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RENEWABLE ELECTRICITY POLICIES:

an analysis of quotas, feed-in laws and a proposal for EU harmonization of feed-in laws.

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Summary

The two main contributions of this dissertation are:

1. a comparison between two types of policy instruments for the promotion of renewable electricity, namely quotas and feed-in laws; and
2. a proposal for harmonization of feed-in laws in the European Union.

This dissertation is structured in five parts.

Part I explains the deregulated electricity sector and the existing renewable electricity technologies. Among these technologies, the ones with the highest growth rates in the last decade are solar photovoltaic and wind power. Part I also explains the main attributes and impacts of renewable electricity technologies.

Part II describes the existing support schemes, policies, measures and financing strategies for the promotion of renewable electricity. The two most important policy instruments are quotas and feed-in laws. Under a quota system, a target (the quota) is mandated for renewable electricity, and a market for renewable electricity certificates is created, to achieve the established target in a cost-efficient way. Under a feed-in law scheme, renewable electricity generators are guaranteed that all their renewable electricity will be bought at a minimum price.

Besides quotas and feed-in laws, other schemes and policies are described, such as tendering systems, voluntary markets, tax credits, clean energy funds, net metering, subsidies, and public research and development. Part II also addresses aspects such as grid access, definitions and standards, administrative issues, target setting, awareness and education, financing strategies, and risk management.

Part III describes country case studies. Because this dissertation does not pretend to be a compendium of data or existing policies in all countries, a few countries in the European Union have been selected. The selection of countries was broadly made for the following reasons: Germany and Spain because they illustrate successful feed-in systems; Denmark

because it is also one of the pioneers of wind power and feed-in laws and illustrates the negative effects of policy changes; France because it illustrates a system hostile to renewables; the Netherlands because it is an example of multiplicity of policies; Ireland because it is an example of tendering systems; Sweden as an example of voluntary markets and green taxes; and the United Kingdom as an example of quotas. The United States is also described, as well as the context of the European Union, particularly with regards to Directive 2001/77/EC on the promotion of renewable electricity.

Part IV provides a comparison between feed-in-laws and quota systems in respect of efficiency, effectiveness, induced innovation, efficiency under uncertainty, administrative issues, regulatory risk, funding, discrimination among technologies and geographical dispersion. Part IV concludes that feed-in laws are superior policy instruments with regards to all those aspects, in some cases based on theory and in some on empirical evidence.

Part V elaborates policy proposals for the harmonization of feed-in laws in the European Union. In particular, it proposes a methodology for harmonization based on a feed-in law with a modular and transparent premium for renewable electricity producers. This premium considers technology costs, some grid services, political incentives and national priorities. The proposed approach includes flexibility mechanisms to update and revise premiums, to avoid windfall profits for producers, and to share technology innovation benefits with electricity consumers while maintaining incentives for innovation. The flexibility mechanisms include a profitability threshold, an automated premium revision, and a target revision trigger. The proposals on Part V are based on the review of the main features of the German and Spanish feed-in laws. Other considerations necessary for harmonization and not described elsewhere in the dissertation are also taken into account in Part V, such as ownership of rights derived from renewables, and exceptions for small non-commercial producers and energy-intensive industries.

KEY WORDS:
renewable electricity policies, quotas, feed-in laws, EU harmonization

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INTRODUCTION

The frame

My involvement in the area of renewable energy policies has been the result of many steps and circumstances which slowly drew me from the seemingly lackluster subject of policies for the promotion of renewable electricity to the inspiring and vibrant field of renewable electricity policies.

Back in 1999, recently graduated from Physics, I was interested in renewable energies, mostly on environmental grounds, but did not really know how I could be most useful. An obvious path was laboratory work, for example in solar photovoltaics, but after some laboratory practices, it became quickly apparent I was not well suited or too interested for laboratory life. While improving the efficiency of renewable energy technologies was a necessary step, I thought it was more important to “sell” the existing technologies. I enrolled in a master on Environmental Management and Ecological Economics at UAB, where I was exposed to the realities of economics and had my first contact with environmental law. Coming from the natural sciences world, it was very revealing to discover not only that other disciplines also thought they were the center of the universe, but that in most cases they also had a point. A purely technological “solution” to a problem is doomed to little success if it does not take into account the economic, legal and many other aspects that reflect the complexity of society. As part of my master dissertation I participated in a project to assess renewable energies in Figuig, a Sahara oasis in Morocco. I was struck by a finding. Farmers with no access to electricity, who were interested in having electricity services (basically radio and TV), and who had the means to pay for a solar photovoltaic installation, were not willing to invest in solar power because they had been promised the electric grid would be extended to service them. Obviously something was wrong that was not explained by technology or economics. This fuelled my interest for policies. After research internships in 2001 and 2002 at Centro de Investigaciones Energéticas Medioambientales y Tecnológicas (CIEMAT) in Madrid and Centre d'Economie et d'Ethique pour l'Environnement et le Développement (C3ED) at Université de Versailles Saint-Quentin-en-Yvelines, France, this interest led me to enroll in 2002 on a Master on International Relations and

Environmental Policy at Boston University, funded by a Fulbright Scholarship. In Boston I approached for the first time the field of renewable electricity policies in a formal manner, including in research for some classes, research assistantship at the Worldwatch Institute and a final paper on the subject. Upon return to Barcelona in summer 2004, I decided to pursue a Ph.D. and center the dissertation on this topic. Since then, I did a three month research internship at the Policy Studies unit of the Energy Research Centre of the Netherlands (ECN) and was awarded an ICTA scholarship for the completion of my Ph.D.

In addition to research on renewable energies, during my Ph.D. candidate years I also pursued my research interests on climate change. Thanks to a collaboration with the Earth Negotiations Bulletin (ENB) I have been able to attend all UNFCCC climate cops and subsidiary body meetings since 2004, as well as the major IPCC meetings related to the fourth assessment report.

The focus

Renewable electricity technologies, particularly wind power and solar photovoltaics, are the fastest growing electricity technologies across all energy technologies. In the last few years, wind power has grown from an anecdote entry in national statistics to provide a few percentage points of electricity supply in a several countries, and even become a significant source in some countries such as Spain, where in 2006 wind power supplied 8.7% of all electrical demand. Wind power and solar photovoltaics are experiencing an industry boom, with sustained yearly growth at or above 30% over the last decade and investment in the order of billions of dollars. Furthermore, renewable electricity technologies, initially confined to a few countries, are now spreading to developed and developing countries, many of which are now at or beyond the deployment stage that Germany or Spain where a decade ago, with the difference that the technology now is cheaper and more mature.

The growth of renewable electricity can be directly traced to support policies by governments, regions and cities. There is no direct correlation between the deployment of renewable electricity technologies and the renewable energy endowment of a particular country. The subject of this dissertation is precisely those support policies, a study of existing market-based support policies and other measures, with a comparison between the two most important ones, namely quotas and feed-in laws.

The focus is on optimizing renewable electricity policies, achieving the most cost-effective instrument. A few years ago, a dissertation of this kind would have needed a lengthy chapter justifying the interest of renewable energies. In 2007, it is fair to say that the interest in renewables is manifest. Therefore, I focus on the policies to achieve the established renewable electricity objectives, and do not dwell on what the causes where for such objectives. These causes range in most cases from energy security, to industrial policy, job creation, environmental concerns and/or climate change, each with a different relative importance depending what policy-maker you ask.

Similarly, this dissertation does not analyze what the optimal levels of renewable electricity are or how they should be determined. Establishing the objectives for renewable electricity is a political decision that will depend on a decision-making process, which typically is a deliberative process weighing-in many factors, including economic, scientific, social, pressure from lobbies and personalities of the decision-makers. In many cases objective-setting will require negotiation among different stake holders, and the final numbers will be a mix of economically and politically feasible targets. This was the case of the negotiation of Directive 2001/77/EC on the promotion of renewable electricity (explained in Chapter 8) and of the non-related but well-known Kyoto Protocol.

This dissertation comprises an innovative and policy-relevant proposal for the harmonization of feed-in laws. I have been very lucky and am very excited that this proposal has the potential to go beyond a mere academic exercise. In the context of EU Directive 2001/77/EC, negotiations will take place at the end of 2007 on possible harmonization of support schemes for the promotion of renewable electricity. Although feed-in laws have proven to be a superior policy instrument than quotas, as it will be shown in Part IV, one of their perceived drawbacks was the difficulty to harmonize them at the European level. Therefore, when I conceived a methodological approach to harmonize feed-in laws, the proposal was greeted with interest from several institutions, including the German Ministry for the Environment, Nature Conservation and Nuclear Safety, the European Commission Directorates General for Transport and Energy (DG

TREN) and Environment (DG ENV), and the Spanish Comisión Nacional de la Energía (CNE) and Instituto para la Diversificación y Ahorro de la Energía (IDAE). I was invited in December 2006 to present my proposal at the 3rd feed-in cooperation in Madrid, a forum for decision-makers to promote feed-in laws organized by the governments of Spain and Germany. As this dissertation is submitted, the main ideas of the harmonization proposal have been published by Elsevier in the May 2007 issue of the journal Energy Policy.

The big picture

This dissertation focuses on very detailed proposals and comparison of specific policies and aspects of policies. Even if not explicitly discussed in the text, it is important to always have in mind the "big picture", and to keep in perspective the relative weight of renewables in the world's energy system. Despite impressive growth rates and massive deployment potential, the role of renewables is still very reduced, particularly the "new renewables"[1], i.e. excluding large hydropower and traditional biomass use. Table 1 shows the world's energy and electricity "mix", i.e. the share of different energy sources, in 2004, the last year with available data in 2007.

