.4025	45.9677
C	10.1124	1	10.1124	40.6175	20.6460
Ab	0.1482	1	0.1482	41.9325	0.3026
Ac	0.0784	1	0.0784	41.1475	0.1601
Bc	32.8902	1	32.8902	42.9925	67.1503
Abc	0.7482	1	0.7482	43.5225	1.5276
Error	3.9182	8	0.4898		
Total		15			

Table 4.8. Analysis of variance (ANOVA) for the solvent extraction of oil using n-hexane

The magnitude of the effects when ethanol was used as the extraction solvent, clearly shows that particle size (factor B) is dominant and has a high significant followed by the interaction of factor A, extraction temperature and factor C, extraction time and the effect of factor A, extraction temperature which is relatively low. Presented in Tables 4.10 and 4.11 are the basic statistical test on the yield of oil from the moringa oleifera seed with n-hexane and ethanol as the extraction solvent respectively. While Table 4.12 present the statistical calculated values of G and F test.

Sources of variation	Sum of square	Degree of freedom	Mean square	Expected mean square	F_o
A	0.5814	1	0.5814	22.9526	1.0561
B	362.6206	1	362.6206	21.8374	658.9508
C	44.8578	1	44.8578	32.4602	81.5152
Ab	36.9372	1	36.9372	22.2200	67.1219
Ac	2.1246	1	2.1246	31.3450	3.8608
Bc	197.4756	1	197.4756	22.5700	358.8508
Abc	3.0625	1	3.0625	32.4602	5.5681
Error	0.5814	8	0.5503	32.0776	
Total		15			

Table 4.9. Analysis of variance (ANOVA) for the solvent extraction of oil using ethanol

	Y_{r1}	Y_{r2}	Y_T	Y_{av}	Y_{cal}	$(Y_{r1}-Y_{cal})^2$	$(Y_{r2}-Y_{av})^2$	$(Y_{r1}-Y_{av})^2$
1	42.03	42.52	84.55	42.28	39.03	9.0000	0.0576	0.0625
2	41.38	41.35	82.73	41.37	39.56	3.3124	0.0004	0.0001
3	42.22	41.98	84.20	42.10	41.40	0.6724	0.0144	0.0144
4	42.81	42.25	85.06	42.53	40.62	4.7961	0.0784	0.3136
5	38.58	38.15	76.73	38.37	41.93	11.2200	0.0484	0.0441
6	37.78	36.92	74.70	37.35	41.15	11.3600	0.1849	0.1849
7	43.01	42.95	85.96	42.98	42.99	0.0004	0.0009	0.0009
8	43.17	43.26	86.43	43.22	43.52	0.0081	0.0016	0.0025
Σ						40.3694	0.3866	0.6230

Table 4.10. Basic statistical test (n-Hexane)

	Y_{r1}	Y_{r2}	Y_T	Y_{av}	Y_{cal}	$(Y_{r1}-Y_{cal})^2$	$(Y_{r2}-Y_{av})^2$	$(Y_{r1}-Y_{av})^2$
1	24.75	25.65	50.40	25.20	22.95	3.2400	0.2025	0.2025
2	28.84	27.05	55.89	27.95	21.84	49.0000	0.8100	0.7921
3	22.16	23.45	45.62	22.81	32.46	106.0900	0.4096	0.4225
4	26.67	27.65	54.32	27.16	22.22	19.80000	0.2401	0.2401
5	20.85	21.74	42.56	21.28	31.35	0.8454	0.2116	0.2116
6	19.90	20.34	40.24	20.12	22.57	7.1289	0.0484	0.0484
7	35.32	34.28	69.60	34.80	32.46	8.1796	0.2704	0.2704
8	38.71	38.96	77.67	38.84	32.08	43.9569	0.0144	0.0169
Σ						238.24	2.2070	2.2405

Table 4.11. Basic statistical test (Ethanol)

Test	From Statistical Table	Calculated	
		n-Hexane	Ethanol
G-test	0.6800	0.6171	0.5003
F-test		34.8073	35.9825

Table 4.12. Statistical calculated values for G-test and F-test

Based on the statistical analysis of experimental results, the regression model for the 2^3 design analysis is therefore given by Equation 5, i.e.

$$Y = \alpha_o + \alpha_1 x_1 + \alpha_2 x_2 + \alpha_3 x_3 + \alpha_{12} x_1 x_2 + \alpha_{13} x_1 x_3 + \alpha_{23} x_2 x_3 + \alpha_{123} x_1 x_2 x_3 \qquad (5)$$

The Residual for 2^3 designs for the yield of oil from moringa oleifera seed kernel using n-Hexane can now be obtained by considering only the three largest effects, which are B, C and A. Equation 5 therefore reduced to;

$$Y = \alpha_o + \alpha_1 x_1 + \alpha_2 x_2 + \alpha_3 x_3 \qquad (6)$$

$$a_0 = \frac{1}{8} \sum (Y_i)$$

$$a_j = \frac{1}{8} \sum (Y_i S_i)$$

Where α_j is the coefficient of factor j and S_i is the sign of eight factor combinations from the design matrix table. Thus

$$Y = 41.275 + 0.265X_1 + 1.1875X_2 + 0.795X_3 \qquad (7)$$

Similarly, the residual for 2^3 designs for the yield of oil from moringa oleifera seed with ethanol as the extraction solvent can be obtained by considering only the three largest main effects, which are B, AC and A. The regression equation can therefore reduced to

$$Y = \alpha_o + \alpha_1 x_1 + \alpha_2 x_2 + \alpha_{13} x_1 x_3 \qquad (8)$$

Thus

$$Y = 27.1488 - 0.1913X_1 + 4.7538X_2 + 0.3663X_1 X_3 \qquad (9)$$

4.2 Discussion of results

The world is presently on the brinks of an environmental disaster owing to the build-up of harmful materials from the use of fossil oil as base oil for lubricants. Coupled with the prediction that the fossil oil will ultimately run out sometime in the future, there is therefore, the urgent need to source for replaceable and environmentally friendly base oil for lubricants. Biodiesels which is the product of transesterification of vegetables oil is considered as perfect alternative and sustainable energy sources, due to less emission and availability. The Promotion of Biomass faces an increasing rate of awareness, research and adoption. One way of increasing the adoption rate is to promote the utilization of the product from plants such as the leaves, fruits, stem, flowers and the roots of the trees. Presently, the alternative way of utilizing the fruit is to extract oil from the seeds, most of which are edible oil which is a source of concern. Despite the wide acceptance of biofuel as alternative energy to supplement or replace the fossil fuel, it will be wise to recognise the consequences of the new technology on the society. For instance, the production of biodiesel from edible oil could result in pressure on farmers, consequence of which is food shortage and environmental problem as a result of deforestation. Hence the need to produce the biodiesel from non-edible oil or from the sources that are not sources of production of edible

oil such as oil from moringa oleifera seed which is the focus of this study. In order to depend fully on less expensive materials for the production of biodiesel, this study also investigates production bio-ethanol from rice husk. The results of the effects of various parameters, such as extraction time, particle size, temperatures and types of extraction solvents influence the rate extraction of oil from moringa oleifera. In this study, effect of extraction on the yield of oil from moringa oleifera seed was investigated using n-hexane and ethanol as the extraction solvent. It has been reported that the entrainer chosen has to be a good selective solvent with sufficient low viscosity for it to circulate freely. A relatively pure solvent will initially increase the extraction rate, but as the extraction proceeds, the concentration of solute will increase and the extraction rate will progressively decrease, firstly because the concentration gradient will reduce and secondly, the solvent will generally become more viscous and thereby decreases its penetration power.

The results of analysis yield a model equation presented in Equation 7, which was not only used to obtain the effect of one factor on the other but also their interaction. From the analysis it was discovered that when n-hexane was used as the extraction solvent, the effect of factor B (particle size), has the highest magnitude of 2.4975 followed by the effect of factor C (extraction time) with a magnitude of 1.5900, the effect of factor A, extraction temperature is relatively low with a magnitude value of 0.5300. A "– "in a 2^k model equation implies an inverse proportionality, while "+" implies a direct proportionality. This means that the extraction temperature, X_1, the particle size X_2 and the extraction time X_3 are all directly proportional to the oil yield (Averill and Kelton, 1996 and Onifade, 2001). Results obtained on the effect of extraction temperature on the yield of oil as expected indicate that rate of extraction of oil from moringa oleifera seed is increases with increase in temperature. Increase in temperature positively affects the diffusivity of the solvent into the inner part of the seed and consequently aid the solubility of the oil in the solvent which increase the rate of extraction of oil from the seed. Though results obtained shows that increase in temperature favoured the extortion of oil, care must be taken not to exceed the limit, which is the boiling point of the solvent n-hexane. Exceeding the boiling temperature of the solvent could result into the evaporation of the solvent consequence of which is the quick usage of the solvent, which is not economical. Also investigated in this research is the effect of particle size on the rate of extraction of oil from the seed and from the model equation, the result reveal that the oil yield is directly proportional to the particle size i.e. oil yield increases with a increase in the particle size. It has been reported that the size of particle could influence the extraction rate and the yield of oil in a number of ways. For instance, the smaller the size of the particle the higher the interfacial area between the solid and the solvent, the higher the rate of transfer of the solute (oil), and the smaller the distance the solute must be diffused within the solid particle, hence the higher the rate of extraction of oil. It is therefore desirable that the range of the particle size should be small so that each particle will require approximately the same time of extraction. It is therefore important that particles size are well selected not to exist a critical particle size at which oil yield will no longer be optimum. Since above the optimum particle size, there will be a reduction in the surface area of the oil molecules exposed to the solvent for dissolution. The effect of time on the extraction of oil from moringa oleifera seed was studied using n-hexane as the solvent. Results obtained as presented in Table 4.1 and the statistical model (Equation 7) indicates that the oil yield has a direct proportion effect with the extraction time. This means that increasing the extraction time will bring about a high yield of oil, however, there is the need to optimized extraction time to save cost of production of oil from the seed. This is

because higher extraction time above the optimum time cannot yield oil more than the maximum oil content in the seed kernel.

With ethanol as extraction solvent, the effect of factor B (particle size) has the highest dominance of 9.5213. The interaction of factor AC, temperature and extraction time has an effect of 0.7288, while temperature has the least effect of -0.3813. The 2^3 factorial analyses, give a model equation (Equation 8). From the statistical model, it can be seen that the extraction temperature, X_1, is inversely proportional to the oil yield, the particle size X_2 and the extraction time X_3 are all directly proportional to the oil yield. The inverse proportion effect of temperature on the extraction of oil from moringa oleifera seed is an indication that a range of 65 – 70°C is adequate to give a better yield of oil. Above this temperature range, the effect of temperature on the oil yield is negative. Thus a reduction in the extraction temperature from the maximum will result in an increase in the yield of oil. Results obtained also shows that the oil yield is directly proportional to the particle size. Hence the effect of particle size on oil yield increases with an increase in the particle size this is because greater surface area of the oil molecules exposed to solvent for dissolution. In the same vein, increase in the extraction time leads to increase in the yield of from moringa oleifera seed with ethanol as the solvent.

Production of ethanol from starch or sugar based feedstock is among man's earliest ventures into value added processing, while the basic steps remain the same, the process has been considerably refined in recent years, leading to a very efficient process. Bio-ethanol is an alcohol made by fermenting sugar components of biomass (Bailey and Ollis, 1986; Elba and Antenieta, 1996). Apart from food and pharmaceutical uses, bio-ethanol is finding alternative uses as motor fuel and fuel additive, ethanol as motor fuel is preferred to fossil fuel in that, it is environmentally friendly, comes from a renewable source and has a higher performance in engine (Eurasia, 2009).It can be mass-produced by fermentation of sugars or by hydration of ethylene from petroleum and other sources (Eurasia, 2009). Hence the need to produce bio-ethanol from relatively inexpensive and readily available raw materials like rice husks. In this study, rice husks were used to produce ethanol through hydrolysis and fermentation with Zymomonas mobilis. In the process of fermentation, the organism fermented the substrate (rice husk) to produce ethanol, Zymomonas mobilis possesses alcohol dehydrogenase (ADH) and pyruvate decarboxylase (PDC) which is key enzymes in ethanol fermentation from organic substrate as stated by Gunasegaram and Chandra (1998). Results obtained of bio-ethanol from rice husks as presented in Table 4.3 indicates that the volume of bio-ethanol is influence by the volume of hydrolysate. The maximum volume of bio-ethanol produced was $43cm^3$ from 150 cm^3 of hydrolysate, while $25cm^3$ of bio-ethanol was produced from $350cm^3$ of the hydrolysate. The high yield of bio-ethanol from rice husk may be due to high carbohydrates contents of rice husk or the high ethanol tolerance of Zymomonas mobilis and the presence of alcohol dehydrogenase in Zymomonas mobilis which appears to facilitate ethanol formation even at high ethanol concentration. Presented in Table 4.2 are the properties of oil, such as viscosity, refractive index, density and flash point of the bio-ethanol produced from rice husk, which compared favorably with those of the commercially available methanol. The slight variation between the values of properties of bio-ethanol and that of the commercially available methanol can be attributed the sources of production and experimental methods employed. It can therefore be inferred that the bio-ethanol produced from rice husk cab be used as an alternative feedstock for the production of biodiesel base on the properties of bio-ethanol presented in table 4.2.

5. Conclusion

The need for alternative sources of energy other than fossil fuel gained momentum recently, and biofuel is considered perfect alternative sources of energy that is sustainable and reliable. However, the possibility of producing biofuel in commercial quantities is not certain; this is blame on the consequence effects of producing the biofuel from vegetable oil, as this can lead to food shortage. To achieve commercial availability of biofuel, it is therefore important to produce biofuel from non-edible oil or from the sources that are not popular sources of edible oil. To achieve commercial realisation of biodiesel production, this work focuses on the extraction and optimization of oil from moringa oleifera seed as an alternative feedstock for the production of biodiesel. Analysis of results indicates that when n-hexane was employed as the extraction solvent, the effect of particle size has the highest effect with magnitude of 2.50, followed by the extraction temperature with magnitude of 1.59, while the effects of extraction time was the lowest with the magnitude value of 0.53. With ethanol as the extraction solvent, particle size also has the highest dominance of 9.52, while the interaction of temperature and time has an effect of 0.73, while the extraction temperature was -0.3813. Based on these results it can be deduce that for an appreciable yield of oil to be achieved with ethanol as the solvent, the particle size and interaction of temperature and time are the factors which have high significance. Results obtained from the production of bio-ethanol from husk indicate that, it is possible to produced bio-ethanol from rice husk, which is also a major a feedstock in the production of biodiesel.

6. Acknowledgment

7. References

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Tall Wheatgrass Cultivar Szarvasi-1 (*Elymus elongatus* subsp. *ponticus* cv. Szarvasi-1) as a Potential Energy Crop for Semi-Arid Lands of Eastern Europe

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1. Introduction

By 2020, proportion of renewable energy sources should be around 20 per cent of the total energy consumption in the European Union, according to the new treaty signed by European leaders in 2009. This vast amount of renewable energy can be sourced from hydroelectric, geothermal, wind, solar power and, of course, from biofuels. To achieve this ambitious target, new technologies must be invented to exploit energy from the abiotic source of renewables and new energy plant species should be developed and produced, serving as source for solid, liquid biofuels and for biogas production. The most intensively studied and used bioenergy crops include miscanthus, reed canary grass, willows and poplars. We already have considerable knowledge about these energy plants from their taxonomical relations to their detailed crop technologies. In this chapter, we introduce a novel energy plant that has been cultivated for more than a century in many parts of the world for numerous purposes (e.g. land remediation, erosion control, forage), but its potential for energy production has not yet been realized. Tall wheatgrass, a new energy crop (*Elymus elongatus* subsp. *ponticus* cv. Szarvasi-1) has recently been introduced to cultivation in Hungary to provide biomass for solid biofuel energy production. The cultivar was developed in Hungary. The main goal of our research was to investigate the performance of Szarvasi-1 energy grass under different growing conditions (e.g. soil types, nutrition supply). We focused on the ecological background, biomass yield, weed composition, morphology, ecophysiology and the genetics of the plant.

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2. Description

2.1 Origin and distribution

Tall wheatgrass is a Pontic-Mediterranean grass species. Its distribution ranges along the Mediterranean Basin from the Black Sea to the Iberian Peninsula. This vast area is covered by two, morphologically very different subspecies. The shorter and more fragile *E. elongatus* (Host) Runemark subsp. *elongatus* occurs in the western basin of the Pontus-Mediterranean area, while the taller and more robust *E. elongatus* (Host) Runemark subsp. *ponticus* (Podp.) Melderis occupies the Eastern Mediterranean Basin. The latter is also native to Hungary, reaching the north-westernmost part of its distribution in this area (Tutin et al., 1980).

Szarvasi-1 energy grass was bred as an intra-specific hybrid of drought-tolerant and robust *E. elongatus* subsp. *ponticus* populations from Hungary and from different pontic areas (Janowsky & Janowszky, 2007). The 10-year-long breeding process was conducted in Szarvas (East Hungary) but more recently the new breed has been involved in extensive crop management studies in different parts of the country. The Szarvasi-1 tall wheatgrass cultivar was officially recognized by the Hungarian Central Agricultural Office in 2004.

2.2 Taxonomy and nomenclature of *Elymus elongatus*

Classification and nomenclature of wheatgrass species has been the subject of much taxonomic debate (Assadi & Runemark, 1995; Mizianty et al., 1999; Murphy & Jones, 1999). Consequently, representatives of this genus are known by several scientific and vernacular names. Synonyms of *Elymus elongatus* (Host) Runemark (tall wheatgrass) include: *Agropyron elongatum* (Host) Beauv., *Elytrigia elongata* (Host) Nevski, *E. pontica* (Podp.) Holub, *Elymus varnensis* (Velen.) Runemark, *Lophopyrum elongatum* (Host) A. Löve and *Thinopyrum ponticum* (Podp.) Liu & Wang.

2.3 Genetic diversity of energy grass cultivar Szarvasi-1

Besides studying the agronomical features of Szarvasi-1, it was important to reveal its genetic background, in order to ascertain its taxonomic position in the system of grasses (focusing on the Triticeae tribe), to assess genetic similarities among the closely related *Agropyron* and *Elymus* genera and to establish genetic relationships among native Hungarian populations of *E. elongatus* (the hypothesised ancestor of Szarvasi-1) and the cultivar.

As a first step the genetic background of Szarvasi-1 and its relatives was studied by RAPD (Randomly Amplified Polymorphic DNA) technique, which allowed the random study of the whole genome with no prior knowledge required. RAPDs can produce a large set of markers, which can be used for the evaluation of both between- and within-species genetic variation, more rapidly and easily than isozymes and microsatellites (Guadagnuolo et al., 2001). To determine the exact taxonomic position of the cultivar among its relatives, specific primers for sequencing specific DNA regions were used. The sequences were compared and phylogenetically analysed. Our results indicated a potential risk of gene flow, which is a possible disadvantage of planting Szarvasi-1 energy grass on large scale.

2.3.1 Interspecific study

The interspecific variation of three *Elymus* and an *Agropyron* species together with the Szarvasi-1 cultivar was screened with 61 RAPD primers (Table 1.). The most informative 16

primers were retained, due to their ability to produce polymorphic, unambiguous and stable RAPD markers. Various banding patterns were revealed by different primers, but only polymorphic fragments of high intensity and moderate size (between 100 and 3000 bp) were used. About 98% (131 bands) of the total number of bands (136) were polymorphic. Though the high number of polymorphic bands allows the easy differentiation of analyzed samples using RAPD markers, it gives poor information regarding the relationships among the studied taxa.

Genus	Species	Synonyms
Agropyron Gaertner	*cristatum* (L.) Gaertner	*Eremopyrum cristatum* (L.) Willk.
Elymus L. (*Roegneria* Koch, *Elytrigia* Desv., *Clinelymus* (Griseb.) Nevski)	*elongatus* (Host)Runemark	*Triticum elongatum* Host *Agropyron elongatum* (Host) Beauv.
	repens (L.) Gould	*Triticum repens* L. *Agropyron repens* (L.) Beauv *Elytrigia repens* (L.) Nevski
	hispidus (Opiz) Melderis	*Agropyron hispidum* Opiz *Agropyron intermedium* (Host) Beauv.

Table 1. Hungarian *Agropyron* and *Elymus* taxa used in the interspecies study

Sequence analysis was performed for two DNA regions: the *rpo*A gene of the plastid genome including partial sequences of *pet*D and *rps*11 genes, which was successfully applied by Gitta Petersen and Ole Seberg (1997) to study the Triticeae tribe; and the intergenic spacers (ITS) of the rDNA, an extensively used marker in molecular phylogeny. These analyses resolved the exact taxonomic position of Szarvasi-1. Plant materials were collected from field and identified carefully using morphological characters. Total DNA was extracted from leaves, the targeted DNA loci were amplified in polymerase chain reactions (PCR) and sequenced. New DNA sequence data were deposited to GenBank. Cladistic analyses were performed with PAUP* 4.0 software (Swofford, 2001) on Windows XP, using maximum parsimony, supplemented with additional public sequence data referring to the tribe. *Bromus inermis* was used as an outgroup. The analysis comprised 32 sequences representing 21 of the 24 monogenomic genera of the Triticeae. In the case of the *rpo*A data, the final matrix contained 1385 characters, of which 1276 (92%) were constant, 84 (6%) variable but uninformative and 25 (1.8%) informative. The analysis resulted in a 129-step-long parsimonious tree (Fig. 1.A) (consistency index including all characters = 0.9225, consistency index excluding uninformative characters = 0.7368, retention index = 0.9048). However, the results were based on only a small number of phylogenetically informative characters (1.8%) – concentrated mostly in the non-coding spacer regions. Therefore the study was completed by the analysis based on the nuclear ribosomal internal transcribed spacers (ITS) (Fig. 1.B). In the latter case the final matrix included 596 characters: 459 (77%) were constant, 53 (8.9%) variable but uninformative and 83 (13.4%) informative (tree length = 214 steps long, consistency index including all characters = 0.7617, consistency index excluding uninformative characters = 0.6731, retention index = 0.7475). In both cases, four sequences – *E. elongatus*, *E. elongatus* subsp. *ponticus* cv. Szarvasi-1, *E. hispidus*, and *A. cristatum* - were newly determined.

The phylogenetic relationships inferred from molecular data of both the *rpo*A gene and ITS regions supported the separation of the studied *Elymus* taxa from *A. cristatum* – formerly

also declared an *Elymus* species. All of the studied *Elymus* taxa form a well supported clade within *Pseudoroegneria*, *Lophopyrum*, and *Festucopsis,* corresponding with the results of Sha et al. (2010). Interestingly, the Hungarian *A. cristatum* is located far from the Danish accession of the species on the *rpo*A based phylogenetic tree. However, the *rpo*A sequence of *E.hispidus* and the ITS sequence of *E. repens* are very similar to those of the Szarvasi-1, suggesting the possibility of unwanted hybridization.
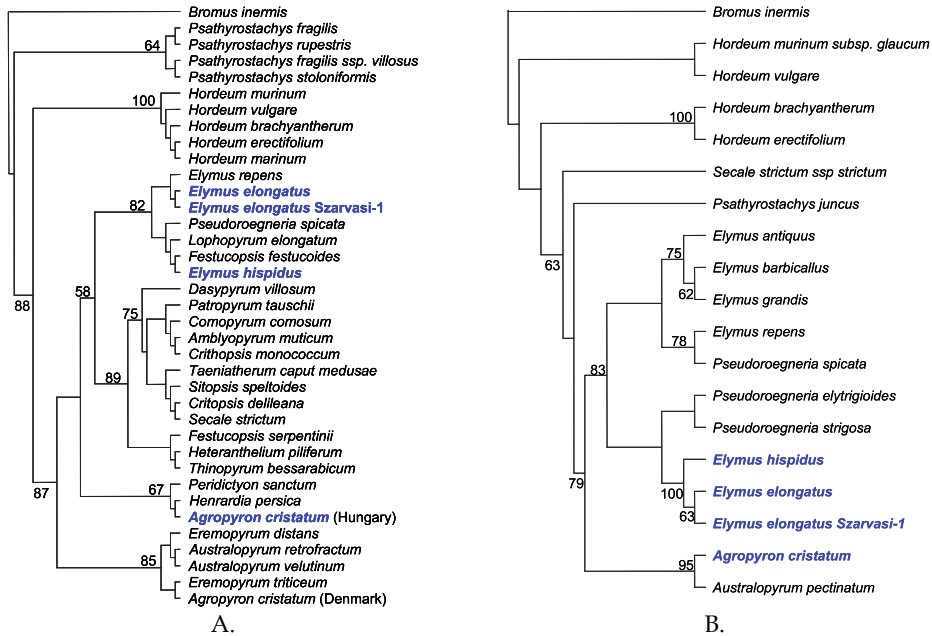
Fig. 1. Strict consensus tree based on phylogenetic analysis A: of the *rpo*A gene B: of the ITS sequence data. Numbers above and below branches indicate bootstrap support.

2.3.2 Interpopulational studies

The interpopulation study compared 15 individuals from each population of *E. elongatus* and the Szarvasi-1 cultivar by RAPD markers. The samples originated from four different locations in Hungary: Hortobágy, Kunadacs, Tiszaalpár and Szarvasi-1 from Görcsöny. The method can be a valuable tool for populational studies (Reisch et al., 2003), though it has often been criticized for low reproducibility; in order to avoid this phenomenon, highly constant conditions were used and all reactions were repeated at least twice. The samples were screened with a total of 80 arbitrary 10-mer primers, out of which only 30 informative primers were retained. The total number of analyzed bands was 373. The percentage of polymorphic bands was 41.3% (154 bands). The RAPD data were used for calculation of pairwise genetic distances using the Simple matching coefficient. The distance matrix was used for cluster analysis using UPGMA (unweighted pair-group method with arithmetic averages). A dendrogram was generated using SYN-TAX 5.0 (Podani, 1993).

Consistent with other results (Díaz et al., 2000; Nieto-Lopez et al., 2000), RAPD analysis discriminated the studied populations. The samples from Kunadacs constituted the most

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homogenous population, the samples differed from each other by only 0.8%. The most heterogeneous population seemed to be the population of Hortobágy with 3.8% difference among individuals. According to the present state of our knowledge of the genetic relationships of Szarvasi-1 and other studied Hungarian tall wheatgrass populations we can claim that there is no genetic difference between the genotype of the Szarvasi-1 cultivar and that of the population of Hortobágy. This result suggests that the genetic material of the populations from pontic areas involved in the breeding process could disappear during the process. The ability to differentiate the tested populations by RAPD bands suggested that this technique may provide a rapid and inexpensive method for the identification of the three *Elymus* populations in Hungary and can be used to monitor the possible changes of energy grass genotype by outcrossing different, closely related *Elymus* taxa during their utilization.

2.4 Morphology and anatomy of *Elymus elongatus* subsp. *ponticus* and Szarvasi-1 energy grass

Elymus species are caespitose or rhizomatous perennials. The roots of *E. elongatus* are fibrous (Fig. 2.), and can reach lengths of 3.5 m. *E. elongatus* can grow to a height of 50-200 cm (Melderis, 1980; Barkworth, 2011), while Szarvasi-1 energy grass can reach 180-220 cm under optimal growing conditions. From the wheatgrass species that are native to Hungary, three members of the genus *Elymus* and a closely related *Agropyron* species were picked for morphological comparison with Szarvasi-1 energy grass (Fig. 3.), taking into consideration both their vegetative (Table 2.) and reproductive features (Table 3.).

Fig. 2. Fibrous root system of Szarvasi-1 energy grass (photo: Róbert W. Pál)

Fig. 3. Stem, leaf, inflorescence and spikelet of Szarvasi-1 energy grass (drawing: Emőke Oláh)

Taxon / Character	Root system	Stem height (cm)	Leaf		
			leaf blade	ligule	auricle
A. pectiniforme	fibrous	25-60	adaxial side with trichomes	membranous, truncate	-
E. repens	rhizomatous	40-120	dense venation	membranous, truncate	long
E. hispidus	rhizomatous	40-150	long, sparse trichomes on adaxial side	membranous, truncate	medium
E. elongatus	fibrous	50-200	prominent venation, surface and margin bearing spinules	membranous, dentate	medium
Szarvasi-1	fibrous	50-220	prominent venation, surface and margin bearing spinules	membranous, dentate	long

Table 2. Vegetative features of wheatgrass (*Elymus* and *Agropyron*) taxa (data are based on our own observations and some literature references, see Melderis, 1980 and Barkworth, 2011)

The stems of *E. elongatus* are robust and glabrous (Melderis, 1980). Our comparative histological studies, conducted on *E. hispidus*, *E. elongatus* and Szarvasi-1 energy grass, revealed that in Szarvasi-1 the epidermis of the stem is sclerenchymatous (Fig. 4.), covered with a thick cuticle, which suggests drought tolerance of the cultivar. Stomatal guard cells are in level with the epidermal cells (mesomorphic position), both in the stem (Fig. 4.) and the surrounding leaf sheath, which is typical in plants that require a moderate water supply. In the internodes collateral closed vascular bundles are arranged in two rings, embedded in the sclerenchymatous hypodermis and parenchyma. In the outermost cortical region of the culm in Szarvasi-1, clorenchyma alternates with sclerenchyma, or a continuous sclerenchymatous ring is formed. Third order vascular bundles are located in the hypodermis, while first and second order bundles can be found toward the centre of the stem (Fig. 5.). Vascular bundles are supported by a sclerenchymatous sheath and/or bundle cap, the latter often establishing direct contact with the hypodermal sclerenchymatous fascicles in the case of the outer vascular bundles.
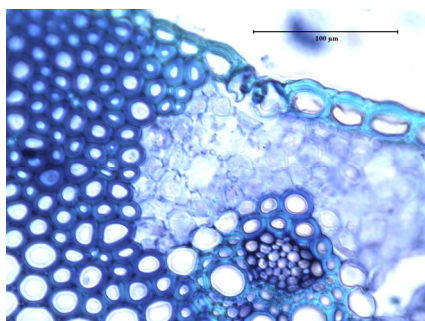
Fig. 4. Sclerenchymatous epidermis with mesomorphic stoma in the stem of Szarvasi-1 (photo: Ágnes Farkas)

Fig. 5. Vascular bundles of varying size in the stem of Szarvasi-1 energy grass (photo: Ágnes Farkas)

In the nodes of *Elymus* species, the bundles located in the outer region possess a well-developed sclerenchymatous bundle cap, which is kernel-shaped in *E. elongatus* (Fig. 6.) and ovate in *E. hispidus*. The phloem consists of sieve tubes and companion cells; the xylem comprises two large tracheas, tracheids and xylem parenchyma, accompanied by a

rexigenous intercellular space. The walls of vessels and tracheids are strengthened by annular or spiral thickening (Fig. 7.).
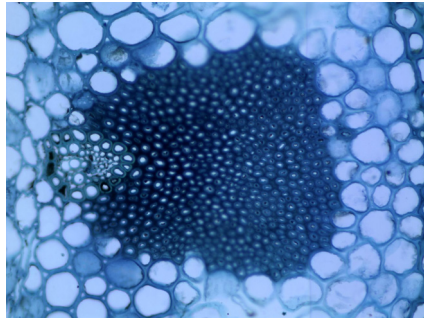
Fig. 6. Bundle cap in the stem of Szarvasi-1 (photo: Ágnes Farkas)
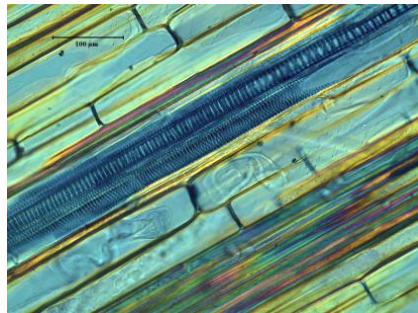
Fig. 7. Vessels with annular and spiral thickening in the stem of Szarvasi-1 (photo: Ágnes Farkas)

The leaves of *Elymus* species are flat or more or less convolute (Melderis, 1980). In *E. elongatus* they are convolute, however, in Szarvasi-1 this feature is not typical. The leaf blade is grey-green in *E. elongatus*, as opposed to the blue-grey colour of *E. hispidus* (Melderis, 1980). The leaf blade of *E. elongatus* is 2.5-5 mm wide, prominently and closely veined. Similarly to *E. hispidus*, one margin of the leaf sheath can bear trichomes in *E. elongatus* as well; sparse spinules, and sometimes also short setae can be observed on the surface and the edge of the leaf (Melderis, 1980). The ligule is short and membranous; the presence and length of the auricle varies with *Elymus* species (Table 2.) (Häfliger & Scholz, 1980; Melderis, 1980; Barkworth, 2011).

The leaf epidermis in Szarvasi-1 is mostly sclerenchymatized, with thickened cell walls and a thick layer of cuticle, all of which highlight drought tolerance of the energy grass. In the intercostal region of the adaxial epidermis, a group of large bulliform cells can frequently be observed, which play a role in rolling up the leaf blade in the case of drought, thereby reducing transpiration. Both the adaxial and abaxial epidermis may contain stomata, however, they are more frequent on the abaxial side. Most stomatal guard cells are at the level of epidermal cells (mesomorphic position), however, in some cases guard cells may rise above the epidermis (hygromorphic position), or the stoma can become slightly sunken

(xeromorphic position), when guard cells reach the bottom half of epidermal cells. Non-glandular trichomes (bristles) are present in large numbers (Fig. 8.), especially on the adaxial side of the leaf, enhancing the drought-tolerance of the plant by reducing water loss. The two epidermal layers sandwich a chlorenchymatous, homogenous mesophyll layer, consisting of spongy parenchyma. In Szarvasi-1 energy grass the basal leaf blade is strongly wavy in transverse section, due to the ridges formed by the longitudinally running veins that correspond to collateral closed bundles, arranged in a characteristic pattern formed by the alternation of smaller and larger bundles (Fig. 9.). The vascular bundles are surrounded by an inner sclerenchymatous and an outer parenchymatous bundle sheath. Bundles of first order are accompanied by hypodermal sclerenchyma. In both *E. elongatus* and Szarvasi-1 the sclerenchymatous bundle cap is more developed than in *E. hispidus*. In *E. elongatus* cell wall thickening also reaches a higher level in the sclerenchymatous tissues. In the adaxial part of the primary bundles we can often see rexigenous intercellular spaces, containing the broken elements of the protoxylem.
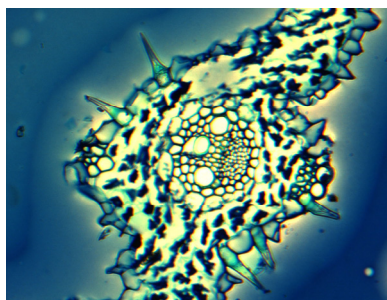
Fig. 8. Non-glandular trichomes on the leaf of Szarvasi-1 (photo: Ágnes Farkas)
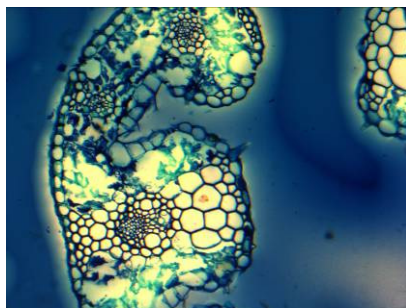
Fig. 9. Vascular bundles in the leaf of Szarvasi-1 (photo: Ágnes Farkas)

The inflorescence is an erect spike, which is long and slender in each wheatgrass species, except for *A. pectiniforme*, where it is short and dense, with numerous, overlapping spikelets. In *E. elongatus* the rachis is nearly flat on the side facing the spikelets, usually spinose-ciliate on the main angles (Melderis, 1980). Compared to *E. repens*, the spikelets are less overlapping and more loosely arranged in *E. elongatus*, sitting close to the rachis, and strongly compressed laterally; the rachilla is strigulose. The spikelet consists of varying numbers of florets in each species (Table 3.).

Taxon / Character	Number of florets/spikelet	Glume	Lemma	Palea
A. pectiniforme	4-8	abruptly narrowing	short-awned	keel with short trichomes
E. repens	4-8	acute, tapering	acute	
E. hispidus	4-8	truncate	obtuse or acute	keel with short trichomes
E. elongatus	5-11	truncate, glabrous	obtuse, awnless	two-keeled
Szarvasi-1	7-15	truncate	obtuse, awnless	two-keeled

Table 3. Reproductive features of wheatgrass (*Elymus* and *Agropyron*) taxa

The glumes of *Elymus* species are indurate-coriaceous, obtuse or truncate, with 1-11 veins, possessing a short awn or no awn at all. The glume can reach half or two thirds of the spikelet in *A. pectiniforme*, two thirds of the spikelet in *E. repens*, and one third of the spikelet in *E. hispidus*, *E. elongatus* and Szarvasi-1 (Fig. 3.). The glumes are 1-3-veined in *A. pectiniforme*, and 3-7-veined in the other taxa. The lemma of *E. elongatus* is obtuse, glabrous, unawned and 5-veined; the palea is two-keeled (Melderis, 1980; Barkworth, 2011). Similarly to other representatives of the Poaceae family, the stigma is feather-like in the *Elymus* genus, where stigmatic secretion is absent even in the mature stage of the stigma, and the receptive surface is discontinuous (Heslop-Harrison & Shivanna, 1977). The fruit is a caryopsis.

The evaluated anatomical features allow the differentiation of *E. elongatus* and Szarvasi-1 energy grass from the other investigated members of the *Agropyron-Elymus* complex. Szarvasi-1 shows several anatomical traits that enhance drought tolerance, such as a sclerenchymatized epidermis covered by a thick cuticle and dense coverage by non-glandular hairs. On the other hand, the mesomorphic position of stoma guard cells is characteristic of an intermediate water requirement. This dual nature of the habitat tolerance of *Elymus elongatus* cv. Szarvasi-1 has to be taken into account when the new cropfields of this energy grass are planned.

3. Ecological requirements

3.1 Habitat preferences

Szarvasi-1 energy grass prefers soil conditions similar to common cereals in terms of soil texture, nutrient and water content. However, on lighter soils (e.g. sandy, sandy-silt) it develops faster compared to medium or heavy soils. On sand and sandy soils it can develop seeds in the first year (after spring sowing) and reaches its maximal photosynthetic assimilation one phenophase earlier. The natural habitats of this indigenous plant mainly occur in the central part of Hungary, where the largest sandy areas are located, but it also has an exceptionally natural population on a more clay type soil in a salty marsh.

Considering only the habitats of the natural populations, tall wheatgrass seems to prefer rather alkaline soils where the pH is between 6.5 and 10. However, optimal growing potential and biomass production can be linked to a narrower pH range of 7.5-9. This means that energy grass, in spite of its alkaline origin, can show a more pronounced biomass production in a near neutral soil pH, similarly to the most common cereal cultivations. Slightly acidic soils do not hinder good biomass production, but soil pH below 5.5 negatively affects the yield.

The life span of Szarvasi-1 energy grass cultivation can be 10-15 years long, but the temporal change of biomass production during this time has not yet been monitored sufficiently. We have only one complete data series monitoring the yields of an energy grass field on solonec alkaline soil for more than 10 years. According to this study it takes two years for energy grass cultivation to reach maximal biomass production, which can then be maintained for at least 7 years. At around the tenth year energy grass cultivation starts decrease in yearly biomass production. In semi-arid climates without a ground water table serving as water source for cultivation the durability of the energy grass crops can be much shorter.

The flood tolerance of energy grass is relatively good, especially when the cultivation is at least two or three years old and the tussocks of the individuals are well developed. However, in the first year, the short and weak stems of the juveniles cannot tolerate permanent water cover and die out. Hence, the cultivated energy grass stand opens, the density of the stems declines and the establishment of the grass cultivation remains incomplete. In such a condition, weeds can gain multiple chances to invade and to establish.

High salt concentrations of the soil can be tolerated by Szarvasi-1 energy grass, but only in wet habitats, where a several weeks long seasonal high water table can occur every year. Because of the high salt resistance, Szarvasi-1 energy grass can be used as salt-tolerant forage and can play an important role in the recycling of saline drainage waters for irrigation.

Since *Elymus elongatus* subsp. *ponticus* is a native species of the continental and subcontinental climate in Eastern Europe, it tolerates well the summer high temperatures exceeding daily means of even 30-35 °C, and can also resist cold winter days when the temperature sinks below – 35 °C.

3.2 Gas exchange behaviour

Tall wheatgrass is classified as C_3 plant with cool season characteristics and seasonally different water use efficiency in moderately saline habitats (Bleby et al., 1997; Johnson, 1991). Several cultivars have previously been developed based on adaptability to different environmental conditions in Europe and Asia, but not from ecophysiological perspective. Szarvasi-1 energy grass was developed from a native population of tall wheatgrass (*Elymus elongatus* subsp. *ponticus*) that was adapted to slightly salty habitats. Therefore it was expected that *E. elongatus* cv. Szarvasi-1 will be a good candidate for biomass crop status because it produces large amounts of organic matter with relatively broad tolerance spectra and a high adaptability to different environments. Here we review the current knowledge on environmental gas exchange responses of Szarvasi-1 energy grass under greenhouse and field conditions to different environmental parameters such as temperature, light, air humidity and carbon-dioxide.

We used the following photosynthetic parameters: *assimilation* as the measure of carbon-dioxide fixation, *transpiration* as the measure of water loss and *photosynthetic water use efficiency* as the ratio of carbon-dioxide input to water output. All of these parameters depend on stomatal regulation and the abiotic environment. In this section capacities and threshold limits of Szarvasi-1 energy grass gas exchange performance will be presented for a better knowledge of its abiotic environmental requirements (Fig. 10.). To define and to compare gas exchange capacities, growing pots were installed using three soil types (sandy soil, Alfisol-Mollisol, Aquic Mollisol) in the Botanic Garden of the University of Pécs with permanent irrigation. In addition, field experiments were established on three soil types (Alfisol, Alfisol-Mollisol, Aquic Mollisol) in South

Hungary, under natural climatic conditions without any irrigation or fertilization. To evaluate threshold values of gas exchange parameters under different environmental regime, steady state and instantaneous field measurements by IRGA methods were executed.