Table 1: World energy and electricity "mix" in 2004.

Source	**Primary energy Exajoules (10^{18}J)**	**primary energy (%)**		**electricity generation (%)**
Oil	165	35.2	36.8*	6.7
Coal	117	24.9	26.0*	39.8
Gas	95.3	20.3	21.2*	19.6
Nuclear	29.9/9.9*	6.4	2.2*	15.7
Total non-renewable	**407/387***	**86.8**	**86.2***	**81.8**
Biomass	49.5	10.6	11.0*	1.0
Hydro	10.1	2.15	2.25*	16.1
Geothermal	0.9	0.19	0.20*	
Wind	0.7	0.15	0.16*	0.8
Solar, tide, wave, ocean	0.8	0.17	0.18*	
Total Renewable	**62**	**13.3**	**13.8***	**17.9**
World Total	**468.7/448.7***			

sources IPCC 2007c, IEA 2007
*see footnote[2]

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[1] throughout the text, when referring to renewable electricity it is generally a reference to "new renewables", i.e. excluding large hydropower.

[2] A 33% efficiency factor is used in international statistics to convert nuclear power into primary. In other words, for each joule of electricity produced, three are accounted as primary energy. The justification for this accounting method is that nuclear energy actually produces heat, which is used to generate electricity at

Table 1 clearly illustrates why our society is fossil-fuel dependent. Oil gas and coal supply 84% of the world's energy needs[3], and 66.1% of electricity. Projected increases in energy demand range between 30% and 50% by 2030 respect 2004 (IPCC 2007c). Despite the impressive growth rates for new renewables, more than ten times the average energy growth for the 1974-2004 period of 2.3% a year (IEA2007), and despite giant strides in some countries, new renewables account for less than 1% of global electricity generation, and about 0.5% of primary energy, which is explained because they begun at an almost nil share. Another aspect to keep in perspective is that this dissertation focuses on electricity, which means that other renewable energy applications such as transport or heat are not considered. Electricity accounts for around 40% of world primary energy (IPCC 2007c). Even if all electricity generation was switched to renewable energies today, there would still be a 58% of primary energy based on fossil fuels.

Renewable energies are important, and their potential is enormous. However, their role should not be overestimated.

The details

From an organizational point of view, this dissertation is structured in five parts. Part I explains the deregulated electricity sector and the existing renewable electricity technologies. Part II describes the existing support schemes, policies, measures and financing strategies for the promotion of renewable electricity. Part III describes country case studies. Part IV provides a comparison between feed-in-laws and quota systems. Part V elaborates policy proposals for the harmonization of feed-in laws in the European Union.

Throughout the text there are 75 figures and 50 tables. All tables and figures that I have adapted from some other publication indicate the source or sources of the figure and/or data. When no source is indicated it means I have done the figure on my own. Some of

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an average 33% efficiency, and thus the heat generated should be measured. Since the only useful outcome of a nuclear plant is electricity, this methodology has the effect of "inflating" nuclear energy by a factor of three in primary energy statistics. As an illustration, hydropower and nuclear energy roughly generate the same electricity worldwide. However, in primary energy statistics, nuclear power has a share three times as large as hydropower. The figures with * have been calculated without the 33% efficiency factor, thus considering nuclear energy production as its electricity output.

[3] different statistics show discrepancies on the accounting of non-commercial biomass. While variations are significant, nonetheless, discrepancies are less than 5 percentage points of primary energy.

those figures are generic, and some of the earlier ones have since also been reproduced in other places.

PART I – BACKGROUND AND DEFINITIONS

Part I is intended to provide the necessary background for the discussions in this dissertation. Part I is meant to be illustrative, but not an in-depth or comprehensive analysis of the issues discussed.

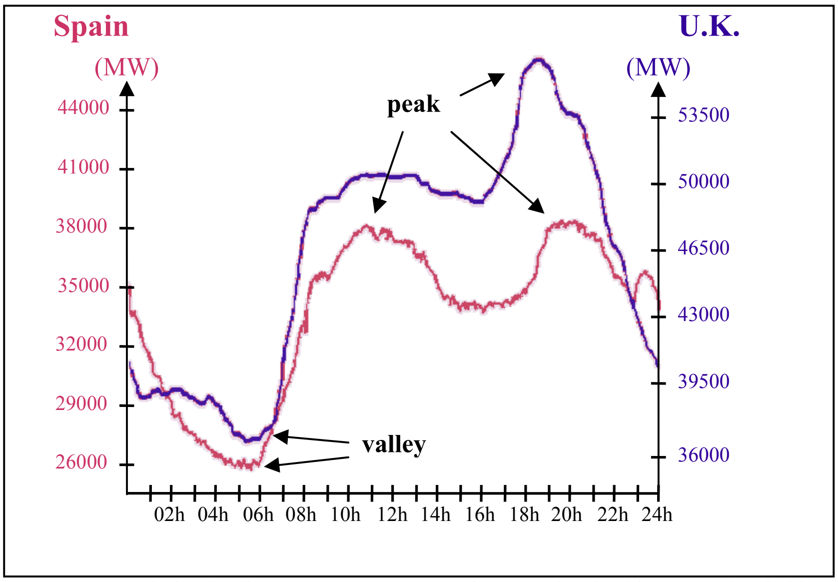
Part I is divided into three chapters. Chapter 1 explains the liberalized electricity sector, which is the arena in which all the policies discussed in this dissertation take place. Chapter 2 includes some technical definitions regarding energy issues and environmental impacts. Chapter 3 describes the main renewable electricity sources and technologies.

1 – Electricity sector - market deregulation

Due to its physical properties electricity cannot be stored in significant quantities or at reasonable cost. Since transmission is almost instantaneous, electricity generation must match electricity demand at all times in order for the system to work properly. If excess electricity is produced the surplus is lost, with the consequent economic loss and squander of resources. If there is an under-provision of electricity, some areas of the grid or the whole grid can be disconnected, producing brownouts or blackouts. In addition to matching supply and demand, the grid must maintain certain technical standards (such as voltage and frequency) within very small variation ranges to ensure the quality of electricity.

Electricity demand shows great variation during the day because demand is associated with people's and industry activities. Figure 1 shows typical daily electricity demand curves in Spain and the United Kingdom (UK). Industrialized countries have demand patterns with specific peak hours that vary depending on national factors such as working hours, lunch and dinner times, tea-time (UK) and school hours. In the short term demand is inelastic (meaning that a change in prices does not affect demand) regarding electricity prices, and depends on external factors such as weather, or a soccer match. Supply has to adjust in order to match the varying demand. This is done by bringing power plants on- and off-line, or adjusting their electric output. Keeping the balance between generation and demand in a large system like a country is a complex task.

Figure 1 - Typical daily electricity consumption in Spain and the UK



Data sources: Red Eléctrica de España (www.ree.es) and U.K. National Grid (www.nationalgrid.com)

Figure 1 superimposes the real electricity consumption curves of two separate days in Spain and the U.K. for a 24-hour period. The different scales, left for Spain and right for the U.K. account for the differences in size of the electricity system between the two countries. It can be readily observed that there are large differences, of almost 50%, in consumption between peak and valley hours.

This complexity, added to the notion that access to electricity was considered a "public service" during the 20th century, led to the so called "natural monopolies", whereby a regional or national company, most times publicly owned, controlled electricity generation, transmission and distribution.

All policies and discussion in this dissertation refer to the context of liberalized/deregulated electricity markets.

Liberalization or deregulation[4] refers to breaking those natural monopolies and bringing market competition to the electric sector. Under fully liberalized electricity markets the electricity system is divided into three segments: generation, transmission and distribution. Generation and distribution are open to competition. In some jurisdictions, generation and distribution companies are required to be legally separated, a process known as "unbundling". Transmission is usually assigned to an independent transmission system operator (TSO), which is responsible for matching supply and demand in real

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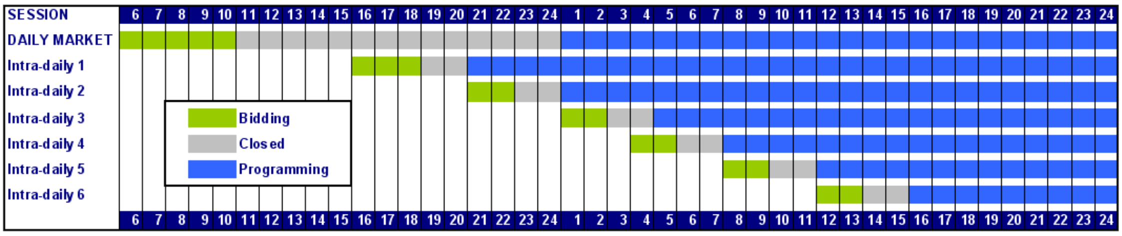
[4] The term "deregulation" may be misleading because in order to liberalize electricity markets a large pack of rules is generally needed. Nevertheless, the terms "deregulation" and "deregulated" are widely used in the electricity sector as synonyms of "liberalization" and "liberalized" respectively.

time. This is done through the bid system. A simplified version of how the bid system works is as follows. All power suppliers bid their offers, stating how much power and at what price can they sell for a particular time period. The regulating body then matches supply with demand, starting with the lowest price offer, then adding the second cheapest offer, and so on until demand is met. When demand is met, all suppliers are paid at the price set by the last supplier brought in, the clearing price, above or equal to their bid. This process is done semi-continuously, as illustrated in Figure 2 for the case of Spain. Different countries have different rules. For instance, in the U.K. bidding windows are of only one hour while in Spain bidding windows last two hours in the intra-daily market (see Figure 2).

Figure 2: Bidding "windows", Spain.



SESSION	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
DAILY MARKET	🟩	🟩	🟩	🟩	🟩	▒	▒	▒	▒	▒	▒	▒	▒	▒	▒	▒	▒	▒	▒	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦
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	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24

🟩 Bidding
▒ Closed
🟦 Programming

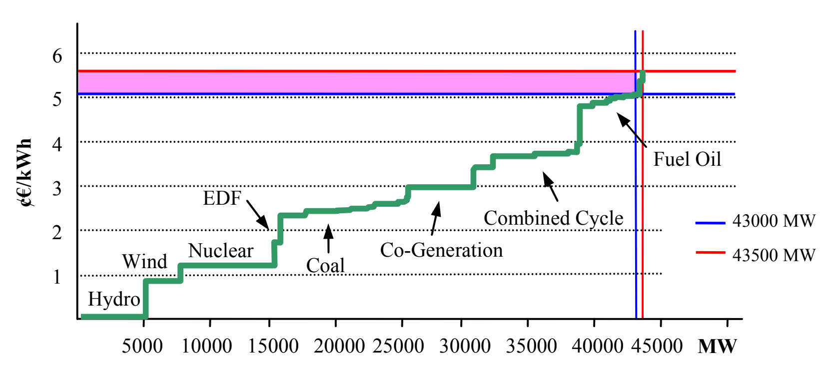
Data sources: feed-in cooperation (www.feed-in-cooperation.org)

Figure 2: This diagram shows the daily bidding "windows" in Spain, extending for a period of 42 hours. In green are the bidding periods, during which producers can make bids to supply during the programmed period (in blue). In the case of Spain there is one daily market, where bids take place at least 14 hours before delivery, and six intra-daily bidding periods, where bidding takes place at least two hours before delivery (in green).

Different energy sources and technologies have different marginal costs, and therefore bid at different prices. The higher cost electricity source brought online is the one that sets the electricity cost. This is illustrated in Figure 3 for the case of Spain.

When demand is low, for example in the middle of the night, wholesale electricity will be cheap and only the power plants with the lowest operating costs will be online. These plants are known as base-load, and usually include most hydropower, nuclear plants, and coal plants (left ofFigure 3). When demand is high, for example at noon in Spain or tea-time in the UK (see Figure 1), other power plants with higher operating costs, such as natural gas combined cycle or fuel-oil power plants (right of Figure 3) are brought online, and wholesale electricity prices rise. These plants are known as peak-load. Wind power is considered by some as base-load, based on its low bidding price, while others do not consider it base-load due to its intermittency (described in the next chapter).

Figure 3: Electricity bidding costs structure, Spain.



Data sources: feed-in cooperation (www.feed-in-cooperation.org)

Figure 3 shows a real bid for electricity in Spain in April 2005. The green line represents the bids of different types of power plants in ¢€/kWh. It can be noticed that peak power plants have significantly higher bidding prices than base load power plants. "EDF" stands for an import contract from France (basically nuclear power). The blue and red lines illustrate what happens at high consumption levels, when the really expensive peak power plants are brought online. At a consumption level of 43000 MW, the wholesale price of electricity is 5.05¢€/kWh At a consumption level of 43500 MW, just 1.2% above 43000MW, the wholesale price of electricity is 5.6¢€/kWh, 0.55¢€/kWh higher than before. If we assume the system to be static for one hour for calculation purposes, the cost of the additional 500MWh at 5.6¢€/kWh is 2.8m€. However, the total cost to electricity consumers for the first 43000MW changes from 217.15m€ to 240.8m€, a 10.1% increase. This cost increase of 23.65m€, reflected in the pink area in the figure, is almost nine times the cost of the extra electricity, and is borne by the whole system. This disparity between the additional electricity provided and additional cost systems is what motivates efficiency measures at high demand times, such as asking the public to switch off appliances, or signing interruptibility contracts with the industry. These practices are know as "demand side management".

2 – Technology definitions, attributes, and impacts

Chapter 3 deals with the definitions of renewable energy sources, as well as the different technologies used to harness those renewable resources and to generate electricity. However, before explaining in detail the different technologies, it is important to understand a few basic definitions regarding energy, physical attributes of different technologies and possible environmental, social and other impacts and restrictions. In particular, the next sections address the following issues:

1. Units
2. Time patterns
3. Location constraints
4. Environmental impacts

2.1 – Units: installed capacity, electricity generated and prices.

The first issue that needs clarification is the difference between installed capacity (power capacity) and generated electricity. Installed capacity is measured in kilowatts (kW), megawatts (MW) or gigawatts (GW). These are power units [$kg*m^2*s^{-3}$] and broadly mean the electric power that a power plant can deliver when functioning at full capacity. Some variants of these units are kilowatt-peak (kW_p), used to describe the power rate of photovoltaic panels under standard conditions (25C, irradiance of 1000W/m^2), or kilowatt-electric (kW_e) used to refer to the electric output of a powerplant. kW_e are generally used when there could be a doubt of whether the figure relates to electric output, thermal throughput or thermal output.

Generated electricity or power produced[5] is measured in kilowatt-hour (kWh), megawatt-hour (MWh) or gigawatt-hour (GWh). These are energy units [$kg*m^2*s^{-2}$]. One kWh is the amount of electricity generated by a one kW power plant running at full capacity during one hour. Other energy units common in the energy sector are tons of oil equivalent (toe), British thermal units (BTU) and Joules. Table 2 summarizes electricity units and conversion factors among the most common units.

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[5] In this case, the mix of common language and scientific language leads to confusion. Power has a clearly defined physical meaning, as described in the preceding paragraph. However, "power" is also used in common language to refer to electricity, which has energy units.

Table 2: Electrical Units and energy conversion factors

Installed capacity or power	1 watt = 1 kg*m^2*s^{-3} = 1 Joule*s^{-1}				
Generated electricity	1 kilowatt-hour (kWh) = 3.6x10^6 Joule				
Energy Conversion Factors		TJ	toe	MBtu	GWh
	TJ	1	23.88	947.8	0.2778
	toe	4.1868e-2	1	39.68	0.01163
	MBtu	1.0551e-3	2.52e-2	1	2.931e-4
	GWh	3.6	86	3412	1
kilo=10^3 / mega=10^6 / giga10^9 / tera10^{12}					

The distinction between capacity and generation is important because capacities of power plants with different technologies cannot be readily compared. Different technologies have different operation times and economic characteristics, and two plants with the same installed capacity can result in very different electric outputs over the year. For example, at the end of 2006 Spain had 11239 MW of installed wind capacity, nearly one and a half times Spain's installed nuclear capacity of 7716MW (REE 2006). Nuclear plants, however, operate more than 8000 hours per year (out of 8,760), while wind farms only generate electricity when the wind is blowing above a certain threshold speed. Spanish wind farms operate on the average 3350h (IDAE 2005a). As a result, wind energy generated 23372 GWh in 2006, 8.7% of total electricity demand, while nuclear power generated 60184 GWh, two and a half times as much and 22.5% of total electricity demand (REE 2006).

Prices and costs of electricity are generally measured in cents of dollars or euros per kWh (¢$/kWh, ¢€/kWh) for the distribution market, and dollars or euros per MWh ($/MWh, €/MWh) for the generation market. Installed capacity costs are generally measured in $/kW or €/kW.

To give an idea of the order of magnitude, in 2006 Spain had an installed capacity of 82336 MW and a total electricity demand of 252878 GWh (REE 2006). In 2005, the

USA had a net generation of 4054668GWh and winter[6] capacity of 1015227 MW (DOE/EIA 2007).

The distinction between capacity and generation is also relevant for the policy maker, as some promotion policies target installed capacity, while others target generated electricity. The different types of policies and goals are described in Part II.

2.2 – Time Patterns

Most renewable energy technologies exhibit time patterns or variations of their electrical output in time. For example, solar energy is only available during the day when the sun is shining; wind power can only generate electricity when the wind is blowing; hydropower needs water to run; etc. Those time patterns can be in the scale of hours, days, seasons or years.

An energy source is said to be intermittent when its output cannot be predicted with sufficient anticipation to allow the grid operator to allocate power generation efficiently. Intermittent sources exhibit daily, hourly or higher frequency fluctuations in their output. As an example, photovoltaic technology is intermittent because a passing cloud can greatly reduce the power output (see Figure 13 under photovoltaics description). However, tidal power, is not intermittent because the timing and intensity of tides can be accurately predicted. The key is not the magnitude or duration of the fluctuation, but the predictability. And predictability (or lack of thereof) has a cost. In a liberalized electricity market bids are made in semi-continuous time. In Spain, for example, bids occur every two hours, as illustrated in Figure 2. Deviations in output above or below a certain percentage[7] are penalized by the transmission system operator. Producers who exceed the established thresholds must compensate for the deviation in their electricity generation

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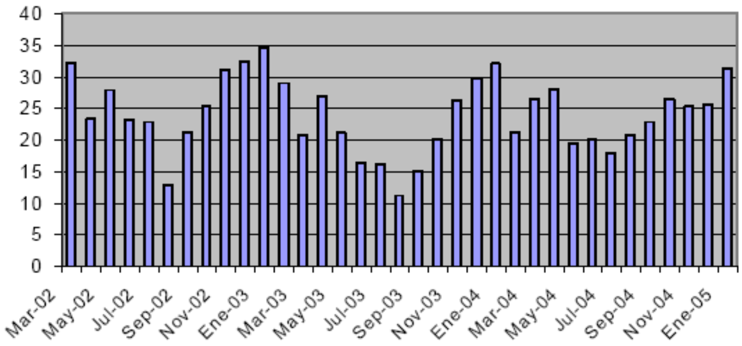
[6] In cold countries winter and summer generating capacities of thermal plants differ significantly due to changes in the Carnot thermal efficiency (η), given by the equation: $\eta = 1 - \frac{T_c}{T_h}$, where Tc is the temperature of the cold focus (generally related to outside temperature) and T_h is the temperature of the hot focus (the operation temperature). Put in simple, the colder it is outside, the more efficient the thermal power plant is. During heat waves, electricity generation of thermal plants, including nuclear, is significantly reduced. The US summer capacity is 978020 MW, compared to winter capacity of 1015227 MW.