Among investigated abiotic environmental parameters photon flux density and air humidity turned out to have an essential role in gas exchange performance and regulation (Salamon-Albert & Molnár, 2009, 2010). Under non-stressed soil water conditions (P2, P3, P5) carbon fixation was the most favourable at the beginning of the growing period described by the assimilation capacity and light efficiency regulated by the air humidity (Fig. 10.A). After seasonal precipitation deficiency in late summer (P4), causing a decline in soil water content, hard reduction was detected in water use efficiency because of strong decrease in assimilation capacity and light efficiency, retaining a regular level of transpiration (Fig. 10.B,C). Effect of climatic air drought was significant for stomatal conductance, going shattered in seasonal response by a greater effectiveness to transpiration (Fig. 10.D). As for the other experimental soil types, overall and seasonal assimilation capacity and light efficiency was a little bit lower on Alfisol-Mollisol and significantly depressed on Aquic Mollisol.
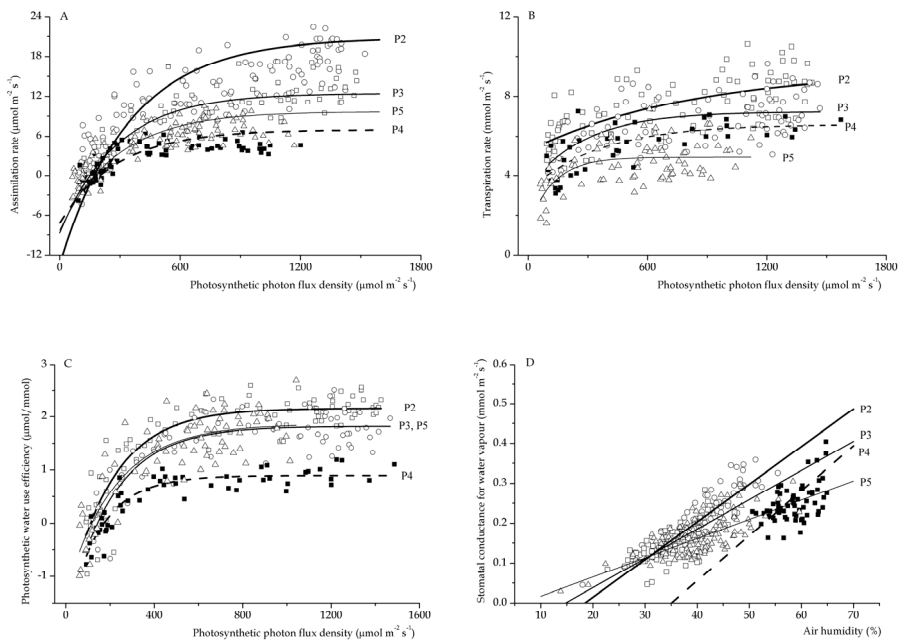
Fig. 10. A) assimilation, B) transpiration, C) photosynthetic water use efficiency as a function of light and D) stomatal conductance for water vapour as a function of air humidity, derived from field measurement (instantaneous data, alfisol, unpublished). Fitted curves p<0.01, P2-P5 the vegetative phenophases.

The assimilation and its capacity as the highest net photosynthetic rate in cultivated and natural C_3 grasses vary greatly from slight to medium values (20-40 µmol m^{-2} sec^{-1}) and in the case of C_4 crops from medium to high (30-70 µmol m^{-2} sec^{-1}) values under natural carbon-dioxide conditions, saturated light intensity, optimal temperature and adequate water supply (Larcher, 2003). Comparing Szarvasi-1 energy grass to other grasses or crop species, it has a low-medium assimilation capacity among C_3 species with a range of 10.3 - 19.2 µmol m^{-2} sec^{-1} in greenhouse, and 10.6 – 20.3 µmol m^{-2} sec^{-1} under field conditions. Optimal water use efficiency was measured under moderate light intensity (500-1100 µmol m^{-2} sec^{-1}) on all of the studied soil types under greenhouse conditions, while the maximum value was observed on sandy soil in spring (3.73 µmol/mmol). Time and phase shifting in plant growth, poor seasonal rates of assimilation and low water use efficiency detected on Aquic Mollisol under both irrigated and climatic drought conditions underline the negative effect of high clay content of soils on the optimal biomass production of energy grass crops. This is presumably due to insufficient water and nutrient availability.

Under non-stressed environmental conditions, optimum gas exchange in Szarvasi-1 energy grass occurred at the beginning of development in early or late spring, depending on irrigation and soil type. Climatic drought has a strong effect on gas exchange performance through the regulation of stomatal conductance, both for carbon-dioxide and water vapour. According to the studied ecophysiological parameters, Szarvasi-1 energy grass could be beneficial as an energy crop in mesic habitats with lighter soils.

4. Propagation

Szarvasi-1 energy grass is propagated by seed. Since *E. elongatus* ssp. *ponticus* has evolved in regions of Europe that have long and severe winters, it germinates relatively late in the spring and by the time it develops its tussocks it is mid summer. This is why the suggested sowing time is in autumn, in the middle of September. Its germination needs no special circumstances. A period of only 7 consecutive days with approx. 16 hours dark each day and 18-20 °C air temperatures can maximize the germination success, up to 90 %. In different conditions the proportion of germinating seeds can vary between 52 and 90 %. Seedlings die rapidly without proper humidity conditions, but too much watering or a high water table are also poorly tolerated by Szarvasi-1 energy grass seedlings and juveniles. Similarly, strong competition of weeds can dramatically reduce seedling survival. The plant gets in full flower by the middle of June. The energy grass seeds belong to the transient seed bank-type, where the longevity of the seeds is shorter than a year. Hence, the seed bank of Szarvasi-1 energy grass fields contains seeds with the same age with no overlapping generations.

5. Crop management and production

The recommended sowing time is between the 1st and 20th of September. The soil must be prepared similarly to any other cereals (e.g. wheat, barley etc). The seeds should be sown at the depth of 2-2.5 cm with the sowing distance of 12-15 cm. The seed quantity for a hectare land is approx. 40 kg. The seedlings emerge in 14-18 days. Weed management is necessary in this phase of the development of energy grass plantations to avoid the weed species strengthening at the expense of energy grass individuals. In the early spring rolling on the plantation can be important to mitigate the negative effects of winter frost on the root

system. The first cut can be made in the Central European climate at the beginning of July when the plantation is in full flower. The later the cut takes place the lower the water content is in the biomass as it is shown in Fig. 11. The water content of the biomass is highest in fresh plant material in spring (approx. 80 %), but during the process of ripening it decreases to 50 % resulting in a higher dry material ratio. Although the highest biomass weight for a unit area can be measured in late spring, the highest dry material weight can be achieved just in the late summer when the seeds are already ripe. The fresh biomass weight reaches its peak with the appearance of the inflorescence, however the high water content decreases its value as solid biofuel. In early August when seeds are ripening plant biomass has a moderately smaller fresh weight but with the highest dry material content. Thereafter, during the autumn (this is not depicted in the figure), dry biomass weight decreases more intensively than water content indicating some loss in dry material content, too.
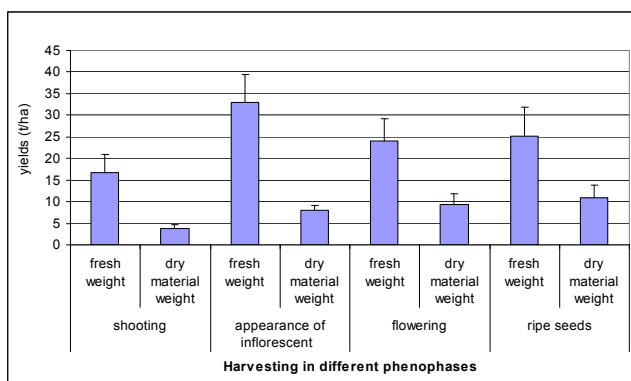
Fig. 11. Changes in fresh and dry weight of yields during a growing season on solonec meadow soil type (mean and SD)

Three or 5 days of full sunshine can reduce the water content of Szarvasi-1 energy grass hay to 9-12 % when it is ready to be baled. In this dry condition the bales can be stored for a long time without a chance of rotting. Later, during the autumn a second mow can be made in October resulting in a lower quantity of biomass with higher content of protein content. The second harvest can be used as forage for cattle or can be grazed in situ.

Soil type has a considerable effect on biomass yields. In the same macroclimatic condition the average weight of the harvested biomass for a unit land can be as much as two times higher thanks to different water and nutrient availability as well as physical soil properties such as texture and compactness of the used soil. An example of this is shown in Fig. 12.

Three soil types were chosen to represent the effect of soil on the yields of energy grass plantations. Alfisol, Alfisol-Mollisol and Aquic Mollisol comprise about 50 % of the cropfields of the South Transdanubian region in South Hungary. The highest yield in fresh as well as dry matter was achieved on Alfisol-Mollisol soil that contained moderate clay fraction and hence it bears a well balanced water and nutrient household. The Aquic Mollisol site was under the control of a relatively high ground water table, particularly in the spring, hindering the early development of the plantation. On the other hand, the high ground water table could serve as a good water source later in the summer, so the overall yield became high enough similarly to that on Alfisol-Mollisol. The relatively higher water content of the biomass produced on Aquic

Mollisol, likely due to the better water availability, can be seen in Fig. 12. as a relatively high difference between the weight of the fresh and the dry matter. The lowest yield was measured on the Alfisol experimental site. Here, both the water and the nutrient supply was under the control of the high clay content of the soil which resulted in a relatively high dry matter content but an extremely low total biomass yield.

Temporal variability of biomass production of energy grass Szarvasi-1 was also studied in a three-year-long field experiment (2004-2007) in the South Transdanubian region (Hungary). According to our results, the main source of variability was the amount of precipitation. Particularly on the sites with low water table, biomass production decreased with up to 50 % of the average biomass quantity in the year of extreme low precipitation. We measured 6 tons of dry matter per a hectare in 2007 instead of 12 tons of dry biomass yield in a better year (2006). Phenotypic plasticity of Szarvasi-1 energy grass cultivations can therefore be regarded as not very high, resulting in considerable variability of biomass yields in different years.

An extended fertilization experiment was conducted in two different environments in terms of climate and soil types in south-eastern and in south-western Hungary at a distance of 250 km from each other, in order to find the optimal nutrient supply of Szarvasi-1 energy grass crop (Fig. 13.). As our results suggested, the demand of energy grass for fertilization depends mainly on the soil types.
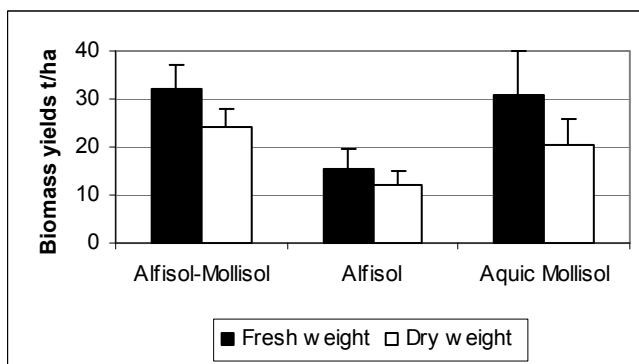
Fig. 12. Biomass yields in 2006 on three study sites near Bóly on different soil types (South Hungary)

Fig. 13. Experimental fields near Szarvas (Southeast Hungary) to find optimal fertilizer management type (photo: Róbert W. Pál)

The response of biomass production to nitrogen is relatively high, already 60 kg N/ha can double the dry biomass matter as can be seen in Fig. 14. Until this dose, increasing amounts of nitrogen contribute to increasing biomass production in a linear relationship. Higher doses than 60 kg/ha nitrogen by itself does not increase the biomass production further due to the lack of other major nutrients, such as potassium and phosphorus. Adding these to the experiment in different doses we have found that biomass production can be increased a further 50 % until it reaches 13 tons dry matter per hectare. The best ratio of the three major nutrients was shown to be 1:1:1 or 3:2:2 to maximize biomass yield of energy grass.
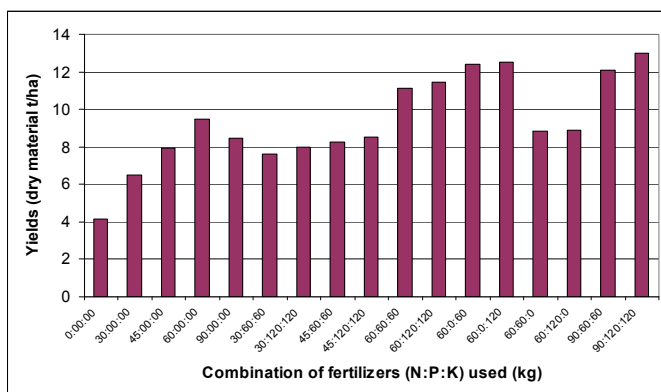
Fig. 14. Biomass yields from fertilizer study near Szarvas (solonec meadow soil)

Nitrogen played an important role in biomass production increasing biomass weight in any phenophases, while potassium and phosphorus were shown to be important only in the early phenophases (spring and flowering period and the beginning of the flowering time, respectively).

The maximum dry matter production of Szarvasi-1 energy grass crop was shown to be dependent on soil types and water supply. In our experiments 13 tons per hectare dry matter derived from solonec meadow soil, while in better soil conditions we got 20-25 tons dry matter per hectare. High and low levels of the average groundwater table can also decrease biomass

yield substantially. Too high water table can prevent the energy grass crop forming closed and well established stands, while too low water table (less then 4 m in depth) can limit biomass production during the dry season in summer. As a consequence, the optimal water table level is estimated to be between 1 and 3 meters in depth in the course of the whole growing period.

In conclusion, we can claim that depending on the soil type, nutrient availability and precipitation, Szarvasi-1 energy grass crop can produce 10-25 dry matter/ha biomass a year, but this value cannot reach 5 tons in the case of soils with a high clay content and low precipitation. One harvest in the middle of August can achieve these biomass yields while in the rest of the year an additional 30-40 cm high second growth can be obtained. Beneficial choice of location for the establishment of Szarvasi-1 energy grass fields can result in considerably higher biomass yields increasing the competitive ability of this new biomass cultivation against conventional arable crops.

6. Plant protection

6.1 Weeds
6.1.1 Weed composition of Szarvasi-1 fields

Knowledge of weed assemblies is extremely important for an effective weed management in all arable cultures. Therefore introducing new crops to large scale cultivation requires comprehensive preliminary investigations. In this chapter the characteristic species composition as well as abundances of weeds on Szarvasi-1 energy grass fields were determined and were compared to other arable crop cultures. Weed-crop competition was also studied in different soil conditions. The analyses were made on the basis of 22 energy grass, 60 cereal, 60 row crop and 15 alfalfa plots that were 4x4 m in size. A detailed study on this topic was published by Pál & Csete (2008).

6.1.2 Relation of weed species composition in energy grass to other arable cultures

Comparing the weed composition of energy grass fields to other cultures on landscape and field level in terms of an ordination diagram showed a distinctive separation from cereals and row crops (Fig. 15.). A partial overlapping was detected with alfalfa fields, suggesting a similar species composition to this perennial crop.
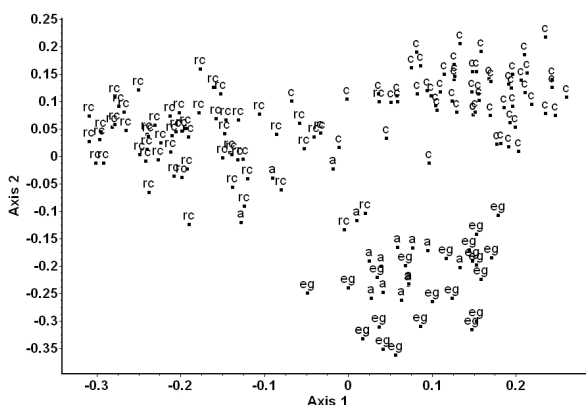
Fig. 15. Scatter diagram of the weed composition of different crops (eg = energy grass, a = alfalfa, rc = row crops, c = cereals) (PCoA, Jaccard similarity index)

Regarding the life form distribution of the weeds in the different cultures, energy grass fields resembled annual crops the most, considering all life form categories. However, geophytes were more representative, while therophytes were less common. In alfalfa, a higher proportion of geophytes and hemicryptophytes were found, while therophytes were even more underrepresented than in energy grass fields. Considering the observed life form distribution of the characteristic weed community of each crop, energy grass took an intermediate position between annual crops and the perennial alfalfa.

The characteristic species composition of the different cultures is shown in Table 4. There was only one species (*Convolvulus arvensis*) which could be regarded as uniformly common in every culture. There were 12 species characterizing the cereals, six the row crops, two in case of alfalfa and only one (*Bromus japonicus*) in case of energy grass. *Bromus japonicus* as a problematic weed was already present from the first year of sowing, and despite its annual life form, it has been continuously present and infesting the fields. On the other hand, energy grass fields are often characterized by a lack or a decreased importance of several serious weed species which are quite dominant in other arable crops: *Amaranthus* spp., *Ambrosia artemisiifolia*, *Apera spica-venti*, *Artemisia vulgaris*, *Cirsium arvense*, *Echinochloa crus-galli*, and *Galium aparine*.

Differential species	Cereals n=60	Row crops n=60	Alfalfa n=15	Energy grass n=22
Cirsium arvense	81.7	48.3	6.7	31.8
Capsella bursa-pastoris	73.3	10	-	22.7
Papaver rhoeas	73.3	-	-	-
Artemisia vulgaris	70	35	26.7	4.5
Consolida regalis	58.3	1.7	-	9.1
Stellaria media	58.3	10	6.7	-
Veronica persica	53.3	13.3	6.7	-
Galium aparine	48.3	3.3	-	4.5
Apera spica-venti	35	-	-	-
Bromus sterilis	30	-	-	-
Viola arvensis	30	-	-	-
Veronica polita	28.3	-	-	-
Setaria pumila	40	86.7	13.3	-
Echinochloa crus-galli	36.7	81.7	26.7	-
Amaranthus chlorostachys	1.7	50	13.3	-
Digitaria sanguinalis	1.7	46.7	13.3	-
Persicaria maculosa	10	45	-	-
Solanum nigrum	11.7	41.7	6.7	-
Taraxacum officinale	40	13.3	93.3	22.7
Lolium perenne	45	16.7	93.3	-
Bromus japonicus	10	-	-	81.8
Frequent species				
Convolvulus arvensis	98.3	88.3	66.7	68.2
Ambrosia artemisiifolia	98.3	88.3	40	13.6
Chenopodium album	76.7	75	33.3	13.6

Table 4. Frequencies of the weed species in different crops

6.1.3 Temporal variation of weed cover and species number

Our results suggested that energy grass cultures are able to develop properly established, nearly weedless stands with an average crop cover that increased from 77.5 to 90% during a 4 year period. Furthermore, a quick leaf-litter accumulation was observed during this time reaching an average ground cover of leaf-litter of as much as 55 %. This can contribute to a significantly low weed cover. The average species number declined from 16.5 to 4.8 and the average ground cover decreased from 62.5 to 2 %. This dynamic process is depicted in an example from an experimental site from the South of Hungary on three different soil types (Fig. 16.).
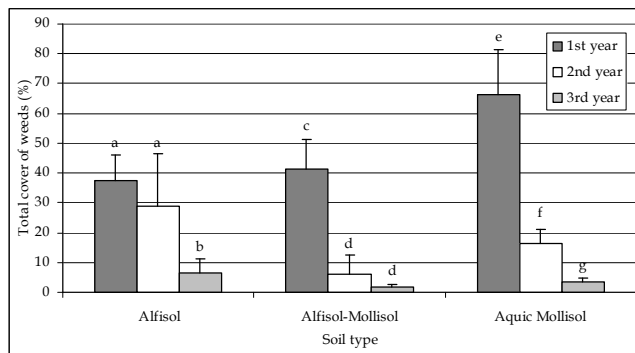
Fig. 16. Changes in total weed cover during three years on three different soil types. Different letters indicate significant differences at P < 0.05; (mean, standard deviation); (t-test)

6.1.4 Competitive ability of energy grass on weeds

The competitive ability of energy grass crop can be demonstrated using experimental plot data. A strong linear relationship was found between the biomass production and the logarithmic values of total weed cover suggesting a high competitive ability of the crop. With less then 10 t/ha of biomass dry yield the cover of weeds exceeded 50 %, while at 15 t/ha the value decreased to 20-25 % and to 2-5 % at 20 t/ha.

Elymus elongatus is a rare, native plant species in Hungary; therefore its agricultural production is much more favourable than other exotic biomass grasses (e.g. *Miscanthus × giganteus, Sorghum bicolor*). Since its stands require a certain weed control only in the year of establishment, chemical input into the environment decreases significantly compared to other intensive cultures. Under favourable conditions, energy grass can entirely close its canopy and exclude more weed species or considerably decrease their cover by the third year of cultivation. This remarkable competitive ability of a crop is appreciated by farmers as it decreases the demand of herbicide use as well as the costs of the agricultural production.

6.2 Fungi

Studies on the pests of Szarvasi-1 energy grass are in progress in Hungary, but it is already clear that the plant is sensitive to many of the most common fungal infections typical for cereals. At our experimental sites the most important fungal infection was mildew (*Blumeria*

graminis). Szarvasi-1 energy grass proved to be sensitive to mildew particularly on those sites where intensive growth of the plant occurred due to optimal nutrient and water availability. The mildew infection can cause severe damage on the leaf structure of the plant resulting in total devastation of whole patches. Proper chemical plant protection is needed to avoid significant biomass production loss. Infection of mildew was mediated by old hay bales deposited along the edge of energy grass fields, so the prompt collection and transportation of bales can contribute to lowering the chance of energy grass fields being re-infected. According to our results, chemical protection of energy grass fields must be taken into account similarly to that in the case of any other traditional agricultural crops.

7. Ecological hazard

Ecological invasion of neophyte plant and animal taxa has now become one of the most feared sources of natural habitat degradation according to many nationwide and international surveys (e.g. Molnár et al., 2008) The most frequent method of neophyte introduction is their agricultural use through which their large-scale distribution and successful establishment are intensively supported by human activities. Suggesting new plant taxa to be involved in agricultural production bears the hazard of suggesting a new potential invasive plant too. Hence thorough investigation and consideration must be taken before introducing any new agricultural crop, especially a new biomass plant.

Elymus elongatus is a rare, native plant species to Hungary; consequently its Szarvasi-1 cultivar is much more favourable for agricultural production in Hungary than other exotic biomass grasses. Szarvasi-1 carries genetic material that is derived from only indigenous populations of *E. elongatus* in Hungary. Hence the cultivar can be regarded as an indigenous taxon, so its potential as an ecological hazard in terms of invasivity is low. Since Szarvasi-1 energy grass has a transient seedbank type (i.e. its seeds lose their viability in a year), its cropfields can be transformed into any other crop without the problem of resprouting.

High competitive ability as well as fast growth dynamics are the main characters of Szarvasi-1 energy grass when it manages to establish itself completely. As our experiments suggested, weed species can outcompete Szarvasi-1 energy grass individuals if there is only incomplete sprouting and the development of tillers are slow. In this case, the stands of Szarvasi-1 energy grass crop remain open, and weeds can gain a significant advantage in growing and spreading. This is why we expect Szarvasi-1 energy grass not to be able to invade intact natural or semi-natural habitats, not even in the close vicinity of energy grass fields from where the seeds can escape in large quantities. Energy grass can germinate only in anthropogenic habitats where continuous and intensive disturbance takes place (e.g. field margins, dirt roads and banks following man-made canals). Since energy grass cannot spread vegetatively (i.e. with rhizomes), it will not become such a hazardous invasive species as for instance *Solidago gigantea* or *Reynoutria japonica*, at least not in its native habitat, in Eastern Europe.

For the rest of the world, it is worth being cautious. From Australia and the US the aggressive spread of energy grass has been reported (e.g. Cox, 2001; Walsh, 2008), where the plant formed homogeneous, closed stands outcompeting all the native elements of the local vegetation. Although this happened only in very close environments to the lands recultivated by *Elymus elongatus* (e.g. steep slopes and bank of canals), this might indicate the possibilities of its invasive spreading, particularly in those countries where natural specialist herbivores, as well as pathogenic agents of *Elymus elongatus* are missing.

8. Utilization

The moisture content of the energy grass at harvest can highly influence the possibilities for storage, processing and utilization. Appropriate logistic and storage conditions can be provided by harvesting at the optimal time and the use of bales. In this manner the processing, chopping and direct energetic utilization of low moisture content of the baled fuel can be solved easily. High moisture content causes quality loss and negatively affects the processability and energetic characteristics of the material.

The application forms of energy grass used as fuel are:
- bale
- chips/chaff
- pellet

The physical and some of the energetic characteristics of the listed fuel forms are different. The characteristics are summarized in Table 5.

Energy grass (abs. dry condition)* (Governing standards: MSZ EN 14961:2005)				
	Unit	Bale	Chips/Chaff	Pellet
Carbon	%	46.594	44.938	45.815
Hydrogen	%	3.487	4.322	3.733
Nitrogen	%	0.988	1.151	1.26
Sulphur	%	0.214	0.258	0.234
Oxygen	%	44.156	44.636	42.551
Chlorine	%	0.211	0.115	0.385
Ash	%	4.35	4.58	6.02
Density	kg/dm³	0.110-0.140	-	1.114 – 1.225
Abrasion index	%	-	-	97.7
Caloric Value	MJ/kg	17.983	17.597	17.645

* values were determined based on the average of several measurements

Table 5. The physical and some of the energetic characteristics of the listed fuel assortment

Data show that independently of its form the energy grass has high ash content. It is necessary to mention however that based on technological and laboratorial investigations we have found that the high ash content is mainly caused by external physical contaminants. This can be significantly reduced e.g. by training the operators in maintaining technological discipline and by using the appropriate harvest-, loading-, and storing processes of the raw material. The elemental compositions of the investigated fuels are also different from the ligneous fuels. Chlorine and sulphur content were investigated by CHNS analysis which shows several times higher values compared to premium quality fuels (according to standards). This factor must be considered for energetic utilization. Herbaceous fuels (such as the energy grass) have low ash melting point, which greatly restricts their energetic utilization. The results, which clearly show the change in amount of ash sample plotted against temperature for ligneous and herbaceous fuels, are summarized in Fig. 17. Based on the results of the measurements it can be stated that the ash melting point of the energy grass is 690 °C, while the ash melting point of the mixed wood-pellet is 1080 °C.
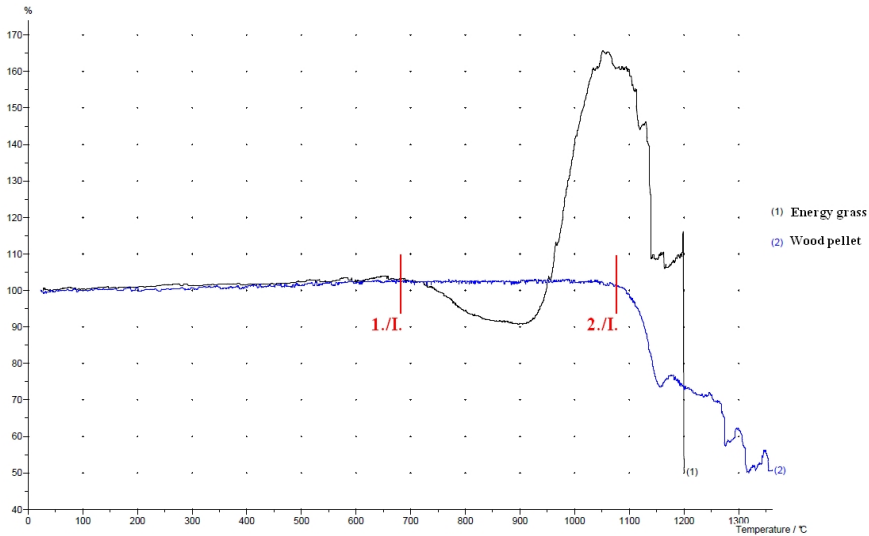
Fig. 17. Ash melting diagram of fuels

The high alkali content, which was adsorbed during the lifetime of the plant, causes the low ash melting point of the energy grass. This causes combustion problems because the ash melting occurs in the operating temperature of boiler. The material can melt and sick onto the surface of the structure elements of the boiler, and this will lead to interior depositions and permanent damage. To solve this problem, new boiler and grate types were developed. The part of the combustion chamber where the fuel burns in solid phase cannot reach high enough temperatures for the ash melting. Continuous movement of the fuel also helps to avoid scorification and interior depositions. Boiler technology was developed so that the fuel is moving on a moving grate in the boiler while the volatile component of the fuel is gasified between 150°C and 400°C. The charred roughage falls off the grate to the ash pit before the fuel would be able to reach the critical melting temperature (Fig. 17.). The volatile component is burnt in the second part of the boiler (the so-called post-combustor) where the temperature of the combustion chamber is approx. 800-900°C. The problem of ash melting was solved and sufficient burnout of the combustion gas was also ensured by this new technical solution. Based on this operating principle there are many structural solutions and performances available on the market.

The boilers, which are suitable for energetic utilization of the energy grass, can be ranked into three different groups based on their performance levels.

-    low power equipment with pellet fuel (≤50 kW)
-    medium power equipment with pellet fuel (50 – 300 kW)
-    heat and power plant equipment with chips or bale fuel (0.3 – 5 MW)

Due to their structure and size the low power equipments are mainly operated with pellet fuel. These automatic systems are suitable for the combustion of energy grass pellets with appropriate efficiency and low emission. The size of the boiler and the manufacturing cost are greatly increased by the necessary moving grate. These equipments are more robust than the prevalent wood-pellet boilers. Medium power equipments are primarily used in communal and social facilities, which are mainly operated using pellets. They are

equipped with "travelling grates" which have a ladder-like structure and consist of more segments. There is another grate, so-called "crawler grate", which was named after its appearance because it resembles a looped ribbon stick. The heat and power plant boiler designs have several solutions. Utilization of the energy grass in coal power-plants was carried out with co-firing which can solve the problem of ash melting. During the combustion of herbaceous fuels higher solid emissions can be measured which mainly deposit in the boiler and exhaust with the flue gas. *The efficiency is highly damaged by deposition on the heat transfer surfaces, and* depending on the composition it can result in corrosive effects in the boiler. In order to prevent this, mechanical or pneumatic equipment should be installed with a dust separator, which cleans automatically the flue duct.

Parallel with this solution it is necessary to reduce the load of solid components of the flue gas, the equipment is usually mounted with cyclone, which allays larger floating particles from flue gas. Electrostatic filter may also be assessed, which significantly reduces the emission of solid component from boilers.

Another possible method for the energetic utilization of energy grass is the so-called pyrolytic procedure where the fuel is fumigated in a multistage process in an oxygen-low environment. The resultant "grass-gas" will be burnt directly or after a cleaning procedure it will be suitable for use in gas engines for electricity production. Because of the high capital costs these technologies are primarily economical in the case of using high-performance equipment. As a conclusion, it can be stated that problems concerning the use of the herbaceous fuels - including energy grass - in low-and high-performance boilers, directly, or with co-firing technique have been solved. The conditions of the application are determined by the logistic aspects and the current production costs. In the current boiler engineering, considering technical, energetic, environmental and economic aspects, the herbaceous fuels and their boilers may play an important role in the medium power-level market of energy systems.

9. Conclusion

A new energy crop (*Elymus elongatus* subsp. *ponticus* cv. Szarvasi-1, tall wheatgrass) has recently been introduced to cultivation in Hungary to provide biomass for solid biofuel energy production. The cultivar was developed in Hungary from a native population of *E. elongatus* subsp. *ponticus* for agronomic and energetic purposes. The main goal of our research was to investigate the performance of Szarvasi-1 energy grass under different growing conditions (e.g. soil types, nutrition supply). We focused on the ecological background, biomass yield, weed composition, morphology, ecophysiology and the genetics of the plant.

The biomass yield of Szarvasi-1 energy grass depends mainly on the presence of macronutrients, soil texture and water availability of fields. Under typical soil nutrient conditions, precipitation has a considerable effect on biomass yield. Average yield of Szarvasi-1 energy grass is as much as 10-15 t DM ha^{-1} with great spatial and temporal variation depending on weather and habitat conditions. As part of an intensive agricultural management, the use of fertilizers can be a good solution when soil nutrients are inadequate. Nitrogen plays an important role in increasing biomass in any phenophases of Szarvasi-1 in the course of annual growth (Fig. 18.).

Fig. 18. Energy grass field in Baranya county (photo: Róbert W. Pál)

Quantitative analyses of the plant material of Szarvasi-1 were conducted to describe the chemical profile of the biofuel. Ash and energy content were determined by combustion experiments in laboratory while the dynamics of firing were studied in different experimental furnaces. We developed best practices for combusting Szarvasi-1 biofuel.

Dry matter content of Szarvasi-1 is highly influenced by the morphological features of the vegetative organs. The occurrence and proportion of mechanical and vascular tissues were investigated in the leaves and culms of Szarvasi-1 in various experimental settings for two years. Having examined the effect of different soil types on the anatomical characteristics of the culm and the leaves, we determined the most favourable habitat types of this energy plant to achieve the highest biomass yields with the greatest dry matter content.

Ecophysiological regulation and the threshold limits of gas exchange parameters (assimilation, transpiration, water use efficiency, stomatal conductance) of Szarvasi-1 were also investigated. For abiotic environmental variables, air humidity and light had the most significant effect on gas exchange parameters. Assimilation curves and some characteristic values (e.g. light compensation and efficiency, assimilation capacity) were different at the beginning of the growing period on all studied soil types. These parameters characteristically declined under water-limited environmental conditions. Water limitation had a slightly positive effect on water use efficiency. Ecophysiological conclusions, drawn from gas exchange analyses, can be utilized for planning biological and agronomical aspects to achieve higher biomass production, in accordance with the abiotic environmental regime.

The typical weed composition and abundance in energy grass fields were compared to other arable crop cultures. Weed-crop competition was also investigated in different soil conditions. The weed composition of energy grass fields is more similar to perennial cultures like alfalfa than to other annual ones (cereals, row crops). Although no herbicide treatment was carried out, percent cover of Szarvasi-1 energy grass increased significantly year by year with decreasing weed cover and species number. By the second year, the average weed cover dropped from the first year's value of 48 % to 17 % and in the third year it did not exceed 4 %. Different soil types had different effect on the temporal variation of weed composition.

In order to maintain a standard quality of Szarvasi-1 as an energy crop, it was essential to clarify its genetic characteristics. RAPD-based DNA fingerprinting revealed a low level of genetic variability among samples of the cultivar. In addition, a comparative analysis of three native Hungarian *Elymus elongatus* populations and Szarvasi-1 cultivar confirmed their genetic identity, having found no specific marker characteristic only for the latter. Ecological risk of unwanted gene exchange among close taxonomic relatives may be rather low but not impossible according to our results.

Moderate phenotypic plasticity, enormous capability to suppress weeds, high potential to produce biomass even among drier climatic conditions and a relatively high energy and moderate ash content suggest that tall wheatgrass cultivar Szarvasi-1 has great potential as a herbaceous energy plant for arid or semi-arid lands in Eastern Europe.

10. Acknowledgement

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Analysis of Time Dependent Valuation of Emission Factors from the Electricity Sector

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1. Introduction

In recent years, energy consumption and associated Greenhouse Gas (GHG) emissions and their potential effects on the global climate change have been increasing. Climate change and global warming has been the subject of intensive investigation provincially, nationally, and internationally for a number of years. While the complexity of the global climate change remains difficult to predict, it is important to develop a system to measure the amount of GHG released into the environment. Thus, the purpose of this chapter is to demonstrate how several methods can accurately estimate the true GHG emission reduction potential from renewable technologies and help achieve the goals set out by the Kyoto Protocol - reducing fuel consumption and related GHG emissions, promoting decentralization of electricity supply, and encouraging the use of renewable energy technologies.

There are several methods in estimating emission factors from facilities: direct measurement, mass balance, and engineering estimates. Direct measurement involves continuous emission monitoring throughout a given period. Mass balance methods involve the application of conservation equations to a facility, process, or piece of equipment. Emissions are determined from input/output differences as well as from the accumulation and depletion of substances. The engineering method involves the use of engineering principles and knowledge of chemical and physical processes (EnvCan, 2006). In Guler (2008) the method used to estimate emission factors considers only the total amount of fuel and electricity produced from power plants. The previous methodology does not take into consideration the offset cyclical relationship, daily and yearly, between electricity generated by renewable technologies. It should be noted that none of the methods mentioned above include seasonal/daily adjustments to annual emission factors. Specifically, the proposed research would include analyzing existing methods in calculating emission factors and attempt to estimate new emission factors based on the hourly electricity demand for the Province of Ontario.

In this Chapter, several GHG emission factor methodology was discussed and compared to newly developed monthly emission factors in order to realize the true CO_2 reduction potential for small scale renewable energy technologies. The hourly greenhouse gas emission factors based on hour-by-hour demand of electricity in Ontario, and the average Greenhouse Gas Intensity Factor ($GHGIF_A$) are estimated by creating a series of emission factors and their corresponding profiles that can be easily incorporated into simulation

software (Gordon & Fung, 2009). The use of regionally specific climate-modeled factors, such as those identified, allowed for a more accurate representation of the benefits associated with GHG reducing technologies, such as photovoltaic, wind, etc. This chapter will demonstrate that using Time Dependent Valuation (TDV) emission factors provide an upper limit while using hourly emission factors provide a lower limit. These factors based on hour-by-hour electricity demand data for the Province of Ontario will provide renewable technology researchers with the tools necessary to make informative decisions concerning the selection of renewable technologies.

2. Traditional methodologies to estimate GHG emission factors from the electricity generation sector

There are two main methods to estimate pollutant and GHG emission Factors from the electricity generation sector: 1) direct measurement or 2) estimation. Direct measurement is considered to be the most accurate since it uses real-time data from the generation sector. However, these data are not readily available and historically, GHG emissions have been estimated from fossil fuel and process-related activities. Estimation is the method used by several countries when preparing their national GHG inventories (ICPP, 1997). In the past, GHG emissions from the electricity generation sector were calculated using the Average GHG Intensity Factor ($GHGIF_A$) (Guler et al., 2008). The $GHGIF_A$ is the amount of GHG emissions per kWh electricity produced. This method assumes that the reduction in electricity demand is uniformly distributed amongst all types of electricity generation. For example, the $GHGIF_A$ estimated in 1993 was 136 g/kWh for the Province of Ontario. Table 1 shows the $GHGIF_A$ values for the years 2004, 2005, and 2006 for the Province of Ontario from the electricity generation sector (EnvCan, 2006).

Annual $GHGIF_A$ (g of CO_2/kWh)		
2004	**2005**	**2006**
200	221	189

Table 1. Annual Emission Factors

The combustion of fossil fuels produces several major greenhouse gases. The amount of emissions from CO_2, CH_4, SO_2, NO, and N_2O varies from one fuel to another, and they are calculated using emission factors. These emission factors are commonly expressed in tons of CO_2 per MWh or grams per kWh of electricity produced (Gordon & Fung, 2009).

3. Accuracy of GHG emission factors

It is necessary to develop methodology to accurately estimate GHG emissions from the electricity generation sector in order to facilitate the implementation of awareness programmes and renewable technologies which are supported with information on current energy usage. It should be noted that the time of use of electricity is related to GHG emissions generated throughout the day (MacCracken, 2006). Therefore, prior to implementing these programmes and renewable technologies, it is necessary to have an accurate model for emission and electricity estimation.

The Province of Ontario has a very unique mix of electricity production technologies. Hydro and nuclear technologies are generally considered to be base load power (IESO, 2006), since

they both operate at constant load and fossil generating plants are typically used to handle fluctuations in electricity demand throughout the day. The GHGIF$_A$ estimate is based on the generation mix for the Province of Ontario (nuclear, hydro, coal, etc.) and is not adequate to account for most of the GHG emissions from the electricity generation sector, which mainly come from fossil generating stations. Therefore, in order to estimate and phase out fossil completely, a different emission factor needs to be developed. In response to this, a second intensity factor (GHGIF$_M$) was developed. The GHGIF$_M$ intensity factor was calculated by dividing the net fossil fuel plant electricity production by the total equivalent CO_2 emissions. The value estimated for 1993 was 903.7 t/GWh (Guler et al., 2008). This emission factor assumes that all electricity consumption is provided by fossil plants. This would be beneficial if trying to replace all fossil plants with renewable technologies. However, both of the methodologies neglect to show hourly changes in emission factors.

4. GHG emission factor methodologies

Renewable technologies (solar and wind) have become an accepted form of generating electricity and heat in the Province of Ontario. There are many advantages in using solar and wind energy such as taking advantage of an abundant source of free energy (sun and wind), as well as being an effective method in reducing GHG emissions. However, the electricity produced by a renewable technology, such as a photovoltaic (PV), or micro-wind turbine and the availability of solar and wind energy, changes throughout the day. Therefore, an hourly GHG emission factor is needed to truly understand the impact that renewable technologies have on emissions since there is a divergence between when electricity can be generated and when it is required.

Some of these renewable technologies that are being used in the residential and commercial sectors include photovoltaic, micro-wind turbines, ground source heat pumps, and advance solar thermal technologies. Continuous improvement of these technolgies have promoted the development of hybrid homes. The combination of several of these technologies together will result in end-use energy savings and GHG emission reductions. However, prior to implementing any of these technologies, it is necessary to have an accurate estimation of the true reduction potential of GHG emission factors in order to have a clear understanding of the saving potentials associated with renewable technologies.

Currently, Environment Canada uses fuel consumption data from the electricity sector in order to estimate emissions. However, this method can be simplistic and time consuming as well as difficult to use due to the unavailability of certain types of data. Moreover, this method only provides an annual average emission factor which does not reflect the cyclic behaviour of emission factors throughout the day. In 2005, Time Dependent Valuation (TDV) was introduced as a viable method to provide the aformentioned data (MacCracken, 2006). This method was adopted by California as an energy efficient standard for residential and non-residential buildings. Time dependent valuation views energy demand differently depending on the time of use (MacCracken, 2006). California has been able to determine the societal impacts of time of use energy consumption. As a result, this method of analysis would allow for a more accurate representation of the potential reduction of GHGs by using renewable technologies.

This following sections will discuss existing emission factor methodolgy and introduce monthly TDV emission factor methodology.

4.1 Hourly GHG emission factors

Different emission factors have been developed in the past: hourly, seasonal, and seasonal time dependent emission factors (Gordon & Fung, 2009). This chapter will introduce monthly TDV emission factors and compare them to existing emission factors. GHG emissions from the electricity generation industry have been calculated using the Average GHG Intensity Factor ($GHGIF_A$) (Guler et al., 2008). This value represents the amount of GHG emissions produced as a result of generating one kWh of electricity. The $GHGIF_A$ for 2004, 2005, and 2006 were estimated using the methodology mentioned above in conjunction with the electricity output information from Gordon & Fung (2009). It should be noted that the emission factor for CO_2 does not take into consideration CH_4 and N_2O since these are considered to represent negligible amounts in comparison to CO_2, SO_2, and NO (Gordon & Fung, 2009). This section will only focus on CO_2 emissions since the majority of pollutants are in this form and the purpose of this chapter is to demonstrate emission factor methodology.