[7] 20% for wind power and solar photovoltaics (RD 436/2004)

through a secondary market called the balance market. The balance market fixes the price of short notice generation, generally provided by power plants know as “spinning” power plants[8].

In addition to daily patterns, several renewable energy technologies exhibit seasonal patterns. Numerous countries have a dry and a wet season, affecting hydropower production. For example, in Portugal there are two different electricity rates reflecting the differences in hydropower output during winter and summer. Likewise, biomass production, particularly in regions far from the equator or with dry seasons, exhibits seasonal trends, with crops concentrated in specific months of the year. In some cases biomass can be stored, albeit at a cost, but in many cases biomass decays and must be used in certain time windows. Cloudiness and day length (hence solar radiation) and windy periods also exhibit seasonal patterns. Figure 4 shows monthly wind variability in Spain over a 30 month period.

Figure 4: Average monthly production vs. installed capacity (%) for wind power in Spain



SOURCE: Alonso 2005

Figure 4 shows the seasonal variability of wind power. The vertical axis shows monthly production as a percentage of installed capacity from March 2002 to January 2005. Winter months tend to be windier than summer months, and the pattern is clearly visible. A secondary trend that might not be so readily noticeable is that the amplitude of variations is less in 2004 than in the previous 18 months. This can be due to a greater number of parks, covering a wider area and thus balancing off some wind variability between regions, and also due to better technology, able to cope with lower (and higher!) wind speeds.

Some years are drier or windier than others in absolute terms. This can affect a country’s energy mix for a particular year. Even when the installed capacity for a particular energy source is the same for two consecutive years, generated power can vary.

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[8] The term originally comes from turbine power plants, which where literally spinning without generating electricity and could generate upon demand almost instantaneously.

This is particularly the case for large hydropower. For example, in 2004 hydraulicity (an index measuring hydropower availabily) was the lowest in Spain in 48 years, and hydropower output was reduced by 34% from the previous season (REE 2005).

Dispatchability is a term used in the electricity sector to reflect the ability of a power plant to generate electricity upon request. As a general rule, renewable technologies producing electricity from a natural flow (air, sunlight, water streams) are not dispatchable because they can generate power only when the flow occurs. Those technologies drawing energy from renewable stockpiles (biomass, water reservoir) tend to be dispatchable. Dispatchability is a desirable quality.

Although it is not a time pattern properly, construction time, from a plant's conception until operation, is a relevant consideration, because it directly affects the financing structure and feasibility of a particular project. The quicker a project can be deployed, the sooner it will generate a revenue stream, and the cheaper it will be to finance. Likewise, if a project can be implemented modularly, this will positively affect its financing because generation, therefore revenues, can start before completion of the entire project.

2.3 – Location constraints

Some technologies have certain restrictions based on location. These restrictions may stem from the availability of the resource, from technical factors such as refrigeration, from access to fuel transport and transmission grids, and from a wide range of social and environmental constraints.

All technologies depend on energy resource availability. Resource availability, then, can restrict plant location to a region, area or very specific site, depending on the possibility to store and transport the renewable energy source if it is stackable, or to divert it if it is a flow.

For example, a mini-hydro power plant can only be located where there is enough water flow and head-height. Photovoltaics, on the other hand, need sunny areas, but particular location within the area does not significantly alter electric output.

Thermal technologies that use a turbine to generate electricity, if of sufficiently large scale, need a cold source for refrigeration, such as a river, lake or the sea. That is why most coal and nuclear power plants are near a river or shore.

Large power plants need access to the power transmission system (high voltage grid) to evacuate the generated electricity and make it reach the final consumer, generally in urban and industrial areas. The farther away a power plant is from the consumption centers, the more electricity losses there are in transport and the costlier the electricity.

Conflicts with other land uses, such as protected areas, military zones, and transport infrastructures, and social and environmental regulations can further restrict the locations available for the deployment of a certain technology to tap into renewable energy sources.

2.4 – Environmental Impacts

Greenhouse gas emissions and Climate Change

Climate change is arguably the largest environmental impact of the current fossil fuel-based energy system. Fuel combustion produces carbon dioxide (CO_2), which is released into the atmosphere. Carbon dioxide concentrations in the atmosphere have risen from an annual average of 280ppm in pre-industrial times to above 380ppm in 2006. Increasing concentrations of carbon dioxide, a greenhouse gas, are the main contributor to anthropogenic climate change: most of the increase in atmospheric carbon dioxide concentrations is attributed to emissions resulting from fossil fuels combustion (IPCC 2007). There are other greenhouse gases, including methane (CH_4), nitrous oxide (N_2O) and others. Their emissions are related to several human activity sectors, including energy, agriculture, forestry and industry, as well as to land-use changes.

Renewable energy technologies do not emit CO_2 from fossil origin during operation. Some technologies, such as wind power, have no emissions at all. Others emit CO_2 from combustion of biomass, but whether they contribute to climate change or not depends on the carbon balance of growing the biomass and how much carbon is fixed.

Greenhouse gas emissions can also be caused by non-combustion processes. For example, methane emissions mostly derive from fermentation of biomass, livestock enteric emissions, fugitive emissions, and flooding of areas such as rice paddies. Certain nitrogen-fixing crops produce N_2O emissions. Renewable technologies that harness the energy of methane flows, such as biogas originating in landfills, have a direct contribution to mitigate climate change by reducing the flow of a greenhouse gas into the atmosphere.

Renewable technologies such as wind power or photovoltaics have virtually no CO_2 emissions during operation. However, it is common practice to attribute them the emissions caused by the energy used to manufacture the components when doing life-cycle analysis. This attribution generally uses either the energy mix where the technology components were manufactured or the energy mix where the technology is deployed. This practice can result in renewable electricity being attributed carbon dioxide emissions, or even nuclear residues.

Air Pollutants

In addition to greenhouse gas emissions, there are a wide range of other air emissions generated by electricity production. Combustion of fuels creates air pollutants such as sulfur oxides (SOx), nitrogen oxides (NOx), volatile organic compounds (VOCs), and particulate matter (soot). Heavy metals, such as lead and mercury are also emitted to the atmosphere by combustion of coal. These pollutants can cause, among other things, adverse health effects, acid rain, reduced visibility, smog, affect wildlife and plants, act as troposphere ozone (O_3) precursors[9], and damage buildings.

Emissions can also stem from leaks (known as fugitive emissions) or unprocessed materials. For example, wet olive cake[10] resulting from olive oil extraction can be used as a biomass energy source. However, open stockpiles of wet olive cake can produce VOC emissions noxious for nearby populations.

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[9] Troposphere ozone (ozone in the lower layer of the atmosphere) is a pollutant which affects human tissue, particularly the respiratory system, and damages monuments, specially marble and carbonate materials. It is not to be confused with stratosphere ozone (ozone in the higher layers of the atmosphere), which constitutes the ozone layer that protects Earth from solar UV radiation.

[10] alperujo in Spanish

Ground and water pollution and habitat destruction

Landscape can be severely affected by energy structures, particularly power lines, reservoirs, cooling towers and windfarms.

Mining and extraction also has local and regional impacts on soil, erosion and hydrology. Particularly damaging is strip mining used for coal (see Figure 5) or extraction of oil from tar sands.

Figure 5: Coal strip mining in Wyoming, U.S.A.

Miquel Muñoz, July 2005

Deforestation due to excessive extraction for fuel purposes is a problem in many developing countries, especially those in arid and semiarid areas.

High densities of livestock and their associated manure outflows are another cause for ground and water pollution through infiltration and run-off. Manure in small quantities is beneficial for the soil, but in higher concentrations it exceeds the carrying capacity and becomes a pollutant.

Oil spills from tankers, broken oil pipelines and hostile actions can cause severe soil and water pollution episodes, such as the marine Prestige, Exxon Valdez, Gulf War and Second Lebanon War black tides, or the land-based Siberia and Niger Delta spills. Spills can also stem from refineries, power plants, and gas stations.

Figure 6: Clean-up of "Prestige" oil spill, Spain, 2003

Courtesy of Jaume Rovira

Most areas around fuel service stations have polluted soil due to slow fuel leakage from underground tanks, which in some case reaches aquifers.

All of the forms of pollution described above contribute to habitat destruction and reduced biodiversity.

In some cases wildlife impacts are quite literal, particularly in the case of birds colliding with power lines, wind turbines and other standing structures.

3 – Renewable Electricity Technologies

Renewable electricity is electricity generated from renewable energy sources. Renewable electricity is frequently used as a generic term describing electricity generated from clean, environmentally preferable energy sources (Lipp 2001). Other authors use the term renewable electricity to refer to "new renewables" (REN21 2005, 2006). Legislation, such as national feed-in-laws, US renewable portfolio standards or the EU Directive on the promotion of electricity produced from renewable energy sources (Directive 2001/77/EC), *in lieu* of a definition generally lists what qualifies as renewable electricity.

What constitutes and what does not constitute a renewable energy source is a controversial issue that depends on many factors including resource base, technology, social perception and national circumstances. There is no universally accepted definition for renewable energy, nor for renewable electricity.