The GHG emissions due to coal fired and natural gas plants were determined using Equation 1 (Gordon & Fung, 2009).

$$HCO_2 = (HECOAL)(i) + (HEOTHER)(j) \tag{1}$$

Where,
HCO_2 = Hourly CO_2 production (kg)
HECOAL = Hourly Electricity generated by Coal plants
HEOTHER = Hourly Electricity generated by Other (natural gas, etc.)
i = CO_2 emission factor (OPG, 2006)
j = Environment Canada natural gas emission factor (Environment Canada, 2006)

Currently, there is a hourly greenhouse gas emission factor ($NHGHGIF_A$) model which is based on the hour-by-hour demand of electricity in Ontario from nuclear, fossil, hydro, natural gas and wind (Gordon & Fung, 2009). The $NHGHGIF_A$ was calculated by dividing the hour-by-hour emissions from CO_2 by the hour-by-hour total electricity generated from the different sources (Gordon & Fung, 2009). It should be noted that the new greenhouse gas intensity factor ($NGHGIF_A$) was estimated by taking the average of the hourly emission factors for each season. The $NGHGIF_A$ was determined using Equations 2 and 3 (Gordon & Fung, 2009).

$$NHGHGIF_A = \frac{HCO_2}{HEGTOTAL} \tag{2}$$

$$NGHGIF_A = \sum_{i=1}^{8760} \frac{NHGHGIF_{Ai}}{8760} \tag{3}$$

Where,
$NHGHGIF_A$= New Hourly Greenhouse Gas Intensity Factor (g CO_2 /kWh)
$NGHGIF_A$ = New Greenhouse Gas Intensity Factor (g CO_2 /kWh)
HCO_2 = Hourly CO_2 production (g)
HEGTOTAL= Hourly Electricity Generated Total (kWh)
i = hour
The values obtained for the $NGHGIF_A$ were compared for the years 2004, 2005, and 2006 (Gordon & Fung, 2009).

4.2 Seasonal time dependent valuation emission factors

Currently, there are several TDV profiles (annual and seasonal) for greenhouse gases for the Province of Ontario in the public domain (Gordon & Fung, 2009). As discussed in Gordon & Fung (2009), the hourly GHG emissions data has been compiled to developed different types (annual and seasonal) of emission factors. The latter has shown that emission factors vary with electricity demand (MacCracken, 2006). It has also been observed that shape and magnitude of GHGIF profiles varies with time of day, year, climate, and geographical location (Gordon & Fung, 2009). Hourly emission data does exist from the power generating sector, but is not publicly available. Therefore, rather than using a single annual GHGIF value for the entire year, seasonal GHGIF profiles based on the electricity demand for the Province of Ontario were developed by Gordon & Fung (2009).

The approach detailed below was used in order to provide a better method to properly estimate greenhouse gases within the Province of Ontario. Hourly electricity consumption data from the IESO and hourly GHG emission factors estimated in the previous section were used to determine Seasonal TDV emission factor profiles for the years 2004, 2005, and 2006. These profiles were calculated using Equation 4 (Gordon & Fung, 2009).

$$\text{Seasonal TDV NGHGIF}_A = \frac{\sum_{i=1}^{N} \text{NGHGIF}_A(h_j)}{N} \qquad (4)$$

Where,

Seasonal TDV NGHGIF_A = Seasonal Time Dependent Valuation New Greenhouse Gas Intensity Factor (g CO_2 /kWh)

N = number of days in the season

i = day number

j = hour number

The hourly and averaged values obtained for the seasonal TDV NGHGIF_A were compared for the years 2004, 2005, and 2006.

4.3 Monthly time dependent valuation emission factors

Currently, there are several TDV profiles (annual and seasonal) for greenhouse gases for the Province of Ontario in the public domain (Gordon & Fung, 2009). However, monthly GHG emission factors are not available. Therefore, this section will provide renewable technology professionals with monthly TDV profiles for estimating emissions.

The approach detailed below was used in order to provide a better method to properly estimate greenhouse gases within the Province of Ontario. Hourly electricity consumption data from the IESO and hourly GHG emission factors estimated in Section 4.1 were used to determine monthly TDV NGHGIF profiles for the years 2004, 2005, and 2006. These profiles were calculated using Equation 5 for each hour in a day.

$$\text{Monthly TDV NGHGIF}_A = \frac{\sum_{i=1}^{N} \text{NGHGIF}_A(h_j)}{N} \qquad (5)$$

Where,

Monthly TDV NGHGIF$_A$ = Monthly Time Dependent Valuation New Greenhouse Gas Intensity Factor (g CO$_2$ /kWh)

N = number of days in the month

i = day number

j = hour number

The hourly and average values obtained for the monthly TDV NGHGIF$_A$ were compared for the years 2004, 2005, and 2006.

5. Test case scenario

The following test case provides an example on how the different GHG emission factors can be used to demonstrate the cyclic behaviour of emission factors througout the day, month, season, and year. In addtion, the test cases also show the beneficial attributes associated with renewable technologies.

Transient System Simulation Tool (TRANSYS) building energy simulation software can be used to perform highly complex thermal analysis, HVAC analysis and electrical power flow simulations.

Tse et al. (2008) performed simulations, using TRANSYS, which included the use of PV on the computational model for a townhouse that would be built in the Annex area in Toronto. TRANSYS was used to simulate and help optimize the performance of the home, as well as the different systems that would be implemented. The systems that were analyzed consist of a solar domestic hot water system, a photovoltaic system (6.25 kW), and a ground source heat pump. Hourly annual simulations were run to demonstrate the potential electricity contribution and emission savings from PV. This data has been utilized in combination with the hourly, seasonal and monthly TDV emission factors discussed in the previous sections to estimate the reduction potential of GHG emissions by the use of PV technology.

6. Results

6.1 Hourly GHG emission factors

The results for the NGHGIF$_A$ for the years 2004, 2005, and 2006 are shown in Table 2 (Gordon & Fung, 2009).

Season	NGHGIF$_A$ (g of CO$_2$/kWh)		
	2004	2005	2006
Annual	208	221	189
Winter	248	231	196
Spring	164	205	164
Summer	174	241	214
Fall	244	205	190

Table 2. Hourly annual and seasonal average GHG emission factors

Table 2 shows a large variance between emission factors throughout the year and from year to year. Clearly, the use of hourly data is necessary to accurately estimate the GHG reduction potential from renewable technologies.

6.2 Annual time dependent valuation emission factors

Table A-1 in Appendix A shows the annual TDV emission factors (Gordon & Fung, 2009). It can be observed that emissions throughout the day vary considerably. It should be noted that the maximum TDV values for the years 2004, 2005, and 2006 occurred at 1 p.m.

Table 3 shows the annual average TDV GHG emission factors. These values were obtained by using the annual TDV GHG emission factors in Table A-1 in Appendix A.

	NGHGIF$_A$ (g of CO_2/kWh)		
	2004	**2005**	**2006**
Annual	224.2	237.3	207.2

Table 3. Annual average TDV GHG emission factors

6.3 Seasonal time dependent valuation emission factors

Seasonal TDV emission factors were also developed for the years 2004, 2005, and 2006 (Gordon & Fung, 2009) as shown in Table 4. Table A-2 and A-3 in Appendix A show the seasonal TDV emission factor profiles for 2004, 2005, and 2006. The following can be observed from Table 4:

- For the year 2004 – the highest emission factors were in the fall (afternoons) and winter (early mornings).
- For the years 2005 and 2006 the highest emission factor was observed in the summer.

Season	NGHGIF$_A$ (g of CO_2/kWh)		
	2004	**2005**	**2006**
Winter	264.7	246.4	213.4
Spring	182.0	221.5	179.9
Summer	190.1	256.6	229.5
Fall	259.8	224.8	206.1

Table 4. seasonal average TDV GHG emission factors

6.4 Monthly time dependent valuation emission factors

Monthly TDV emission factors were developed for the years 2004, 2005, and 2006 as shown in Table 5. Table A-4 in Appendix A shows the monthly TDV emission factor profiles for 2004, 2005, and 2006. The following can be observed from Table 4:

- For the year 2004 – the highest and lowest emission factor was observed in January and May, respectively.
- For the year 2005 – the highest and lowest emission factor was observed in August and May, respectively.
- For the year 2005 – the highest and lowest emission factor was observed in July and April, respectively.

This section discussed the different types of existing and new GHG emission factors for the years 2004, 2005, and 2006. The hourly emission factor proved to be the most accurate and monthly TDV were more accurate than using the seasonal average value.

However, it is the user's responsability to select the appropiate emission factor depending on the type of analysis conducted. In certain cases it might be more practical to employ seasonal, time dependent valuation (seasonal or monthly), or annual average emission factors to estimate CO_2 emissions without sacrificing much accuracy.

Season	NGHGIF$_A$ (g of CO_2/kWh)		
	2004	2005	2006
January	284.3	242.2	215.1
February	259.3	228.9	198.8
March	214.5	230.4	180.8
April	171.3	209.6	125.5
May	144.0	183.2	164.8
June	156.0	238.7	216.9
July	166.4	236.8	233.9
August	179.4	245.4	205.3
September	210.9	222.1	188.0
October	265.0	206.0	193.6
November	242.4	192.9	191.1
December	199.9	214.3	155.4

Table 5. Monthly TDV average GHG emission factors

6.5 Test case study

The electricity generated by the PV simulations performed for 2005 is illustrated in Figure 1 (Tse et al., 2008). It can be observed that PV electricity generation was the highest during the summer.

Table 6 shows the total electric power generated by PV for year 2005 using the test case townhouse located in the Annex part of Toronto (Tse et al., 2008).

Photovoltaic
Electricity Generated (kWh)
7767

Table 6. Total electricity generated by PV for test case study

Figure 1 shows the total monthly electric power generated by the PV system for the year 2005. Electricity generation was the highest during July and throughout the summer.
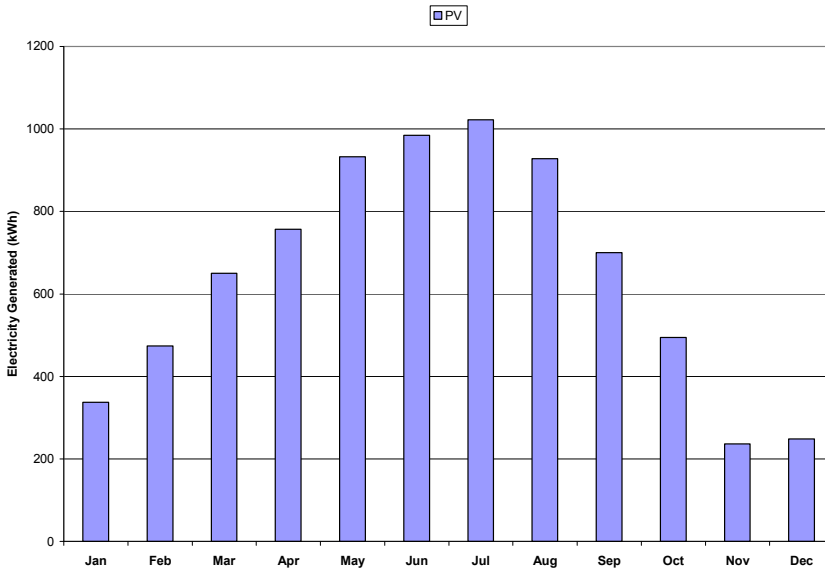
Fig. 1. Monthly electricity generated by PV for test-case study

In order to calculate the CO_2 emission reduction potential by PV, the hourly electricity data was multiplied by the different emission factors as defined in Equations 6, 7, 8, 9 (Gordon & Fung, 2009), and 10.

$$GHG_{el,HNGHGIF_A} = \sum \left[\left(Generated_{el,hourly} \right) \left(NHGHGIF_A \right) \right] \tag{6}$$

Where,

$GHG_{el,HNGHGIF_A}$ = Annual GHG emission reduction using the new hourly emission factor (g of CO_2)

$Generated_{el,hourly}$ = Hourly electricity generated by renewable technology for test case house (kWh)

$NHGHGIF_A$ = New Hourly Greenhouse Gas Intensity Factor (g CO_2/kWh)

$$GHG_{el,SANGHGIF_A} = \sum \left[\left(Generated_{el,hourly} \right) \left(SANGHGIF_A \right) \right] \tag{7}$$

Where,

$GHG_{el,SANGHGIF_A}$ = Annual GHG emission reductions using the seasonal average emission factor (g of CO_2)

$Generated_{el,hourly}$ = Hourly electricity generated by renewable technology for test case house (kWh)

$SANGHGIF_A$ = Seasonal Average New Greenhouse Gas Intensity Factor (g CO_2/kWh)

$$GHG_{el,AANGHGIF_A} = \sum \left[\left(Generated_{el,hourly} \right) \left(AANGHGIF_A \right) \right] \tag{8}$$

Where,

$GHG_{el,AANGHGIF_A}$ = Annual GHG emission reductions using the annual average emission factor (g of CO_2)

$Generated_{el,hourly}$ = Hourly electricity generated by renewable technology for test case house (kWh)

$AANGHGIF_A$ = Annual Average New Greenhouse Gas Intensity Factor (g CO_2/kWh)

$$GHG_{el,TDVNGHGIF_A} = \sum \left[\left(Generated_{el,hourly} \right) \left(TDVNGHGIF_A \right) \right] \qquad (9)$$

Where,

$GHG_{el,TDVNGHGIF_A}$ = Annual GHG emission reductions using the seasonal time dependent valuation new greenhouse gas intensity factor (g CO_2/kWh)

$Generated_{el,hourly}$ = Hourly electricity generated by renewable technology for test case house (kWh)

$TDVNGHGIF_A$ = Seasonal Time Dependent Valuation New Greenhouse Gas Intensity Factor (g CO_2/kWh)

$$GHG_{el,TDVNGHGIF_A} = \sum \left[\left(Generated_{el,hourly} \right) \left(TDVNGHGIF_A \right) \right] \qquad (10)$$

Where,

$GHG_{el,TDVNGHGIF_A}$ = Annual GHG emission reductions using the monthly time dependent valuation new greenhouse gas intensity factor (g CO_2/kWh)

$Generated_{el,hourly}$ = Hourly electricity generated by renewable technology for test case house (kWh)

$TDVNGHGIF_A$ = Monthly Time Dependent Valuation New Greenhouse Gas Intensity Factor (g CO_2/kWh)

Table 7 summarizes the total emission reduction results from PV by using the different emission factors. The upper and lower limits of CO_2 reductions were obtained by using the seasonal TDV and annual average emission factors, respectively. It should be noted that the new monthly TDV emission factors resulted in an emission reduction potential very close to that of using hourly emission factors.

Emission Factor Type	Emission Reduction Potential (kg of CO_2)	% Difference
Hourly	1856	
Seasonal Average	1727	-6.97
Annual Average	1716	-7.54
Seasonal TDV	1974	6.36
Monthly TDV	1854	-0.12

Table 7. Emission reduction potential comparison for test case study

The total monthly emission reduction potential by PV is shown in Figure 2. During June and July the emission reductions were the highest and in November, the lowest.
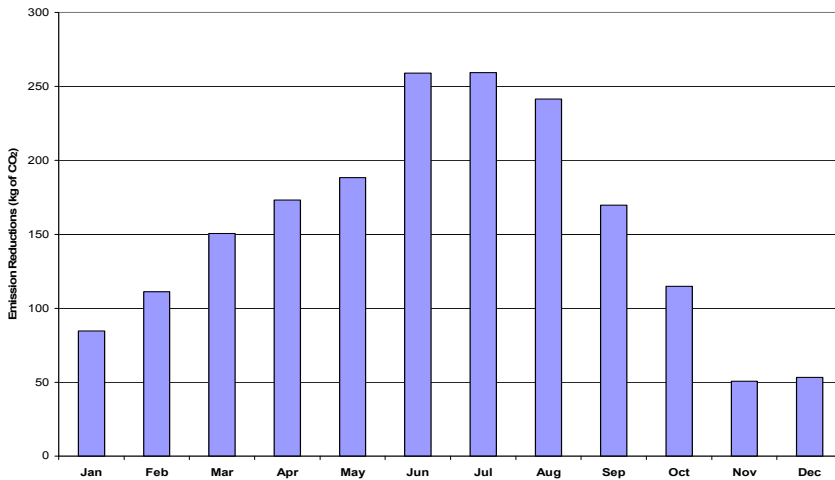
Fig. 2. Monthly emission reductions for PV test case study

7. Conclusion

Several emission factors were developed for the years 2004, 2005, and 2006. The hourly emission factor proved to be the most accurate. In addition, depending on the type of analysis conducted it might be practical but not as accurate to employ seasonal, time dependent valuation, or annual averages emission factors to estimate CO_2 emissions. It was observed that TDV and seasonal average emission factors were more accurate than using the annual average value. It should also be mentioned, that monthly TDV emission factors proved to be as accurate as using hourly values. The use of hourly emission factors to accurately estimate the potential reduction of renewable technologies should be incorporated in all renewable technology assesments.

8. Recommendations

This chapter discussed the use of hourly, seasonal, monthly and annual emission factors in order to demonstrate the daily fluctuations from the electricity generation sector. In the future, peak, weekly and marginal emission factors could be developed in order to increase the accuracy of emission estimations. In addition, emission factors could be updated every year in order to allign with current renewable technology analysis models and electricity generation mix.

9. Appendix A

Annual			
TDV NGHGIF$_A$ (g of CO2/kWh)			
Hour	2004	2005	2006
1	185.9	219.7	181.2
2	179.2	213.3	170.5
3	173.6	206.2	161.5
4	171.6	203.9	159.4
5	177.1	209.1	167.9
6	192.5	216.8	178.3
7	210.7	223.7	191.5
8	227.8	236.7	209.1
9	237.0	244.2	218.3
10	243.6	248.5	223.1
11	248.1	251.5	227.3
12	251.1	253.6	229.5
13	253.0	255.6	229.9
14	252.0	255.2	228.7
15	249.7	252.9	225.4
16	248.4	249.3	223.3
17	247.8	248.3	223.7
18	246.5	249.6	224.9
19	244.3	248.6	225.5
20	246.6	249.0	228.1
21	246.9	252.1	228.0
22	236.4	247.3	219.5
23	215.2	235.0	207.0
24	195.0	226.0	191.4

Table A-1. Annual TDV emission factor comparison for 2004-2006

Winter				Spring			
TDV NGHGIF$_A$ (g of CO2/kWh)				TDV NGHGIF$_A$ (g of CO2/kWh)			
Hour	2004	2005	2006	Hour	2004	2005	2006
1	254.9	241.8	200.7	1	133.3	192.3	147.0
2	254.8	234.8	191.4	2	129.1	188.5	138.9
3	252.9	229.3	183.1	3	126.6	180.0	132.9
4	250.9	226.8	179.8	4	125.6	179.0	130.8
5	252.4	227.5	183.8	5	130.7	186.8	140.2
6	255.3	231.9	186.5	6	148.2	201.2	153.0
7	258.8	234.7	196.6	7	171.0	213.2	171.3
8	262.5	240.9	208.5	8	192.4	228.5	189.7
9	265.6	247.1	216.3	9	203.0	234.2	194.5
10	266.8	250.5	219.7	10	208.7	237.0	198.7
11	268.8	253.1	225.7	11	213.2	239.8	202.8
12	270.9	254.8	228.5	12	214.8	241.8	204.5
13	272.8	256.5	229.0	13	215.5	244.3	204.4
14	272.8	256.5	227.8	14	215.2	244.1	203.4
15	271.3	252.8	224.8	15	212.3	242.0	201.3
16	268.8	246.5	219.2	16	212.4	240.8	200.7
17	268.6	244.9	218.8	17	212.4	240.5	201.1
18	270.9	250.3	224.4	18	205.0	234.4	195.9
19	274.6	257.5	233.3	19	198.5	224.8	190.5
20	273.4	258.5	235.3	20	204.2	228.6	198.7
21	273.3	260.1	234.2	21	206.5	238.3	203.1
22	271.4	259.2	229.1	22	190.3	231.9	187.3
23	265.4	253.5	217.6	23	161.5	218.2	170.4
24	255.3	243.3	207.8	24	138.8	206.0	155.6

Table A-2. Seasonal TDV GHG Emission Factors for Winter and Spring

Summer				Fall			
TDV NGHGIFA (g of CO2/kWh)				TDV NGHGIFA (g of CO2/kWh)			
Hour	2004	2005	2006	Hour	2004	2005	2006
1	129.4	244.9	199.8	1	226.1	199.9	177.2
2	119.8	236.6	186.5	2	213.2	193.4	165.1
3	112.5	227.6	175.2	3	202.5	187.9	154.8
4	109.9	224.1	173.2	4	200.2	185.7	153.8
5	114.3	225.6	181.9	5	210.9	196.5	165.8
6	134.7	229.1	189.5	6	231.7	205.0	184.0
7	159.5	232.4	202.1	7	253.4	214.3	196.0
8	187.5	251.1	227.3	8	268.7	226.4	211.0
9	205.0	262.4	243.1	9	274.5	233.2	219.4
10	220.1	268.1	250.7	10	278.8	238.4	223.4
11	228.3	270.4	254.0	11	282.2	242.6	226.6
12	234.5	273.4	256.3	12	284.2	244.4	228.5
13	237.8	276.7	256.3	13	285.7	245.0	230.0
14	236.6	276.4	254.6	14	283.5	243.8	229.1
15	234.1	275.3	251.0	15	281.3	241.3	224.5
16	234.7	273.5	251.3	16	277.4	236.3	221.8
17	234.4	272.4	252.9	17	275.9	235.4	221.8
18	228.5	272.1	252.0	18	281.7	241.4	227.3
19	218.7	267.5	248.3	19	285.5	244.4	229.8
20	223.3	267.3	251.3	20	285.4	241.8	227.1
21	226.3	269.8	252.6	21	281.5	240.2	222.2
22	209.7	264.3	245.7	22	274.0	233.9	216.1
23	176.2	249.8	236.9	23	257.9	218.4	202.9
24	146.7	248.7	214.9	24	239.2	206.1	187.5

Table A-3. Seasonal TDV GHG Emission Factors for Summer and Fall

January				February			
TDV NGHGIF$_A$ (g of CO2/kWh)				TDV NGHGIF$_A$ (g of CO2/kWh)			
Hour	2004	2005	2006	Hour	2004	2005	2006
1	282.1	229.9	195.4	1	254.4	221.2	183.0
2	288.0	226.7	184.4	2	251.0	210.6	174.1
3	286.6	224.6	174.3	3	248.6	203.0	168.0
4	285.0	221.4	169.0	4	245.2	201.2	165.5
5	283.9	221.2	172.5	5	252.0	203.9	169.8
6	283.1	222.6	177.0	6	256.5	212.1	173.6
7	279.3	223.0	190.0	7	258.5	220.0	184.0
8	278.0	231.9	210.2	8	260.3	228.9	196.5
9	280.2	241.9	221.7	9	263.7	234.0	203.7
10	280.1	244.0	222.7	10	264.0	236.1	207.3
11	280.5	248.4	228.0	11	264.7	238.4	214.9
12	282.2	251.1	232.1	12	264.6	238.5	216.3
13	285.4	253.7	233.7	13	266.6	241.0	215.2
14	286.5	256.6	235.2	14	268.1	239.9	213.4
15	287.0	251.7	233.9	15	265.6	236.0	209.5
16	285.8	246.0	224.5	16	260.5	230.3	206.3
17	283.3	245.4	224.5	17	258.3	228.4	205.0
18	284.5	251.8	233.5	18	257.9	231.6	205.4
19	289.6	258.7	244.5	19	262.6	240.9	219.0
20	287.5	257.2	241.6	20	264.6	246.0	223.2
21	287.9	258.7	240.7	21	265.2	246.5	220.7
22	287.7	256.9	236.7	22	264.2	244.6	213.9
23	286.4	249.9	227.9	23	257.5	238.6	195.6
24	281.4	238.9	208.7	24	248.1	222.3	187.1
March				April			
TDV NGHGIF$_A$ (g of CO2/kWh)				TDV NGHGIF$_A$ (g of CO2/kWh)			
Hour	2004	2005	2006	Hour	2004	2005	2006
1	191.2	228.4	172.8	1	116.9	177.5	79.7
2	189.0	223.7	164.0	2	115.1	175.7	74.9
3	187.4	217.9	153.9	3	114.6	167.2	73.7
4	185.6	215.7	150.9	4	115.6	167.9	76.1
5	184.9	218.5	155.3	5	124.2	176.9	82.3
6	192.3	225.1	158.6	6	147.0	197.9	99.0
7	205.3	227.6	170.8	7	168.2	207.5	121.3
8	218.1	227.8	179.1	8	188.0	219.8	138.7
9	224.8	233.2	185.2	9	196.1	224.8	144.1
10	225.1	235.3	188.7	10	201.3	229.1	151.5
11	227.2	236.3	192.2	11	204.2	230.6	155.4
12	230.4	239.7	193.6	12	204.1	230.7	157.4
13	230.2	241.5	194.1	13	204.5	232.4	155.7
14	231.8	240.3	193.4	14	203.8	230.9	153.3
15	229.0	237.5	193.2	15	201.8	229.9	149.3
16	228.5	233.3	189.2	16	199.9	231.1	148.0
17	228.2	231.5	187.9	17	197.9	229.9	146.4
18	225.8	229.9	185.2	18	189.2	221.8	139.5
19	225.4	226.2	183.8	19	183.2	211.1	134.5
20	228.9	229.9	196.4	20	196.0	219.0	150.9
21	229.1	232.8	198.1	21	198.1	227.1	155.8
22	223.2	235.2	193.4	22	176.1	213.8	129.5
23	210.3	232.1	182.6	23	145.9	197.9	105.1
24	195.7	230.3	176.9	24	120.4	180.0	89.4

Table A-4. Monthly TDV GHG Emission Factors for the years 2004, 2005, and 2006

May TDV NGHGIF$_A$ (g of CO2/kWh)				June TDV NGHGIF$_A$ (g of CO2/kWh)			
Hour	2004	2005	2006	Hour	2004	2005	2006
1	87.4	147.5	129.1	1	106.4	215.9	194.7
2	80.3	143.0	123.9	2	102.3	208.1	181.1
3	78.8	134.0	117.5	3	94.5	197.4	169.5
4	78.1	135.9	115.5	4	91.3	191.1	161.9
5	83.8	146.6	130.6	5	93.5	194.7	168.9
6	101.9	163.8	142.3	6	110.6	199.7	180.1
7	132.0	175.9	158.1	7	134.9	216.6	201.0
8	156.6	192.7	176.8	8	158.2	241.7	223.1
9	168.1	197.1	180.4	9	173.1	251.5	227.5
10	175.3	199.1	181.8	10	184.3	254.4	231.6
11	180.8	202.9	185.2	11	190.5	257.7	235.8
12	180.9	206.4	187.3	12	196.1	259.4	238.7
13	182.1	209.0	188.0	13	198.2	261.1	239.0
14	181.4	209.4	186.4	14	196.9	259.9	238.7
15	178.7	208.2	184.2	15	193.6	257.3	237.1
16	180.7	204.4	184.5	16	194.3	256.6	239.2
17	180.8	203.6	187.1	17	193.9	256.6	241.7
18	172.8	194.8	182.7	18	184.6	255.1	236.1
19	164.8	185.5	178.2	19	175.6	250.0	230.5
20	168.1	187.8	183.1	20	174.7	251.1	232.1
21	170.5	201.4	186.0	21	177.6	259.1	236.3
22	152.0	196.7	171.9	22	169.5	256.3	230.5
23	120.8	181.8	154.6	23	137.7	241.7	224.1
24	99.5	169.5	140.5	24	112.9	236.3	206.5
July TDV NGHGIF$_A$ (g of CO2/kWh)				August TDV NGHGIF$_A$ (g of CO2/kWh)			
Hour	2004	2005	2006	Hour	2004	2005	2006
1	108.1	227.5	213.4	1	123.7	236.7	174.9
2	98.2	216.4	200.6	2	113.7	230.3	158.5
3	92.8	207.3	188.6	3	106.1	220.2	146.9
4	91.4	203.8	183.7	4	101.6	217.2	145.7
5	96.7	203.2	187.5	5	103.7	219.0	156.9
6	111.3	202.4	186.1	6	125.3	221.8	163.9
7	131.4	204.0	197.0	7	146.6	221.5	173.8
8	157.4	228.6	225.1	8	177.9	239.2	201.5
9	175.8	244.3	243.1	9	195.5	247.5	218.4
10	191.4	251.0	252.4	10	209.2	253.8	227.6
11	201.6	251.0	257.0	11	216.3	257.3	230.3
12	207.4	251.8	260.0	12	223.2	260.5	232.7
13	212.0	255.7	260.3	13	226.9	264.1	233.5
14	210.6	257.2	258.8	14	225.4	264.1	233.3
15	209.1	256.2	255.6	15	221.9	262.0	229.2
16	209.0	255.5	252.3	16	220.4	260.7	230.7
17	210.3	255.5	252.5	17	218.8	259.2	233.2
18	205.7	254.5	253.6	18	212.3	260.5	232.2
19	196.0	251.2	250.3	19	201.2	255.7	228.8
20	194.1	246.3	249.4	20	208.6	254.6	228.7
21	199.4	248.3	253.0	21	219.5	261.2	232.5
22	193.5	248.7	252.8	22	201.8	251.8	220.6
23	159.8	235.0	248.2	23	167.3	232.4	209.7
24	130.3	228.5	232.4	24	139.1	238.0	184.5

Table A-4. (Continued)

September				October			
TDV NGHGIF$_A$ (g of CO2/kWh)				TDV NGHGIF$_A$ (g of CO2/kWh)			
Hour	2004	2005	2006	Hour	2004	2005	2006
1	137.1	195.8	138.8	1	207.5	159.8	144.3
2	125.9	190.5	127.7	2	192.9	149.6	136.0
3	116.4	184.4	118.3	3	182.2	142.8	127.4
4	117.4	182.9	120.8	4	185.0	143.9	131.5
5	129.8	191.0	138.8	5	205.8	165.5	154.0
6	162.9	202.9	164.1	6	241.3	187.5	175.2
7	199.0	212.5	183.0	7	274.1	203.7	189.4
8	221.9	224.8	201.7	8	290.1	216.6	203.0
9	229.7	232.4	215.0	9	290.6	223.7	210.3
10	243.3	234.8	220.1	10	295.2	228.1	217.1
11	250.6	238.4	222.1	11	298.7	232.1	221.7
12	255.9	243.5	222.5	12	300.3	235.1	223.1
13	257.0	245.6	222.0	13	303.1	234.4	222.5
14	257.5	244.6	216.8	14	300.9	234.1	222.2
15	255.8	245.0	212.9	15	296.7	233.6	220.3
16	259.2	240.4	213.7	16	295.3	235.0	220.9
17	260.5	239.0	214.2	17	294.9	233.9	219.1
18	255.1	237.1	211.0	18	291.3	228.6	215.3
19	248.3	231.7	209.0	19	294.0	228.9	219.0
20	261.5	238.1	217.9	20	293.6	228.3	217.4
21	251.5	235.1	209.2	21	286.7	224.2	209.9
22	221.1	222.8	191.9	22	271.9	213.5	199.9
23	187.7	212.2	172.8	23	244.6	189.7	185.0
24	157.7	203.8	148.7	24	222.8	170.9	161.4
November				December			
TDV NGHGIF$_A$ (g of CO2/kWh)				TDV NGHGIF$_A$ (g of CO2/kWh)			
Hour	2004	2005	2006	Hour	2004	2005	2006
1	232.7	175.2	176.0	1	192.7	218.3	141.8
2	218.2	166.8	159.5	2	180.7	214.3	130.9
3	205.8	160.7	148.2	3	171.5	210.8	122.6
4	197.8	153.9	144.6	4	163.7	208.8	116.8
5	200.6	156.0	148.3	5	164.8	213.3	118.3
6	210.4	159.0	164.2	6	170.8	206.7	127.0
7	223.4	172.8	173.6	7	180.8	199.6	134.5
8	238.6	191.3	192.1	8	192.4	200.4	147.1
9	248.8	197.9	201.4	9	201.9	207.1	156.3
10	252.4	207.0	204.8	10	208.0	211.3	159.1
11	254.8	213.3	207.8	11	211.7	215.8	163.8
12	256.8	213.3	209.3	12	213.7	218.4	170.2
13	258.7	214.5	211.9	13	214.8	219.7	171.9
14	254.7	211.9	211.4	14	214.5	217.7	170.6
15	257.0	206.6	205.6	15	209.7	213.7	164.5
16	250.2	196.6	200.8	16	199.6	207.3	160.3
17	246.3	197.0	199.9	17	197.7	206.4	164.8
18	260.6	212.3	211.2	18	215.9	224.2	183.6
19	266.6	219.4	213.0	19	222.8	227.2	185.3
20	264.3	213.1	209.3	20	219.7	221.3	179.5
21	262.9	212.8	207.3	21	220.4	222.5	176.9
22	261.6	207.6	204.4	22	219.5	223.0	174.9
23	255.0	191.3	195.4	23	213.2	218.2	161.8
24	239.7	179.4	187.5	24	197.0	216.9	148.0

Table A-4. (Continued)

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Photovoltaic Conversion: Outlook at the Crossroads Between Technological Challenges and Eco-Strategic Issues

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1. Introduction

Photovoltaic (PV) conversion or the production of electricity directly through the use of solar energy (Fig. 1) is undoubtedly a promising source of renewable energy despite the negligible position it still holds in the global energy landscape, namely barely 0.2% of the global electricity produced in 2010 (European Photovoltaic Industry Association [EPIA], 2011a; British petroleum Global [BPG], 2011).

In fact, it is difficult not to take its breathtaking growth into consideration since the production of PV electricity increased from 1 TWh in 1999 to 50 TWh (40 GW) in 2010, for an annual increase of 36% with a spectacular leap of 50% between 2009 and 2010 (Observ'ER, 2010; EPIA, 2011; BPG, 2011). Various hypotheses predict a global capacity between 131 GW and 196 GW in 2015 (EPIA, 2011). In comparison, from 1999 to 2009, wind energy increased 29% whereas fossil energy only grew 3.7% (Observ'ER, 2010).

Therefore, it is not surprising that the term "solar revolution" was already in use in the field of renewable energy as of 2006 (Bradford, 2006). However, although PV conversion is a credible and preferred candidate as a safe source of energy in the highly probable context of mixed energy and sustainable development, it remains marginal and there are legitimate questions concerning its development, which is still in the very early stages, particularly with respect to performance, production costs and competitiveness. It should be noted that fossil energies still satisfy 80% of the global demand for electricity (Observ'ER, 2010).

The purpose of this chapter is to assess both the performance of PV conversion, in economic and energetic terms, in a favourable global market and the intense research into the use of innovative technologies to improve performance. These assessments require an excursion into the life cycle of PV systems from the synthesis of semi-conductors to the use of the electricity generated, the storage of the energy and finally on to the dismantling and recycling of facilities.

The development of PV systems, from the design to the end of their life, is accompanied by environmental, health and safety concerns related to the expansive use of potentially toxic

materials. Logically, the assessment of the life cycle of PV systems will raise concerns about their compatibility with the global approach of sustainable development in terms of ecological footprint, economic profitability and social acceptability. Social acceptability is even more fundamental in terms of the sustainability since the user should adopt a less traditional energy approach. Will solar energy, which is perceived as the future of renewable energies, be able to challenge of meeting the essential concepts of clean and green energy?
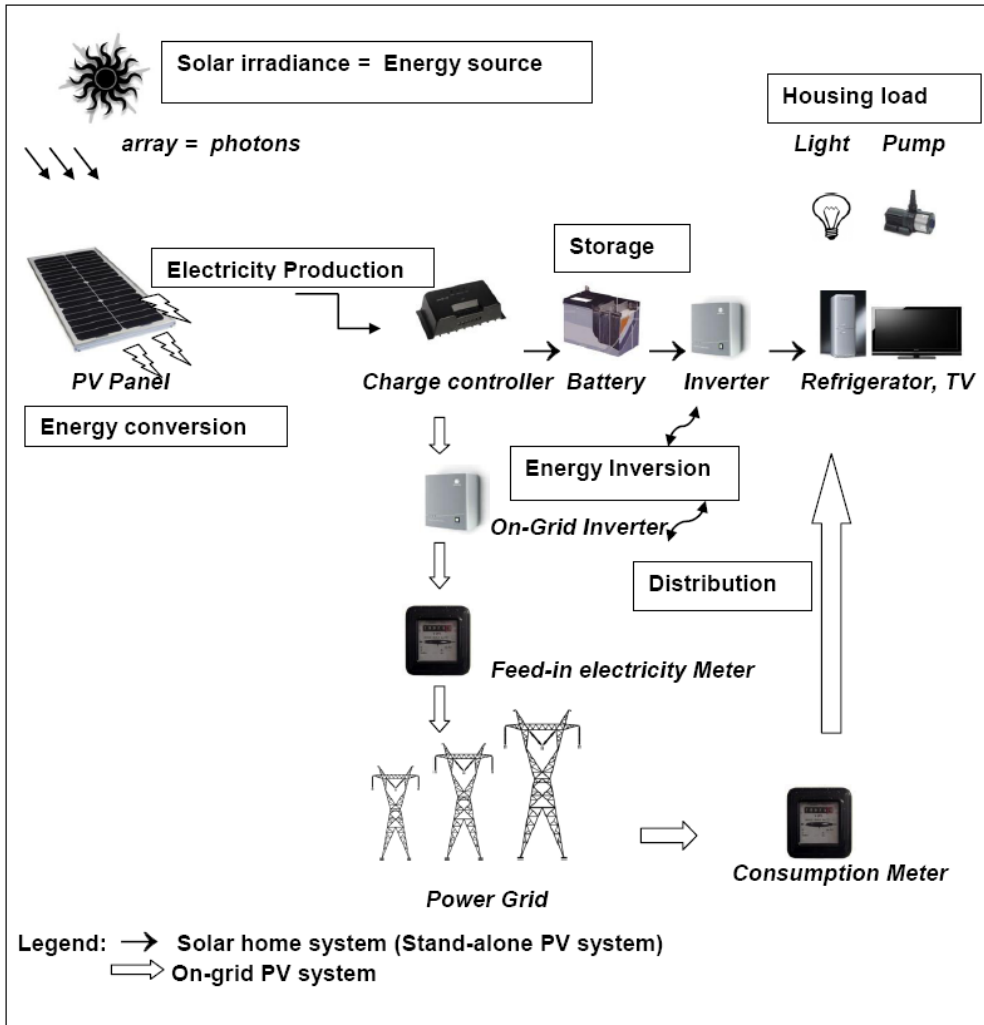

Fig. 1. Diagram of Photovoltaic Conversion and Practical applications

2. Genesis and context of solar energy use

Although the history of solar energy dates back to the earliest days of humanity, its evolution has been extremely slow and laborious, swinging between euphoria, aborted attempts, total disinterest and re-birth. The first time this resource was used in prehistoric times, namely when the rays of the sun were captured and used to kindle flames, apparently took place in Mesopotamia, in the Arabic desert.

The ancient Greeks were the first to describe the famous "burning mirrors" or solar reflectors, the ancestors of parabolic mirrors, created with silver, copper or brass, which were used to light the Olympic flame (Butti & Perlin, 1980). In addition, solar energy was used by the ancient Greeks in a passive form which had a major impact on the architecture of homes since, even in that distant time, deforestation was an issue, resulting in a shortage of charcoal as a result of the unchecked use of this fuel for heating and cooking.

The Roman Empire quickly adopted similar architectural habits since the Romans were also suffering from an over-consumption of charcoal. Outrageous taxes were even imposed for the domestic use of wood (Butti & Perlin, 1980). In 1515, Leonardo da Vinci attempted to build a giant mirror, a primitive solar concentrator, intended to transform the rays of the sun into heat for commercial purposes (Butti & Perlin, 1980; Lhomme, 2004). It would only be during the Industrial Revolution of the 19th century that the solar energy pioneers would emerge in a universe suddenly filled with scientific and technological effervescence in order to improve energy performance and eliminate dependency on wood and charcoal. However, these efforts, while praiseworthy and ingenious, were only partially successful.

One of the most brilliant and prolific of these pioneers was Augustin Mouchot, the French inventor of the first solar engine in 1880. Despite his scientific fervour and his obvious desire to demonstrate the potential of solar energy, he failed to draw France into the Solar Age (Butti & Perlin, 1980). William Adams improved on Mouchot's prototype by installing a group of mirrors to boil the water to a faster way and doing his utmost to demonstrate the great potential of solar energy for the British Empire (Bradford, 2006). John Ericsson, invented the "caloric" engine in 1833, which used hot air as the operating fluid; this air was provided by a solar engine, thereby limiting energy losses (Butti & Perlin, 1980; Bradford, 2006). These pioneers provided the basis of thermodynamic solar energy, by transforming the rays of the sun into energy.

In 1839, Edmond Becquerel first observed the PV reaction, which involves the creation of a spontaneous electrical current when a chain of conductive elements was lit. The first solar batteries, ancestors of modern solar cells, used selenium and were developed in 1883 by Charles Fritts. At that time, they had an efficiency of 0.2% (Lhomne, 2004). In 1921, Albert Einstein explained the PV effect that earned him the Nobel Prize in physics. According to history, Einstein considered the description of the PV effect of greater value than the theory of relativity (Bradford, 2006).

Between 1900 and 1915, the first efforts were made to market thermodynamic solar energy. Aubrey Eneas built and sold two immense machines to be used as boilers; they were equipped with more than 1700 individual mirrors generating 2.5 steam horsepower. Unfortunately, a major storm and hailstorm overpowered his inventions and forced him to abandon any idea of pursuing this line of research as he concluded that his projects were not economically viable (Butti & Perlin, 1980; Bradford, 2006). In 1912, Frank Shuman, one of the greatest visionaries in matters of solar energy, built a plant in Egypt that was strangely similar to modern solar power plants. Unfortunately, it was destroyed during the battles

that took place in Northern Africa during World War I. Moreover, the advent of fossil fuels, with more affordable costs and better performances, ruined all efforts for the economic existence of solar energy for close to 50 years.

In 1954, the idea of solar energy was revitalized as a result of the efforts of Gerald Pearson, Calvin Fuller and Daryl Chapin, three researchers who developed the first silicon solar cells with an initial efficiency of 6% which soon increased to 14% (Singh, 1998). The first commercial applications started in 1958 but these cells were essentially used for space applications. Even though the terrestrial use of solar energy was slow, the scientists and the public were enthusiastic (Goetzberger & Hoffman, 2005; Bradford, 2006; Krauter, 2006).