Some technologies are clearly renewable under any definition, for example, wind power, ocean waves or photovoltaics. Other technologies are clearly not renewable, such as landfill gas or waste incineration, but are sometimes placed under the "renewables" category because of their environmental benefits in certain circumstances. Biomass may be considered renewable depending on its EROI (energy return on investment). For policy purposes, whether an energy technology is considered renewable or not greatly depends on political and country-specific considerations. The issue of policy-oriented definitions is addressed in Chapter 6.

This chapter does not intend to sanction the renewability of particular sources or technologies, but instead seeks to provide the necessary background on the different technologies involved in the renewable electricity debate and literature. Only grid connected applications of each renewable source/technology are discussed, including:

- wind power
- solar photovoltaics
- solar thermoelectric
- hydropower
- geothermal

- biomass
- tidal energy
- wave energy
- landfill gas
- solid waste incineration
- co-firing and combined heat and power (CHP)
- other future technologies

3.1 Wind Power

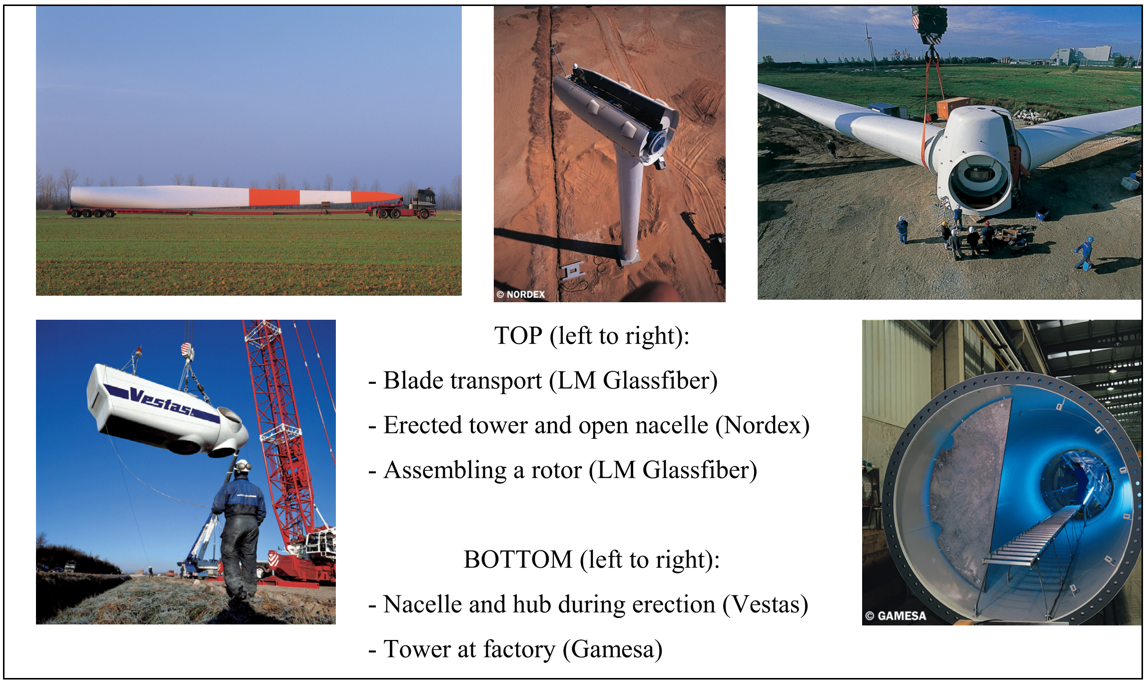
Wind power takes advantage of the wind's kinetic energy, transforming it into electricity, which is then fed into the electricity grid. This process is done through a device known as a "wind turbine" (Figure 7). Modern wind turbines consist of a tower, a nacelle, where the generator, gears and other components are contained, and a rotor, consisting of a hub and three blades (Figure 8). For a detailed description of wind turbine components, see for example (www.windpower.org/en/tour/wtrb/comp). There are other models for small-scale power generation or mechanical uses of wind energy, but these are not considered in this dissertation.

Figure 7: Wind turbine with wind farm in the background

Courtesy of Vestas

Wind turbines can operate alone, or in groups, known as wind farms (Figure 7). Single turbines are generally installed by farmers, or entities such as a municipality, high school or cooperative. Wind farms can be large industrial facilities, requiring high investments in the range of hundreds of million dollars/euros for the larger ones. Wind farm projects are generally undertaken by utilities, companies, independent power producers (IPP), venture capital, or *ad hoc* promoters.

Figure 8: Hub, nacelle and blades



TOP (left to right):

- Blade transport (LM Glassfiber)
- Erected tower and open nacelle (Nordex)
- Assembling a rotor (LM Glassfiber)

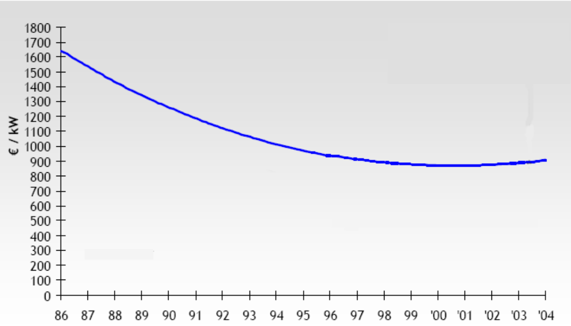
BOTTOM (left to right):

- Nacelle and hub during erection (Vestas)
- Tower at factory (Gamesa)

Courtesy of LM Glassfiber, Nordex, EWEA, Vestas and Gamesa

Wind power has experienced a very rapid technological improvement and impressive growth rates in installed capacity and generated electricity over the last decade.

Figure 9: Evolution of wind power installation costs (in current €)



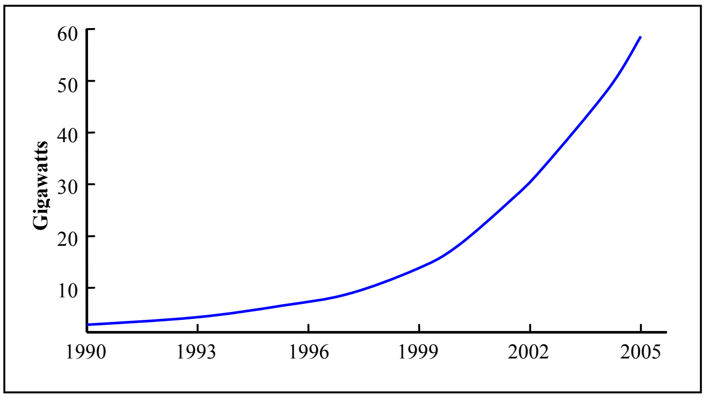
source: IDAE 2005

Figure 9: This figure shows the evolution of installation costs for wind power over the period 1986 to 2004. The costs are expressed in €/kW. A rough rule of thumb is that it costs around one million €/MW to install wind power.

Figure 9 shows the decrease in installation costs for wind power in Spain, which is comparable to those in other countries.

The slight rebound observed for 2004 in Figure 9 is due to three factors: (1) the installation of improved turbines that have higher per kW cost, but also higher utilization of the wind resource and higher quality of the electricity output (sustained voltage, no sudden disconnection on high winds); (2) increased steel prices worldwide which increased hub (tower) costs; and (3) an incipient worldwide shortage on turbines (made evident in 2005 and 2006) due to strong demand. The average size of installed turbines in 2004 was 1.25MW (REN21 2005). Figure 10 shows growth in wind power from 1990-2005.

Figure 10: Wind power world capacity 1990-2005

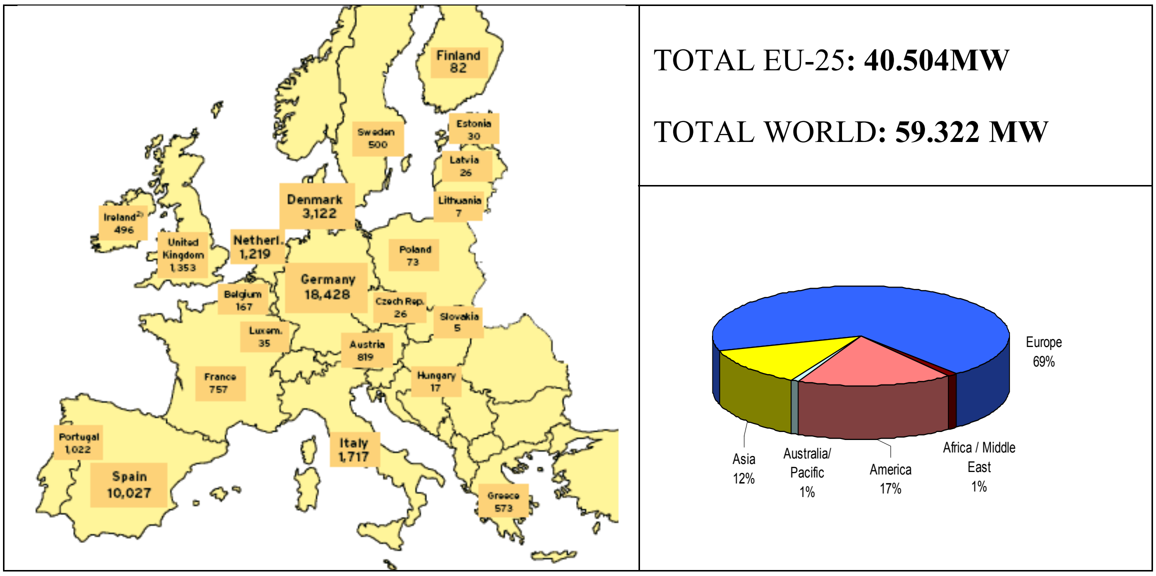


Data from: REN 21 2006

Figure 10: This figure shows cumulative wind power capacity in the world, from 1990 to 2005. The capacity is measured in GW, or thousands of MW.

Wind power has sustained high growth rates for the last decade, with annual growth of nearly 30% during the 2000-2004 period (REN21 2005). Wind power growth rates are the second largest growth rate among all energy technologies, behind photovoltaics. Wind power development is not homogeneous, with three countries clearly leading the way: Germany, Spain and Denmark. Development of wind power so far is not correlated to wind energy resource, but to effective promotion policies, the subject of this dissertation. Figure 11 shows deployment of wind power in Europe and in the world.

Figure 11: Installed wind power in the EU and worldwide in 2005



Sources: Federal Ministry 2006a

Table 3 shows the Top 10 countries in wind power capacity at the end of 2004, as well as their added capacities for that year.

Table 3: Added and existing wind power in 2004 - Top 10 Countries

Country	Added in 2004 (MW)	Existing 2004 (MW)
Germany	2.050	16.600
Spain	2.070	8.300
US	390	6.700
Denmark	10	3.100
India	880	3.000
Italy	360	1.300
Netherlands	200	1.100
Japan	230	990
UK	250	890
China	200	770

source: REN 21 2005

Most installation up to date has been inland (also known as on-shore). Marine installations, usually referred to as off-shore, are expected to play an important role since the wind resource tends to be better at sea and there are no interferences with land use. Some off-shore wind farms have already been developed and many more are under consideration (Figure 12).

Figure 12: Off-shore wind turbine assembly and wind farm

Courtesy of Vestas and GE Wind

On-shore windfarms are compatible with certain land uses including grazing or agriculture (observe the lambs and fields in Figure 7).

Technology Attributes

Wind power is intermittent and non-dispatchable, since turbines only generate when the wind is blowing. Power output is proportional to the cube of wind speed, so specific location is very relevant. The minimum wind thresholds for turbine operation are reduced year after year with technological innovation.

Wind farms can be constructed in separate phases, thus wind power can be considered somewhat modular. However, wind turbines cannot be added individually to existing wind farms due to limitations in control and voltage transforming capacity, therefore is not a truly modular technology.

Wind power exhibits hourly, daily, seasonal and yearly time patterns. Much effort is being spent on developing short term forecasting tools for wind farms, and the more farms there are in operation, the more data is gathered and more progress is made.

Environmental Impacts

Environmental impacts of wind power include those associated with construction, the need for power lines, aesthetics and wildlife impacts.

Construction impacts are those associated with moving of heavy equipment, opening roads, building foundations, and, in some cases, clearing forests in a radius 10-20 times turbine height. Power lines have their own impacts such as bird collision, forest fire hazards, electric hazards and electromagnetic radiation. Noise was an early problem of wind power. Noise has been greatly reduced by the use of low speed turbines, which, together with better sitting, also reduced bird collision problem. Collisions are not limited to birds. For example, there is also concern about bat collisions in the US, a problem being addressed by a coalition of industry, conservationists and government (AWEA 2004).

For off-shore wind farms, impacts include those to navigation, fishing and possible effects (not yet proven) on marine life. Laying or burying power line in the seabed also can have impacts on fragile ecosystems. Collisions with birds are also an issue if windfarms are near the shore or in migratory routes. However, there is evidence that migratory birds might be learning to avoid turbines and wind farms (Desholm & Kahlert 2005).

Aesthetics is probably one of the most contentious and difficult to solve problems associated with wind turbines. Even if completely quiet and harmless, people can contend that a 100+ m moving structure degrades the visual quality of the landscape. In other cases, the problem comes from aviation safety regulations that require structures above certain height to be market with a red or flashing light at night. Although these are subjective perceptions, opposition to wind power on aesthetics basis happens in many places and seems to be a solid phenomenon. Aesthetics is a difficult to assess and remedy impact. Some experiments have been made with turbine sitting and painting the towers with sky-tonalities.

Other impacts of wind turbines can be radar interferences and hazard for air traffic, particularly near airports.

Table 4: Wind power Technology Summary

Technology	Intermittent	Dispatchable	Modular	Hourly	daily	Seasonal	yearly	Climate Change	Pollution	Wildlife	Health Hazards	Landscape	Location Dependency and Constraints
Wind power	**Y**	**N**	**~**	**Y**	**Y**	**Y**	**Y**	**N**	**N**	**Y**	**N**	**Y**	**S/L**

3.2 Photovoltaics (PV)

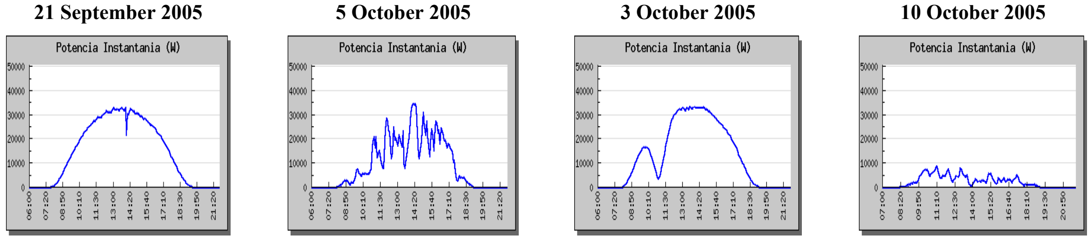
There are two main approaches to generate electricity from solar energy. One approach, photovoltaics, exploits the photoelectric effect, observed in the nineteenth century, and first explained by Albert Einstein in 1905. The other approach, generally know as solar thermoelectric, uses the heat caused by solar radiation and is explained in the next section.

Photovoltaic panels take advantage of the photoelectric effect by transforming direct sunlight into electricity. The photoelectric effect is a property exhibited by some materials, mainly semiconductors. Put simply, when a photon hits the semiconductor, it releases an electron. If many photons, i.e. light, collide with the photoelectric material, a flow of electrons, i.e. electric current, is generated. This current can be collected and used as an electricity source.

For all practical interests for the policy maker, a photovoltaic cell is a device that, when exposed to sunlight, generates electricity. Photovoltaic cells are arranged in photovoltaic panels, which can be assembled modularly into all sizes, ranging from a calculator using less than watt, to 18MW power plants, such as the one in Clark County, Nevada.

Photovoltaics behave as an intermittent electricity source. The number of daylight hours are exactly known for any particular day, in any given latitude and longitude. The sun's elevation (zenith) direction (azimuth) and sunlight intensity, are also known. However, sunlight energy reaching a particular surface (known as insolation) is not so predictable. Insolation is a function of the location's latitude, and the zenith. However, insolation is modulated by meteorological variables, such as humidity and haziness. In addition, passing clouds and cloudy days greatly reduce PV's electricity output (see Figure 13). Figure 13 illustrates daily production patterns for a real photovoltaic installation in Universitat Autònoma de Barcelona.

Figure 13: Daily generation, 50 kW$_p$ photovoltaic roof, UAB, Spain.


21 September 2005 | 5 October 2005 | 3 October 2005 | 10 October 2005

Sunny day, one small passing cloud. | Passing clouds. | Sunny day, solar eclipse. | Rainy day.

source: Xarxa Solar

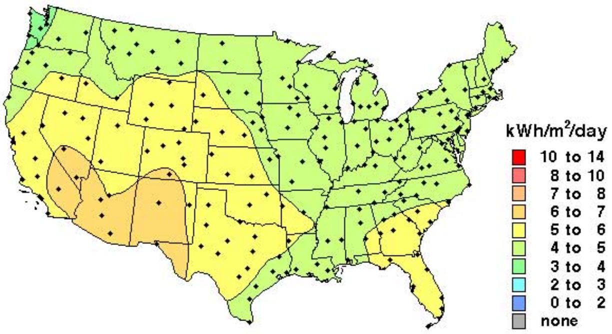
Figure 13: This figure displays electricity generation from a 50kWp photovoltaic installation in four different days of Fall 2005. Since electricity output is directly proportional to solar insolation, these graphs can also be interpreted as a measure of solar insolation. The main objective of this figure is to highlight the contrast in generation variability from a photovoltaic installation, ranging from full installed power to nil, and ranging from high frequency variations to a smooth pattern.

It is worthwhile to compare the generation curve of photovoltaics as shown in Figure 13 with the typical daily demand curves as shown in Figure 1. Photovoltaic electricity is produced during peak hours. This gives photovoltaics an additional value because generation occurs at a time when electricity is more expensive, as explained in Chapter 1. Any additional generation at peak hour will displace inefficient power plants, reduce the price of electricity, and increase the overall system's efficiency. In this respect, Martin 2004 calculated that installing 1GW of PV power in Massachussets, even at its higher generation costs, would have saved 3-5% on final electricity costs due to peak-shaving.

Solar photovoltaics also has additional value because it is a decentralized electricity source that feeds directly into the low voltage grid, increasing the grid's stability.

As described, photovoltaic generation is intermittent. Nonetheless, average power generation over periods of time can still be accurately predicted. There is empirical data of insolation for different regions. For example, Figure 14 shows insolation averages for the continental United States. Insolation is the main factor to calculate solar potential in a particular area. Other factors are land availability, technical capacity and, for grid connected applications considered in this dissertation, access to grid.