The development of solar PV systems was strongly influenced at the outset by the price of fossil fuels. Thus, the oil crisis of the 1970s and the sudden increase in the price of oil revealed the precariousness of fossil energy resources and encouraged the solar industry. As a result, the Solar Energies Research Institute was created in the USA and the first subsidies were granted, injecting three billion dollars. In 1979, solar panels were installed on the roofs of the White House, a gesture considered highly symbolic (Bradford, 2006). Thermodynamic solar energy, however, declined in the 1970s and 1980s, for the benefit of by PV energy (Vaille, 2009). At that time, the USA accounted for 80% of the solar market. However, when the price of oil once again declined in the 1980s and the early 1990s, the enthusiasm for solar energy dropped and the solar panels were removed from the White House. Nevertheless, research into PV technologies continued, but was less sustained (Bradford, 2006).

During the 1990s, the world became aware of the need to revise energy policies based on sustainable development and concerns about climate change. Obviously, these issues involved the consideration of the level of energy consumption as well as the environmental consequences (such as greenhouse gas emissions, GHG) and the precariousness of fossil resources (Bradford, 2006). Thus, more attention was paid to PV solar resources.

This time, Europe took the lead in this industry which was predestined to flourish. Thus, of the 40 GW of solar electricity generated in 2010, 30 GW were generated by the European Union, of which 17 GW were produced by Germany. For the same year, Japan and the United States trailed behind with 3.6 GW and 2.5 GW respectively (EPIA, 2011).

The applications of PV are incredibly diverse at present, ranging from small to large, including solar calculators, irrigation pumps, the heating of single-family homes, and solar facilities (roofs, facades, etc.) connected to the power grid (Labouret & Villoz, 2009; Bradford, 2006). PV systems are interesting because they can also be installed in zones that are completely devoid of electrical networks or energy infrastructures, particularly in certain developing countries where the isolated segments intended for rural electrification are experiencing a veritable boom (Singh, 1998). Current applications and future projections differ by region since socio-economic concerns are dissimilar. Thus, in the developed countries, future visions focus on the large-scale integration of PV energy in the urban environment. The idea of a city as a gigantic PV power plant is germinating in peoples' minds as they wait for a large-scale study on the potential environmental and social impacts (Gaidon et al., 2009). In the developing countries, PV energy provides added value and is becoming a symbol of progress and openness to the world, outside the outlying rural zones that could enjoy the benefits (Singh, 1998).

3. Solar radiation: Geophysical considerations and energy potential

Located nearly 150 million km from Earth, the Sun is a huge nuclear power plant—the oldest in the history of mankind—and has a capacity of 25 million kW/h per gram of hydrogen, its main component. The nuclear fusion of one kg of hydrogen releases an energy value of 8.3 million tons oil equivalent (Lhomme, 2004). Since the sun accounts for some two billion tons of material, over 90% being hydrogen of which it uses 600 million tons per second, the energy produced is unimaginable. In fact, it produces 4 x 10^{17} GW, or the equivalent of 400 million billion nuclear power plants! The Earth receives only a tiny fraction of this energy (Centre National de Recherche Scientifique, n.d.; Lhomme, 2004).

The major characteristics of sun energy, despite a certain ubiquity, are a large regional disparity and more or less marked by seasonal imbalance. For instance, the average energy received by Europe is 1,200 kWh/m^2/y vs 1,800 to 2,300 kWh/m^2/y in the Middle East (EPIA/Greenpeace, 2011). Latitude, exposure and altitude are parameters that influence the overall daily and seasonal radiation. Tropical regions corresponding to 25–30 degrees latitude are sunnier compared to European countries above the 45-degree parallel.

Climatologists have long endeavoured to assess the solar energy of a given area as thoroughly as possible and even be able to predict the evolution. Statistics on solar radiation were therefore compiled from data collected to input into valuable databases (EPIA/Greenpeace, 2011). Assembling data of a given region based on different criteria is strategic for the design and dimensioning of PV systems, especially their orientations and inclinations (Labouret & Villoz, 2009).

Characterization of increasingly sophisticated global solar energy resources is a sign of PVs' promising potential. Thus the calculations by the International Energy Agency (US IEA) lead to surprising conclusions. Installing PV systems on only 4% of the area of the world's driest deserts would likely be able to provide all of humanity's primary energy needs (EPIA/Greenpeace, 2011).

4. Technological aspects from solar energy to photovoltaic electricity

The PV effect consists in the direct conversion of solar energy into electricity (Fig.1). Three interdependent and successive physical phenomena are involved: a) the optical absorption of light rays, b) the transfer of the energy from the photons to the electrons in the form of potential energy; c) the collection of the electrons excited in this manner so that they recover their initial energy. The ideal converter is still the semi-conductor, since both the conductivity and the collection method are both sufficient and efficient. However, there are two major obstacles with respect to PV conversion. The first one is related to the photons and electrons. In fact, not all the photons are absorbed and not all of the excited electrons are collected. This impacts the energy performance of a semi-conductor, one of the key parameters for the PV industry. In practical terms, the performance of a solar cell is the maximum power produced, expressed in Watts-peak (Wp) and the higher the Wp is, the better the performance of the cell is (Goetzberger & Hoffman, 2005 ; Labouret & Villoz, 2009). The other major obstacle is the price of the solar module. Development of the technologies and the PV materials is continuing while the two goals are to increase energy performance and reduce the cost of the Wp beneath the symbolic threshold of $1 US/Wp (Krauter, 2006; Xakalashe & Tangstad, 2011).

The material currently used preponderantly in the design of PV cells is silicon, which is abundant in nature, accounting for 90% of the global market for the production of the modules. More than 80% of the silicon used is in crystalline form with an energy performance between 14% and 22% for a solar cell, compared to 12%-19% once assembled in modules (Labouret & Villoz, 2009; EPIA/Greenpeace, 2011; Xakalashe & Tangstad, 2011).

There are currently three generations of photovoltaic cells. Those referred to as the first generation are made of crystalline silicon. The cells are provided in plates or wafers and have to be made from very pure silicon, using a manufacturing process that is still very onerous (Goetzberger & Hoffman, 2005; Labouret & Villoz, 2009; Jaeger-Waldau, 2010). The price of the solar module based on first generation cells is estimated at close to $2 US/Wp (Xakalashe & Tangstad, 2011; SolarServer, 2011).

The second-generation solar cells, so-called thin layer cells, require less material and should cost less to design. Their development is more and more promising since their market share grew from 5% in 2005 to 16%-20% in 2009. Their production capacity, estimated at about 10 GW in 2010, could grow to 20 GW in 2012 and 70GW in 2015 (Jaeger-Waldau, 2010). The thin-layer solar cells include, first and foremost, amorphous silicon, with a very uncompetitive performance of between 4% and 8% although the price per Wp is advantageous, approximately $1.3 US in 2011 (EPIA/Greenpeace, 2011; SolarServer, June 2011). The second generation also includes other polycrystalline thin-layer films, particularly those based on cadmium telluride (CdTe), copper indium selenide (CIS) and its alloy copper indium gallium selenide (CIGS). The average performance of the CdTe cells is between 8% and 10%. The price per Wp was $0.81 US in the first quarter of 2010 and at the end of the same year, CdTe modules contributed to the production of almost 14% of the PV solar electricity generated by thin-layer cells (Jaeger-Waldau, 2010).

In theory, the CIS and CIGs cells have the highest performance for thin-layer cells, which is estimated at 20% in laboratory tests. However, the modules installed yield only 7% to 12%. Nevertheless, this technology is in the early stages of development and the manufacturing process is still complex, particularly since indium is a material that is in high demand in the flat screen (LCD) industry, which makes its use in PV systems problematic (Labouret & Villoz, 2009; EPIA/Greenpeace, 2011).

The objective set for the third generation cells is in the vicinity of 30% and these cells rely on innovative technologies. This group includes primarily: a) multi-junction cells with a thin layer of silicon or gallium arsenide combined with a solar concentrator, b) organic polymer cells or poly-electrochemical cells, also called Grätzel cells; c) thermophotovoltaic cells, primarily with an indium arsenide base (EPIA/Greenpeace, 2011). The multi-junctions, equipped with solar concentrators with a factor of up to 1000, are by far the most performing, with a record performance of 35.8% announced in 2009. However, the applications remain limited since they are confined to the space and military fields (Chataing, 2009; Guillemoles, 2010). While the performances of the organic cells are lower, from 8% to 12%, interest in such cells and particularly the Grätzel cells is growing since the production costs are constantly declining with an interesting price outlook estimated at $0.73 dollars US (0.5 Euros) per Wc in 2020 (Chabreuil, 2010; EPIA/Greenpeace, 2011).

One of the emerging technologies in the field of PVs is nanotechnology, which uses nanocrystalline particles or quantum dots, which would significantly increase the efficiency of the conversion compared to conventional semi-conductors (Nozik et al., 2010). Current

research is focussing on the use of hybrid organic-inorganic cells with a great deal of load mobility that uses cadmium selenide as the inorganic material (Freitas et al., 2010).

5. Practical applications

The solar modules consist of cells assembled in series, encapsulated between supports made of tempered glass, a special Tedlar® type plastic or "solar" resin, and then framed. In order to amplify their power, the modules may be grouped in voltaic panels or even voltaic fields with power output ranging from 1 kWp (kilowatt peak) to more than 100 kWp (Antony et al., 2010).

The two types of PV systems in use are autonomous (off-grid system) systems and those connected to the public electrical network (on-grid system); they differ in terms of their finality and the nature of their components. The electricity produced by the autonomous systems is consumed on site whereas that generated by facilities connected to the network is intended to fully or partially supply that network (Labouret & Villoz, 2009; Antony et al., 2010).

Moreover, there is a hybrid system, an intermediary and emerging form of the PV market that allows connection to another source of energy. Efforts to combine sources of energy are continuing particularly as a complementary source of energy although this type of system remains complex, laborious and onerous (Goetzberger & Hoffman, 2005; Labouret & Villoz, 2009).

There are many applications for autonomous systems such as internal market for solar gadgets (calculators, clocks, etc.), solar home systems and water pumps. These systems are still a preferred solution for developing countries where more than two billion people are not connected to an electrical network and have no hope of being connected to one someday (Goetzberger & Hoffman, 2005; Labouret & Villoz, 2009). Nevertheless, despite their appeal as sources of energy and their potential for development, these systems are still the source of major concerns requiring intense consideration so as to ensure both their sustainability and their wide-scale generalization in developing countries.

In this case, it would be possible to enhance their tangible added value in the global energy landscape. First, apart from the internal market and "sun-related" applications such as pumping or ventilation, the autonomous systems would have to include judicious storage batteries in order to accumulate excess electricity, but these batteries are problematic. The financing for the autonomous generators is the first negative element since, even if only 20%-30% of the initial investments are for storage, the reduced lifespan of the batteries (batteries have to be replaced every 2, 5 or 10 years) results in a final cost that could amount to 70% of the total costs (Labouret & Villoz, 2009).

It is a fact that the positive development of individual solar systems in the developing countries is having pernicious effects since that easier access to electricity could lead to an increase in the acquisition of electrical appliances and, consequently, to the overuse of batteries, thereby reducing their lifespan (Goetzberger & Hoffman, 2005). Moreover, the scarcity of training on autonomous systems, aggravated by the high rate of illiteracy in the developing countries, could result in difficulties in maintaining the batteries which, obviously, influences their durability. Thus, the integration of batteries, although essential for autonomous systems, will have an impact on their costs, already high ($500 to $1500 US), thereby handicapping, to a certain extent, their generalization in terms of rural electrification in developing countries (Goetzberger & Hoffman, 2005; Labouret & Villoz, 2009).

The other issue with respect to autonomous systems concerns the nature of the batteries, which are essentially lead-based. The lead battery has two disadvantages: the most particular concern is the potential effect on public health and safety and its impact on the environment, mainly resulting from the presence of lead, a toxic heavy metal. Concerns are not only to the manufacture and handling of this type of battery but also to end-of-life recycling (Vest, 2002).

6. Energy and economic performances

It is possible to evaluate the competitiveness of PV systems in terms of economic and energy performances. The prominent economic parameters are the global cost of the PV systems and the price of the solar energy generated while energy profitability is estimated in terms of the Energy Pay-Back Time [EPBT] as well as the Energy Return Factor [ERF].

Two realities affect the photovoltaic market: a) growth has been spectacular in just a few years and b) the price of the energy produced remains the most expensive (Aladjidi & Rolland, 2010). Thus, when a price per Wp is announced, it only reflects the price of the solar unit when it leaves the plant. The overall cost of the PV solar energy includes an entire series of parameters, such as the cost of the initial investment, the operating lifespan of the system, the energy performance during operation, the cost of maintenance and whether or not storage batteries are integrated (Goetzberger & Hoffman; PVResources, 2011).

The crucial parameter that will condition price fluctuations is certainly the maturity of the market, even more than the type of application for which the photovoltaic system is used. Thus, countries such as Germany and Spain are considered, as a result of their precocious commitment to the development of solar energy, the driving forces behind the growth of the PV market (Labouret & Villoz, 2009).

The cost of the initial investment, depending on the power desired, includes several elements, in particular the retail price of the unit and the various components of the system, the feasibility study, planning, and the cost of installing the equipment. The various components vary according to the type of system. Those connected to the network, in residential segments on rooftops or facades or in solar fields, require more assembly structures, a cabling system and eventually grounding work (EPIA/Greenpeace, 2011). On the other hand, in addition to storage batteries, autonomous systems include load controllers which, although they represent only 5% of the initial investment, are essential for protecting the systems against solar overloads and discharges (Labouret & Villoz, 2009).

In 2009, the price of PV installations varied from 3.5 to 5 Euros/Wp for 1 Kw of power with projections of 0.7-0.9 Euro/Wp in 2030 and even 0.56 Euro/Wp in 2050 (PVResources, 2011; EPIA/Greenpeace, 2011). The price of the photovoltaic unit is the most important factor in determining the cost of the initial investment. It is still rather high and is currently estimated at between 40% and 60% of the total cost, depending on the technology used, although it has decreased significantly over the past five years (EPIA/Greenpeace, 2011).

Since silicon dominates the PV market, the retail price of the units made using crystalline silicon reflects fluctuations in the price of the raw material, which is closely related with the production capacities of the industry. The spectacular overproduction of silicon noted in 2009, particularly as a result of the opening of an Asian PV market, although it destabilized the supply and demand through the multiplication of the number of independent producers, helped to remove the spectre of a silicon shortage (EPIA, 2011).

In addition to readjusting the silicon market as a condition for stability requiring the consolidation of firms, the real issue with respect to reducing the price of the units involves improving the manufacturing process through automation. Thus, major efforts should be made to improve refining capacity, reduce the thickness of silicon wafers and increase conversion performances through an equitable manufacturing process that respects specific standards (Aladjidi & Rolland, 2010; EPIA/Greenpeace, 2011).

Although there are still good days ahead for silicon, the development of various emerging technologies in the field of photovoltaics would necessarily have a most beneficial effect since they would either use less silicon, as in the case of amorphous or micro-crystalline cells, or they would use innovative materials other than silicon (Aladjidi & Rolland, 2010).

The lifespan of the PV systems is a key parameter not only for the assessment of the overall cost of the systems but also for estimating the EPBT and ERF. Most of the manufacturers of PV units provide performance guarantees, namely a life span between 20 and 25 years at 80% of the minimum nominal power for both crystalline and cadmium telluride units, while stating that this average would be a minimum estimate and not a definitive value since it would be estimated at 40 years in 2020 (Labouret & Villoz, 2009; EPIA/Greenpeace, 2011).

The improvement in lifespan is both technological and technical in nature since it is closely related to the stability of the PV systems in use elsewhere, which are negatively impacted by a deterioration process that affects both the solar units, despite the encapsulation of the cells, and the support frame. This degradation can result from the aging of the semiconductors, the delamination or loss of adhesiveness between the solar cells and from the intrusion of humidity. The fragility of the systems has a major impact on the energy performance during operation. However, only few studies were done on the estimation of losses, while a decrease in performance of 1%-2% per year was observed for some systems (Goetzberger & Hoffman, 2005).

The cost of maintenance, including the ongoing control of the performance and the appearance of the systems as well as their cleaning, remains low and is estimated to be between 0.01 and 0.1 Euro/kWh (PVResources, 2011). However, integrating storage batteries in the autonomous systems, which are characterized by a decrease in lifespan of a factor of 2 for every 10 degrees Celsius as a result of corrosion, leads to a long-term increase in the cost of the investment as seen earlier (Labouret & Villoz, 2009).

The average price of the solar electricity generated depends, among other things, on the initial installation costs and the rate of sunshine and is estimated at 0.22 Euro/kWh in Europe and remains, despite a significant decrease of 40% between 2007 and 2009, less competitive than the electricity generated using fossil fuels, which is evaluated between 0.09 and 0.27 Euro/kWh (EPIA/Greenpeace, 2011). However, there is no shortage of programs intended to make PV systems profitable, such as investment contributions (subsidy, green loan), tax benefits (reduction, exoneration) and direct pricing support, including the compensatory redemption rate systems in place in several European Union countries, particularly Germany and Italy (Goetzberger & Hoffman, 2005).

Germany was the first country to implement a law giving priority to renewable energy and has been a powerful driving force behind the development of PV programs. This law, and others which have been based on it, establishes the right to inject solar energy into the public network and to be reimbursed per PV kWh (EPIA/GREENPEACE, 2011; PVResources, 2011).

Photovoltaics consume necessarily energy throughout a system's life cycle, i.e. during the manufacturing of modules, their installation and, at the end of their useful life, disassembly and recycling. The energy balance is defined by two common parameters: the EPBT, meaning the time required for PV energy to repay its energy debt, and the ERF or how many times the consumed energy is reproduced. These two parameters are determined by the rate off sunshine, the purpose and design of the PV system, and the type of technology (International Energy Agency-Photovoltaic Power Systems Program [IEA-PVPS], 2006; EPIA/Greenpeace, 2011).

The energy balance is closely related to the lifespan of the systems. A 2006 study gives an EPBT of between 1.6 and 3.3 years for systems installed on roofs and 2.7 to 4.7 years for those integrated into facades. The ERF, estimated for a business life of 30 years, is between 8 and 18 for roofs and from 5.4 to 10 for facades (IEA-PVPS, 2006). Data collected in 2009 for systems integrated into roofs in southern Europe indicate an EPBT of nearly 1.75 years for systems that use silicon cells, except for silicon ribbon, which is estimated at just over one year. Thin film technologies remain effective with nearly 0.7 years for cadmium telluride systems (EPIA/Greenpeace, 2011), which was adjusted to 0.7 to 1.1 years by the Held team from Germany (Held & Ilg, 2011).

Preliminary results related to commercial applications for solar concentrators present an EPBT of 0.8 to 1.9 years (Wild-Scholten et al., 2010). It appears that the silicon wafer industry is highly energy intensive and that the development of thin-film technologies, which require few materials, would be more compatible with an energy gain reducing the EPBT, maximizing the ERF and consequently optimizing the energy efficiency (Wild-Scholten et al., 2010; EPIA/Greenpeace, 2011).

However, a low EPBT does not always equate low energy efficiency and this finding makes perfect sense when applied to autonomous systems, which are of great use in developing countries. These systems are somewhat not considered in these calculations since few studies reinforce this reality, except one with an EPBT of 3.5 to 6 years due to the presence of storage batteries that must be regularly renewed and excess energy during periods of strong sunlight (Kaldellis et al., 2010).

These energy assessment calculations include the end-of-life recycling of systems. Although the first large-scale PV applications were installed in the 1990s, increasing growth of the market will require that more systems be disassembled and recycled. Once disassembled, in terms of waste to be treated, PV modules represent about 2,300 t in 2007, over 7,500 t in 2011 and a forecast of 132,000 t in 2030 considering average annual growth of 17%. Silicon modules currently represent over 80% of this waste. But if trends in thin film and emerging technologies continue, by 2030 they could account for over 65% of waste generated (Sander et al., 2007).

The era of waste collection and recycling PVs is still in its infancy despite voluntary measures in the PV industry (PVCycle, 2011) and the ongoing search for more efficient recycling techniques, both energy and economic, for all types of modules (Radziemskai et al., 2010). The recent integration of PV in the Waste Electrical and Electronic Equipment (WEEE) directive (Council of European Commission, 2011a) is only a first step and a strong legislative framework underpinned by sustained efforts is required in order to structure PV waste management, generalize the most competitive recycling processes for all system components, including batteries, and make them applicable to the extent of PV installations worldwide (PVCycle, 2011).

7. Life cycle of photovoltaic systems and ecological footprint

As a result of the accelerated growth of the PV industry, a rigorous assessment of the environmental impacts of the systems has become necessary, conducted through a life cycle assessment (LCA) integrating all of the manufacturing, operating, collection and waste recycles. The LCA is an orderly process that analyzes the input/output impact of the PV industry from the "cradle to grave", with the inputs referring to the materials and energy consumed and the outputs illustrated by greenhouse gas (GHG) type emissions and solid and liquid waste.

A form of environmental management that is as exhaustive as possible, the LCA is a series of tools and techniques for which the ultimate objective, beyond the descriptive and quantitative aspect of the environmental profile, is to reinforce the sustained effort to limit the environmental impacts in a context of sustainable development (Fthenakis et al., 2005a; IEA-PVPS, 2011). The key factor that will determine the pertinence and the credibility of the LCA will be the voluntary and transparent cooperation of the manufacturers with respect to the accurate and full disclosure of the various inputs/outputs (Fthenakis et al., 2005a; Stoppato, 2008; IEA-PVPS, 2009; Ecoinvent , 2010; IEA-PVPS, 2011).