Figure 14: Insolation in the US

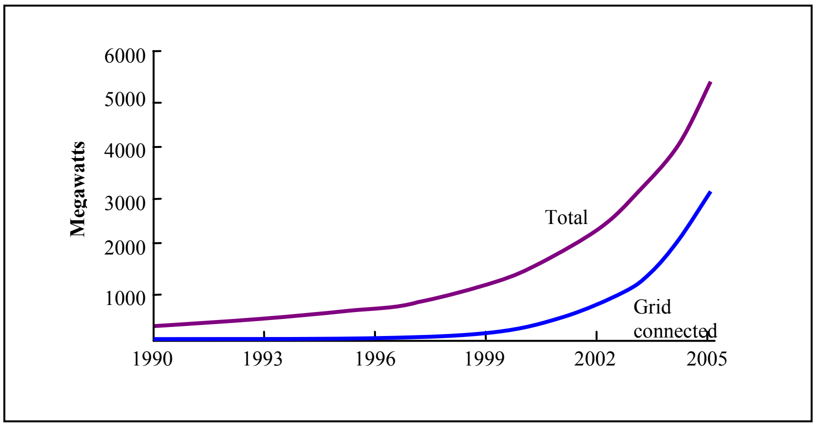


Source: Renewable Resource Data Center

Figure 15 shows worldwide installed capacity for PV, grid connected and in total.

Deployment of photovoltaics in different countries, as it was the case with wind power, is not correlated with resource potential, but with effective policies, the subject of this dissertation.

Figure 15: Installed PV capacity: World 1990-2005



Data from: REN21 2006

Figure 15: This figure displays world installed capacity of photovoltaic electricity generation. The blue line shows cumulative capacity of grid-connected photovoltaic installations, while the purple line shows total cumulative capacity, including off-grid application such as solar homes, calculators and watches. It is important to note that there is no way of measuring off-grid installations, and even grid connected systems are hard to monitor because in many countries are such a small fraction that do not show in the statistics. Therefore, proxy measures are used, particularly manufacturing of solar modules, which is well known and documented.

Environmental Impacts

The environmental impacts associated to grid connected photovoltaic systems are (1) aesthetics and (2) the manufacturing process for solar panels, which uses many toxic products.

As with wind power, aesthetics are a difficult impact to assess. Nonetheless, in many urban areas there are building and zoning codes sanctioning what is and what is not aesthetically allowed. Photovoltaics can occupy marginal spaces, such as building roofs, or road and railroad margins. Photovoltaics can also be integrated into roofs, facades, noise barriers, shade structures (such as in parking lots), etc.

Table 5: Photovoltaics technology summary

Technology	Intermittent	Dispatchable	Modular	Hourly	daily	Seasonal	yearly	Climate Change	Pollution	Wildlife	Health Hazards	Landscape	Location Dependency and Constraints
Photovoltaics	Y	N	Y	Y	Y	Y	Y	N	~	N	~	~	R

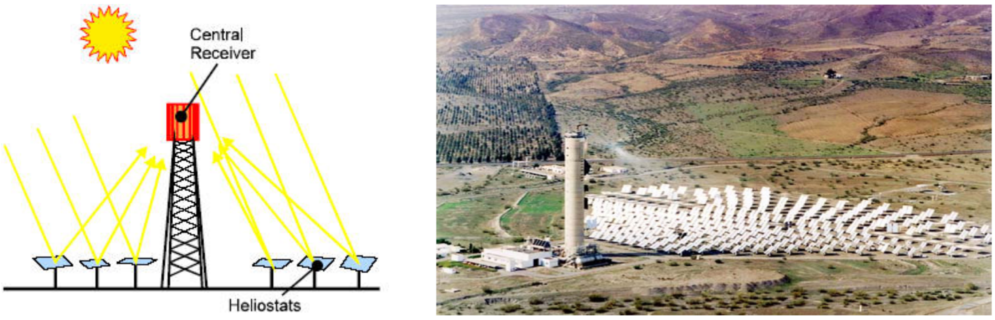
3.3 Solar Thermoelectric

Solar thermoelectric energy is not to be confused with solar thermal energy that generates hot water for domestic use. This confusion may arise because solar thermoelectric is also commonly referred to as solar thermal power or solar thermal electricity.

Solar thermoelectric energy comprises three main technologies which concentrate solar power to produce heat which in turn is used to generate electricity. These technologies are at the demonstration stage, with only one commercial plant in the world located in California (see Figure 17).

The three main technologies are power tower systems, parabolic through systems and parabolic dish systems.

Figure 16: Solar Tower, diagram and experimental 7MW$_t$ Plataforma Solar de Almería, Spain

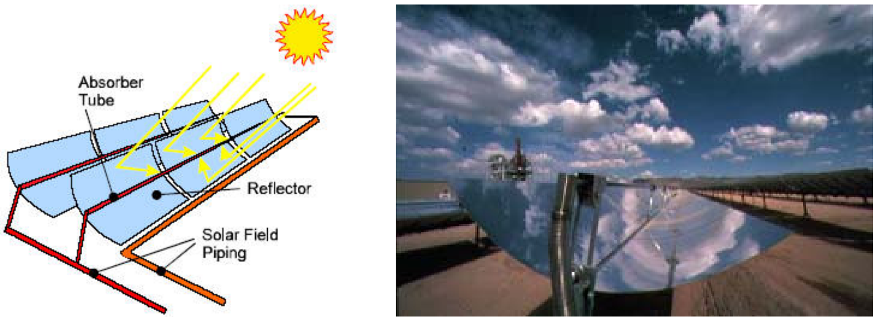


source: www.solarpaces.org

source: IDAE 2005

Solar towers use adjustable mirrors (called heliostats) to concentrate sunlight from large areas into a relatively small surface, which can reach above 1000°C. The heat can then be used to generate electricity. Some demonstration projects, as the Plataforma Solar de Almería shown in Figure 16, have been built, but the technology has not been commercially deployed yet. There is one 11MW project under construction in the province of Seville, Spain, and several commercial projects under consideration in Spain and the United States.

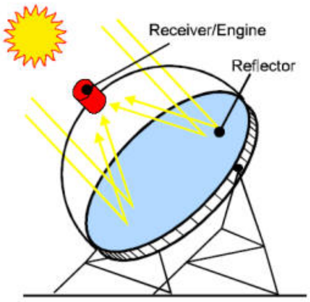
Figure 17: Parabolic through, diagram and Mohave Desert 354MW plant, California USA



source: www.solarpaces.org source: California Energy Commission

Parabolic through technology uses cylindrical parabolic mirrors to concentrate sunlight along the focal axis, reaching temperatures up to 400°C. Concentrators are adjustable on the vertical axis to track the Sun. Heat is evacuated by a fluid (generally mineral oil) and used to generate vapor and run a steam turbine to generate electricity. The largest existing thermoelectric commercial plant, in the Mohave Desert, California, belongs to this technology, and is shown in Figure 17. A 64MW power plant is under construction in Boulder City, Nevada, and several small ones, in MW order of magnitude, have been constructed or are under construction.

Figure 18: Solar Parabolic Dish



source: www.solarpaces.org

Solar parabolic dish technology uses parabolic mirrors to concentrate solar light in a focal point. This system needs horizontal and vertical tracking. Concentrating factors are higher than for cylindrical concentrators, but the technology is less developed (Figure 18).

Solar thermoelectric is an intermittent electricity source. As in the case with photovoltaics, it depends on direct sunlight. Nonetheless, some desert places have “guaranteed” fewer than a few cloudy days per year.

There are no major environmental impacts associated with thermoelectric power, although solar towers might have some visual impact.

Thermoelectric plants require exclusive land use, since the surface is covered by mirrors or other sunlight concentrating devices.

Costs for thermal through technology are estimated at 17-23 cent€/kWh in Spain for the period 2005-2010 (IDAE 2005).

Table 6: Solar Thermoelectric technology summary

Technology	Intermittent	Dispatchable	Modular	Hourly	daily	Seasonal	yearly	Climate Change	Pollution	Wildlife	Health Hazards	Landscape	Location Dependency and Constraints
Solar Thermoelectric	**Y**	**N**	**N**	**Y**	**Y**	**Y**	**Y**	**N**	**N**	**N**	**N**	**~**	**R/E**

3.4 Small hydropower

Hydropower is a mature renewable energy technology that uses water's gravity potential energy to generate electricity. Hydropower is usually divided into two categories, large and small hydropower. The definition of small hydropower changes from country to country and from one organization to another. Common definitions are: a) facilities with power capacity of less than 50MW or 15m high dams, and b) facilities with less than 10MW installed power. However many definitions are more stringent.

There is a limited potential for additional capacity of large hydro in developed countries, because potential sites have either been already developed or are unavailable due to social and environmental constraints.

Small hydropower uses a dam and a reservoir or takes advantage of a natural water body such as lake or river in a high location and divert some water through pipes. Small hydro is also used to retrofit old abandoned hydropower stations with state of the art technology. In some cases, small hydro can run directly off a stream without reservoir.

Large hydropower is generally considered separate from renewable energy sources in energy statistics. Unless otherwise specified, when referring to hydropower in this dissertation, I will be referring to small hydropower.

Figure 19: Small hydropower plant in Austria

Source: European Small Hydropower Association

Technology Attributes

Hydropower is dispatchable (as long as there is a reservoir). Most small hydropower plants display seasonal and yearly time patterns.

Small hydropower is not modular, as each project is engineered to particular location, Although in some cases dams can be enlarged or turbines added, that endeavor is considered a retrofit or a new project rather than a modular addition.

Environmental Impacts

Environmental impacts are very high for large dams. They flood entire valleys, changing the habitat at regional levels, and modifying the nutrient and water cycles of rivers and delta areas. Dams also force the abandonment of human settlements in flooded valleys, and change the socioeconomic structure of the region, with new economic activities such as tourism, power generation and irrigated agriculture. Large dams are also emitters of methane from decomposition of organic matter.