In addition to the energy considerations previously illustrated by the calculation of the EPBT and the ERF, the parameter most frequently estimated for the LCA assessment is the ecological footprint describing and quantifying the entire greenhouse gases (GHG) released during the lifespan of the PV system and expressed in carbon dioxide equivalents per kWh. The environmental gain expected by the reduction of GHG related to the operation of PV electricity has also to be taking into account. These two assessments are always determined in comparison with the emissions attributed to fossil energies (Fthenakis et al., 2005a; IEA-PVPS, 2011).

The estimate of the GHG attributed to PV systems is an increasingly complex exercise since it includes criteria that are as diversified as the technology used, the choice of manufacturing processes and the type of energies consumed, the techniques for assembling the cells and units, the power generated, the transportation of raw materials and the finished product, the components required for the installation of the units (Balance Of System/BOS) as well as the recycling processes. The BOS will, in turn, depend on the applications, the dimensions, the orientations and, above all, the location selected (Krauter & Rüther, 2004; Stoppato, 2008; Fthenakis & Kim, 2011; Reich et al., 2011).

A major distinction is acknowledged between indirect emissions, which concern the overall energy, electricity included, needed to manufacture the units, and the direct emissions, which concern all of the chemical compounds, raw materials included, that are involved in the manufacturing process and are a potential source of GHG (Reich et al., 2011). It is essential to point out that the GHG emission estimates for PV systems are not absolute since they are subject to a certain number of constraints, particularly the quality of the information provided by the manufacturers involved throughout the life cycle. Thus, the estimates are subject to future revisions as are the EPBT and ERF calculations (Reich et al., 2011; Held & Ilg, 2011).

With respect to the direct emissions of the silicon industry, three critical phases are identified: the development of metallurgical-grade silicon from silica, its transformation into solar-grade silicon and the development of a structure and framework in the form of panels. While the production of metallurgical-grade silicon requires the consumption of roughly 14 kWh per kg of metallurgical-grade silicon whole releasing 3 tons of CO_2 equivalents for one

ton of metallurgical-grade silicon, the solar-grade silicon stage is by far the most energy consuming, with 150 kWh per kg obtained (Miquel, 2009) or 1190 MJ/panel (0.65 m^2) (Stoppato, 2008).

Assembling the panels with an aluminum frame also consumes energy, ranging between 53 and 245 kWh with emissions varying between 15 and 19 kg CO_2-eq, all per kg of aluminum consumed (Krauter & Rüther, 2004). Overall, the estimation of GHG emissions for silicon panel manufacturing is variable as shown in table 1.

The silicon technologies release also GHG directly, with the primary sources being the raw material itself, the various fluoride compounds involved in the manufacturing process as well as the incineration of the plastic used to encapsulate the solar cells, one of the common processes in the recycling of plastic materials. According to the estimates, the emission is virtually negligible, about 0.16 g CO_2-eq/kWh for the raw material, whereas the incineration of plastic would be a source of 1.1 g (Reich et al., 2011).

Emission estimates (g CO_2-eq/kWh)	Reference
15-25	EPIA/Greenpeace, 2011
30-45	Fthenakis & Alsema, 2006; Fthenakis et al., 2008
43-73	Weisser, 2007; Miquel, 2009
148-187	Stoppato, 2008

Table 1. GHG emissions for silicon panel according to different authors

The fluoride compounds remain the Achilles heel of silicon cells since they have an even higher Global Warming Potential (GWP). CO_2, methane and the nitrogen oxides have GWPs of 1, 23 and 296. There are also issues with respect to CF_4 (carbon tetrafluoride), SF_6 (sulphur hexafluoride), C_2F_6 (hexafluoroethane) and above all NF_3 (nitrogen trifluoride) for which the GWPs range from 7,400 to more than 17,000 (Fthenakis et al., 2010; Miquel, 2009). Despite this fact, these fluoride compounds, excluding SF_6, are not included in the Kyoto protocol whereas NF_3 is considered to be the gas with a significant environmental impact (Prather & Hsu, 2008).

Concerning the thin layer technology and, more specifically, the cadmium telluride (CdTe) technology, the small amount of data available relies on a certain number of parameters such as the geographic location of the facility, the conditions at the site of the installation and, certainly, the type of databases used. The information about the recycling procedures has a particular impact on the calculation, as for all of the technologies, but the recycling process is in the experimental stage since the CdTe market is still relatively young (Held & Ilg, 2011). From 18 to 20 g CO_2-eq/kWh (Fthenakis & Kim, 2005; Fthenakis, 2009) the estimates are currently being revised slightly upwards (Held & Ilg, 2011).

The autonomous PV systems include, in their calculations, the emissions generated by the storage batteries and eventually those caused by the diesel generators integrated in most of the hybrid systems. Taking into account the 1.26 kg CO_2-eq released per kg of batteries produced, the cost of transportation and maintenance, and based on an operating life of more than 20 years, the individual systems, namely solar home systems (SHS), with a power of 15 Wp release an average of 160 kg CO_2-eq whereas SHS with a power of 50 Wp release 650 kg (Posorski et al., 2003).

Notwithstanding this disparate data, the GHG emissions of PV systems are well below those of fossil energies as summarised in table 2. The overall production of electricity, all energy sources combined, generates an average of 600 g CO_2-eq/kWh, although this varies between countries (Stoppato, 2008; EPIA/Greenpeace, 2011).

Energy system	Average emission	Reference
PV Systems	15-187	See references in Table 1
Coal	800 – 1280	Dones et al., 2003 ; Weisser, 2007; Evans; 2010
Oil	519-1200	Dones et al., 2003; Weisser, 2007; Evans; 2010
Natural Gas	360-991	Dones et al., 2003; Jaramillo et al., 2007; Weisser, 2007; Evans; 2010

Table 2. GHG emissions (g CO_2-eq/kWh) resulting from different energy systems

Moreover, the ecological footprint may be evaluated in terms of environmental gains resulting from the expected reduction in GHG caused by the use of PV systems. Based on the principle that, once installed, the systems (with the exception of the diesel generators and the transportation of maintenance services) do not emit GHG, it is possible to calculate how many CO_2-eq will be saved throughout their lifespan. Scenarios have been developed to extrapolate this reduction with a forecast of 0.6 kg CO_2-eq/kWh on average saved by the extension of the systems connected to the network and taking into account emissions (optimistic) of 12-25 g CO_2-eq/kWh. Almost 4 billion tons of CO_2-eq could be saved by 2050 (EPIA/Greenpeace, 2011).

As for the autonomous systems, 70% would experience a reduction of more than 200 kg of CO_2-eq per year, namely 6 tons of CO_2-eq and 8.9 tons of CO_2-eq for 15 and 50 Wp systems respectively with a lifespan of more than 20 years (Posorski et al., 2003). The projections go even further, considering that the implementation of PV plants in developing countries, combined with a generalization of systems connected to the network in order to supplement the hybrid systems and reduce emissions related to the transfer of technology from the supplier country to the consumer country would be even more beneficial in ecological terms with more than 26 tons of CO_2-eq/kWh saved per site implemented (Krauter, 2006).

8. Potential health effects

The photovoltaic industry, with its ambitious goal to provide clean electricity, paradoxically uses materials and/or manufacturing processes that are not free from inherent potential health and safety effects. The sector is therefore facing a dual objective: increase energy efficiency and reduce or even abandon processes that use potentially toxic compounds.

Health concerns date back to the 1960s (Neff, 1979) and many frameworks have been developed since. The integration of PV panels into the European Waste Electrical and Electronic Equipment directive also shows awareness of PV systems potential toxic waste, which is classified as electronic waste (Silicon Valley Toxics Coalition [SVTC], 2009; Council of the European Union, 2011a). Legal frameworks such as the European REACH directive (Registration, Evaluation, Authorisation and Restriction of Chemicals) have lent support to the trend. As a whole and regardless of the technology, potential risks are a reality that must be addressed thoroughly, without invoking the environmental benefits to delay the risk assessments and possible adoption of mitigation measures.

The solar-grade silicon industry involves potential risks primarily during the manufacturing phase. However, mining of quartz or sand, precursors of metallurgical-grade silicon, also presents various risks mainly due to chronic exposure to crystalline silica dust, causing diseases of respiratory and urinary systems, arthritis, scleroderma and even lung cancer (International Agency for Research on Cancer [IARC], 1998; Yassin et al., 2005).

Developing solar-grade silicon from metallurgical-grade silicon through the Siemens process, which is still the most common in the sector despite the existence of other non-standardized techniques (Miquel, 2009), releases chlorosilanes especially silane gas and silane tetrachloride ($SiCl_4$). Silane gas is extremely explosive, which is potentially dangerous both for workers and the community surrounding manufacturing sites. Fatal explosions have been reported in Germany (1976), Taiwan (2005) and India (2007) (Ngai, 2010).

As for $SiCl_4$, it is a potent eye and lung irritant that can also affect the central nervous system. It reacts with water and can lead to skin burns and no carcinogenicity or reproductive toxicity studies have been performed so far (Right To Know, 2010). This same gas is the cause of various irritative symptoms observed in the residents of a Chinese village in the Henan province, some 50 meters from a polycrystalline silicon cell plant (Cha, 2008). Cutting solar-grade silicon ingots into plates exposes workers to silica dust (kurf) that can induce breathing problems due to overexposure despite the use of protective masks (Yassin et al., 2005). Other non specific chemicals are also involved in the manufacturing process including sodium hydroxide, sulphuric acid or hydrofluoric acid, and pose potential risks to workers.

It is therefore important for the following two priorities to be applied in order to adjust the accelerated development of the market: a) review the manufacturing processes for emission-reducing technology (abatement technologies), b) carry out or complete the appropriate risk analyses of all potentially toxic compounds with great transparency from manufacturers.

In terms of potential risks to public health, thin film technologies are no exception. The risks are still poorly documented for copper indium selenide and its alloy copper indium gallium selenide but two compounds that are particularly irritating to eyes and lungs are still being handled, namely hydrogen selenide and selenium dioxide (Agency for Toxic Substances and Diseases Registry [ATSDR], 2003). Indium is also problematic as it can induce various diseases including lung cancer and reprotoxic and embryotoxic effects and remains without a standard toxicological reference value (Nakano, 2009).

Technologies using cadmium telluride (CdTe) generate some controversy for two main reasons: a) the presence of cadmium (Cd), a metal classified as a group 1 carcinogen by the International Agency for Research on Cancer (IARC, 1997) and b) little documentation exists about the extent of their particularly chronic potential toxicity (Norwegian Geotechnical

Institute [NGI], 2010). These concerns also include emerging CdTe and CdSe-based solar nanotechnologies (Peyrot et al., 2009; Werlin et al., 2011).

The other element worth considering is the limited number of manufacturers using CdTe, which limits the scope of studies based mainly on data supplied by the manufacturers. The sector handling cadmium salts suffers from a confusion of nomenclature (Classification & Labelling [C&L]) since the physical and chemical properties of Cd salts are quite different from Cd just as the nanoparticles of cadmium salts differ from Cd salts in a thin layer (Fraunhofer Institute, 2010; NGI, 2010).

However, this controversy does not seem to have influenced the Council of the European Union, which will maintain exception concerning Cd use in PV modules in RoHS (Restriction of Hazardous Substances) so that the ambitious targets set by the EU for renewable energy and energy efficiency can be achieved (Council of the European Union, 2011b).

Nevertheless, current data attribute a lower acute toxicity to CdTe than to elemental Cd (Zayed & Philippe, 2009). Toxicity studies of CdTe nanoparticles are contradictory and inconclusive at this time although the nanocrystals' small size would be a priori more damaging thus high cytotoxicity is suspected (Su et al., 2010).

During the operation of CdTe solar panels, the risk of emission in case of breakage or fire would be considered negligible (Steinberger, 1997, as cited in Nieuwlaar & Aselma, 1997; Fthenakis, 2003; Fthenakis et al., 2005b, Raugei & Fthenakis, 2010). Optimistic findings concerning the risk of CdTe emission in case of fire should be reviewed since, although established according to standard procedures, they were provided on the basis of flame temperatures between 750 and 900°C.

However, in building fires where temperatures in the thermal plume are between 600 and 1,000°C, those in the flame can reach 2,000°C (Fraunhofer Institute, 2010; Gay & Wizenne, 2010). Since the risk of emission in case of accident is not clearly defined, better protection of workers responsible for installation and maintenance of PV systems is required.

The dismantling and recycling of PV systems can be problematic because of the potential risks associated with handling hazardous toxic compounds, especially polybrominated diphenyl ethers (PBDEs) used as flame retardants including inverters incorporated into photovoltaic systems (SVTC, 2009). The potential toxicity of PBDEs such as the carcinogenic risk due to bioaccumulation in the body is not yet clarified (ATSDR, 2004).

Other major health concerns inherent in the PV industry are to be considered in the tally of potential risks to human health. These are the risks associated with manufacturing and recycling processes for lead batteries, which involve handling a number of hazardous compounds such as, in addition to lead, heavy metals harmful to the central nervous, endocrine and cardiovascular systems, sodium nitrite, sulphur dioxide, arsenic and sulphuric acid (Vest, 2002).

9. Environmental impacts

Throughout the life cycle, the PV industry can generate potentially toxic compounds, either during normal production or during accidental situations that could be released into the atmosphere, in solid or liquid effluents. The possible consequences would include alterations in the quality of the air, the soil and the water, with potential impacts on biota (Electric Power Research Institute, 2003; SVTC, 2009).

The vast majority of the studies on ecotoxicity and potential environmental impacts essentially pertain to the plant manufacturing phases, whereas little data is available with respect to the possible direct emissions or releases during operation as well as during the dismantling, the processing of waste and the recycling of the solar panels.

In terms of atmospheric emissions, the principal pollutants are essentially sulphur oxides (SOx), nitrogen oxides (NOx) and certain heavy metals such as arsenic, cadmium or mercury (Fthenakis, 2009; SVTC, 2009). Table 3 compares the average SOx and NOx atmospheric emissions from PV systems to those from various fossil fuels used to produce electricity. The results provide eloquent evidence that PV systems are clearly advantageous comparing to various fossil fuels. The data concerning PV systems varies according to the technologies used, the energy performances of the solar cells, the capacities of the systems, the impact assessment methods used and, therefore, the databases used.

Energy system	SOx (g/kWh)	NOx (g/kWh)	References
Photovoltaic	0.05 to 0.36	0.025 to 0.34	Pehnt, 2006; Fthenakis et al., 2008; Hatice & Theis, 2011.
Coal	5.2 to 12.0	1.3 to 4.5	Gagnon et al, 2002; Fthenakis et al., 2008; Jaramillo et al., 2007; Hatice & Theis, 2011.
Heavy fuel	1.1 to 8.0	0.5 to 1.5	Gagnon et al., 2002; Hatice & Theis, 2011.
Diesel generator	0.2 to 1.3	0.3 to 12	Gagnon et al., 2010; Hatice and Theis, 2011.
Liquid or solid natural gas	0.14 to 1.8	0.3 to 4.5	Jaramillo et al., 2007

Table 3. Average SOx and NOx atmospheric emissions associated with energy systems

The PV industry also produces ammonia emissions (NH_3) and volatile organic compounds (VOCs) (Pehnt, 2006; Fthenakis et al., 2010), but the existing data cannot be used to provide a rigorous comparative assessment. If there is a stage that could be crucial for the PV industry, it would be the end of the systems' lifecycle. Indeed, this could be the source of environmental and ecotoxicity concerns. In fact, the potentially toxic materials involved throughout the life cycle could be found, as a result of a routine or accidental release, in the solid and/or liquid effluents that could contaminate the soil and aquatic environments (Electric Power Research Institute, 2003; SVTC, 2009).

The emerging technologies require just as much vigilance as a result of the shortage of current ecotoxicological data, which would invite more refined investigations in the future in order to keep up with the growing dynamics of the market. The cadmium-based PV industry is specifically concerned since the current data seems to indicate that CdTe nanoparticles have the potential of bioaccumulation in aquatic organisms (Peyrot et al.,

2009) and there is a possible bioamplification of CdSe nanoparticles (Werlin et al., 2011). Overall, there is a consensus that the evaluations performed to date seem to give the PV industry much more credit than fossil fuels, but the fragmentary nature of the results indicate that more in-depth investigation is required.

10. Sustainable development: Issues and prospects

The current vitality of the photovoltaic sector is taking place in a context marked by the need to review energy policies given both the increasing spectre and the growing number of the obvious consequences of climate change. In fact, the current policies serve only to draw sombre and unfavourable prognoses, resulting in particular from a lack of balance between a high rate of energy consumption and a problematic supply of conventional fossil energies associated with highly volatile prices and market instability (Bradford, 2006; Labouret & Villoz, 2009).

The current concept of sustainable development is positioned as an enlightened response to major concerns, based on the fact that it reconciles, inasmuch as possible, three parameters which have been completely divergent to date: the economic efficiency, the social equity and the socio-economic development and, finally, the preservation of the ecosystems. The compromises sought through sustainable development require the implementation of several complex actions focussed on a fundamental objective: to ensure a balance between the energy offer and demand for current generations while respecting the resilience of the biosphere. It is, therefore, a response to real, current concerns that could compromise the wellbeing of future generations (International Union for Conservation of Nature, 2006).

Applied to the energy sector, such actions involve the implementation of strategies that are essentially corrective in nature and are part of a dynamic process based on the guiding principal of using renewable natural resources. Given this more functional vision and, based on the economic, health, safety and environmental profiles of PVs, as assessed and presented throughout the chapter, it is possible to provide an overall appreciation of the extent to which the photovoltaic industry respects different principles of sustainable development, inspired by those defined by the Ministry of the Environment of the Province of Québec, Canada (MDDEP, n.d.). This assessment is based on the current state of knowledge for an industrial sector extremely fertile in terms of technical and technological developments.

Table 4 aligns the PV industry with several principles of sustainable development. It can be considered as a barometer of human and equitable sustainable development. It also summarizes the extent to which different principles of sustainable development are respected. Although the results may be considered favourable, recommendations are issued in order to enhance the respect for the various principles.

Despite the universality of the sun as a resource and the fact that it is inexhaustible and safe, there are still many issues. Whether they are technical or technological, they will require a solid political focussing on subsidy systems and financial accessibility, strong programs to integrate photovoltaic systems in buildings, and administrative flexibility to ensure that the sector is dynamic (Bradford, 2006; EPIA/Greenpeace, 2011).

Moreover, a major issue concerns the social acceptability of PV systems, not only as a source of reliable energy but also as a system that can easily accompany daily life at a reasonable cost, while being integrated into local architecture without major visual impacts.

Several principles	Level of adherence	Recommendations
Economic efficiency	**Average** Price of solar electricity still not competitive.	To increase efforts in research and development, standardization of manufacturing procedures, more encouraging redemption policies, better penetration of PV systems, development of smart grids, long-lasting batteries.
Health and safety	**Average to good** Possible accidents, reduction of GHG, toxic substances.	To increase occupational health and safety, technological innovations, reduction even elimination of potentially toxic compounds, policy to reduce emissions and spills, emission control, performance of exhaustive risk analyses.
Quality of life	**Good to very good** No eco-visibility, good integration in space.	To reduce hybrid systems using diesel generators.
Precaution Prevention	**Average** Use of potentially toxic components.	To refine the assessment of the life cycle. Organization of the waste management and recycling sector.
Subsidiarity/ delegation	**Average** Administrative processes still difficult.	To implement a one-stop-shop system to facilitate administrative procedures.
Equity and social solidarity	**Average to good** Solar resource ubiquitous; onerous systems.	To generalize rural electrification in developing countries.
Environmental protection	**Average to good** There is little documentation about certain emissions**.**	Technological innovation to limit the use of fossil energy and raw materials, increased contribution of manufacturers and better organization of the photovoltaic sector.
Preservation of biodiversity and respect the ecosystems	**Average** Clearly advantageous compared to fossil energies, lack of data about emissions, waste and recycling**.**	Reduction of potentially toxic compounds, more elaborate analyses of toxicological and ecotoxicological risks.

Table 4. Aligning the photovoltaic industry with the principles of sustainable development

The informed acceptance of the public, including the public authorities, would have a definitive impact on the decision-making powers (Hirschl, 2005). Information, awareness raising and education would serve to optimize the understanding, reception and adaption of PV systems.

11. Conclusion

Despite the fact that photovoltaic conversion is still under developed, it is certainly a technology that will progress in a sustained manner since the prospects of this technology are favourable and appealing. Generating few or no greenhouse gases during the operating stage, producing no sound pollution, able to be integrated both aesthetically and functionally into the urban landscape, it should generate more interest and surpass, in an intelligent manner, the technical and technological limitations.

It is crucial to back research and development on persistent considerations to potential health effects and environmental impacts. This is also a means for driving progress in a sector that has already reached the boiling point. Humankind, which absolutely must deal with the depletion of fossil resources and the increasingly obvious consequences of greenhouse gas emissions, has neither the means nor the time to waffle.

The conciliation of the photovoltaic industry with the principles of sustainable development, its integration in the clean energy mix, based on social acceptability and international solidarity are obvious requirements. PV conversion should be able to develop an advantageous place both in the global energy landscape and in the urban landscape while being the preferred candidate for energy equity despite the unequal distribution of solar layer around the globe.

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