There is discrepancy on the level of environmental impact for small hydropower, but it is generally accepted to be less than large dams. Typical impacts of small hydropower include affecting wildlife in streams through physical fragmentation of a water course, decreased water levels (because of stream diversion), changes in water temperature, changes in habitat due to reservoirs and ponds, and proliferation of invasive species. Some environmental organizations, such as the Swedish Society for Nature Conservation oppose hydropower of any scale, on the grounds that the environmental impact per kWh is high regardless of the hydro plant size.

Table 7: Mini-hydro power technology summary

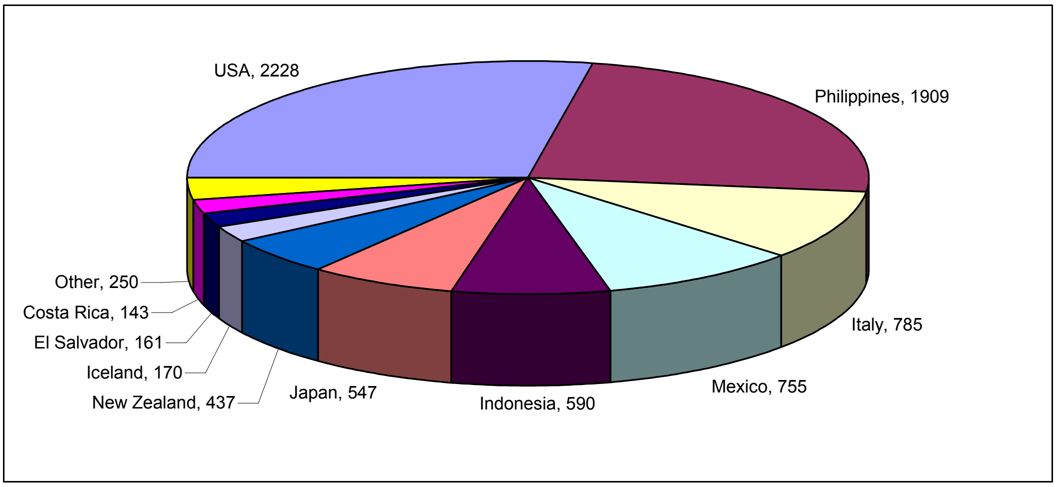
Technology	Intermittent	Dispatchable	Modular	Hourly	daily	Seasonal	yearly	Climate Change	Pollution	Wildlife	Health Hazards	Landscape	Location Constraints
Hydropower	**N**	**Y**	**N**	**N**	**N**	**Y**	**Y**	**~**	**N**	**Y**	**N**	**Y**	**S/L**

3.5 Geothermal energy

Geothermal technology uses the energy from Earth's inner heat. It can use the heat to generate steam and run it through a turbine that generates electricity, or directly capture steam from natural geysers.

The US is the country with largest geothermal installed capacity. Within the US, California's thermal power plants produce about 40% of the world's geothermal electricity. In 2004, there were 2492MW of installed geothermal capacity in California, generating 13571GWh, a 4.8% of the state's power generation. Figure 20 shows installed geothermal capacity worldwide. It is significant that two countries have half of the world's installed capacity, and six countries have more than 80% of total capacity.

Figure 20: Country distribution of world geothermal installed capacity (MW).



Data from: International Geothermal Association

Figure 20: This chart shows distribution of geothermal power capacity around the world. Besides the limited number of countries with geothermal installations, it is noteworthy that almost half of the world's capacity is installed in developing countries.

This is in part due to the fact that geothermal energy is very site dependant. Particular geothermal conditions and water access are needed for electricity generation. Applications for heating water are a much more common use of geothermal energy.

Technology Attributes

Geothermal energy is not intermittent or seasonal. In general it cannot be dispatched, though that would be possible with additional investment to store heat or steam. Time patterns are specific to each plant. Some plants exhibit the same patterns as geysers, erupting at intervals ranging from minutes to days, while other plants operate continuously.

Figure 21: Geothermal power plants:

Olkaria II Power Plant, Kenya

Casa Diablo Power Plant, California, USA

Miquel Muñoz, November-December 2006

Environmental Impacts

The use of geothermal energy for electricity generation has been linked to minor earthquakes (Stevenson 1985, Lepisto 2007).

Other impacts can derive from temperature changes in water courses, or more rarely, from pollution if the process mixes heavy metals, sulphurs or other underground pollutants with surface or aquifer water.

Geothermal plants generally extract heat from different wells. The heat is transported in insulated pipes which can cause a severe visual impact.

Table 8: Geothermal electricity technology summary

Technology	Intermittent	Dispatchable	Modular	Hourly	daily	Seasonal	yearly	Climate Change	Pollution	Wildlife	Health Hazards	Landscape	Location Constraints	Other
Geothermal	N	N	N	Y	Y	N	N	N	~	N	N	Y	S/L	**earthquakes**

3.6 Biomass

Biomass is a generic name for organic matter, including materials such as plant and animal parts and derivates, dung, and food residues. Electricity generation from biomass includes a wide range of technologies, such as direct firing, biogas and gasification.

All biomass technologies are characterized by the fact that they use an organic matter flow and burn it, directly or indirectly, extracting the energy. The environmental benefits of biomass largely depend on the combustion process used and on the origin of the biomass itself. From an energy perspective, whether biomass should be considered renewable or not depends on its EROI. If biomass has a net positive EROI once all the energy inputs have been considered, including farming machinery, transport and fertilizers, then biomass can be considered renewable. However, as noted previously, the definition of renewables for policy-purposes is not clear-cut, and in many cases depends on other considerations.

Typical biomass sources include agriculture and forestry residues (such as straw, tree bark, sawdust, etc.), food and industry waste (nut shells, cooking oil, spoiled or non-saleable food and spirits, etc.), energy crops, sludge from wastewater treatment plants, the organic fraction of urban waste, and manure. Energy crops are conventional cereals, oil seeds or sugar cane, or more specialized plants, which are planted solely with the intention of producing energy. Energy crops are less commonly used for renewable electricity and more frequently used for biofuels, particularly ethanol from sugarcane and corn.

Direct firing, as the name suggests, consists of burning the biomass. The heat is used to generate steam, which is run through a turbine to generate electricity. It works like a conventional coal power plant but using a different fuel. Biomass can be standardized and homogenized in pellets, as illustrated in Figure 22.

Figure 22: Biomass pellets

Source: IEA

Biogas is a technology that degrades biomass through biologic processes and generates a methane rich gas (natural gas is mostly methane). This gas can in turn be burned to generate electricity in a gas turbine, a steam turbine or a combined cycle.

Gasification is a more complex way of burning biomass that is more efficient and can produce chemical feedstock as a byproduct. It has been developed for fossil fuels but can also be applied to biomass.

While biomass has a huge potential for thermal and biofuel applications, its use for electricity generation is less promising, in part because it has more attractive thermal and transportation applications.

Technology Attributes

Electricity generation from biomass encompasses a wide range of technologies and applications, therefore, technology attributes will vary accordingly. In general, biomass can be stored and is usually non intermittent and dispatchable. Biomass can exhibit seasonal or yearly time patterns or not, depending on the fuel source.

Environmental Impacts

Burning biomass emits CO_2. However, net CO_2 emissions depend on how the biomass was grown, transported and processed, as well as on the burning technology. To calculate CO_2 balance, a life-cycle assessment is needed.

Air pollutants can also be emitted during combustion depending on the technology and type of biomass used.

Biomass includes a very large range of fuels and applications. Therefore, its environmental impacts can be negligible or very large.

Table 9: Biomass technology summary

Technology	Intermittent	Dispatchable	Modular	Hourly	daily	Seasonal	yearly	Climate Change	Pollution	Wildlife	Health Hazards	Landscape	Location Constraints
Biomass	**N**	**Y**	~	**N**	~	~	~	~	~	~	~	~	**L/R**

3.7. Tidal Energy

Tidal energy uses the gravity potential created by tides. This source of renewable energy has been exploited in Western Europe at least since the middle ages, with tidal mills and salt works.

In modern uses of tidal energy for electricity generation, tidal energy can be harnessed through tidal dams or through underwater turbines.

Worldwide there is only one tidal dam operating as a power plant, La Rance, France, built between 1951-57, which dams a whole estuary (see Figure 23). When the tide goes up, the water is 13.5m higher on the sea side of the wall, and is allowed into the estuary through turbines that generate electricity. When the tide goes down, the estuary is full, and water is allowed out through the same turbines (which are reversible) generating electricity. The whole installation, comprising 24 turbines, has a rated power of 240MW. While this scheme works, it is a result of the politics of the moment when it was built and is not replicable. The social and environmental implications of destroying an estuary are too large, and the locations worldwide too few, for successful replication to take place.

Figure 23: Usine Maremotrice de La Rance

Source: www.crdp.ac-caen.fr

Tidal lagoons are another approach to storing tidal energy in a reservoir with lower environmental impacts than a dam. Nevertheless, this approach has the inconvenience that the stored energy is orders of magnitude smaller. Tidal lagoons for electricity generation are still on the experimental stage.

Tidal currents would be the equivalent of installing an underwater windmill. The potential is relatively high, and can be installed in river mouths in many places of the world. One of the advantaged of tidal turbines is that they can be installed right near consumption in places such as New York, London and other major cities.

Tidal turbines to extract energy from tidal currents are still in the development phase, and many issues, from engineering to environmental impacts have to be addressed or studied before they can be deployed at large scale. For example, Figure 24 shows the installation of two experimental underwater tidal turbines off the east side of Manhattan, in New York. Each turbine measures over 6m and weighs 4 tons. The installation took place in December 2006, in two consecutive days. The first turbine to be installed was destroyed in less than 24hours, due to unknown causes yet. The blades were badly bent.

Figure 24: Experimental tidal turbine in Roosvelt Island, Manhattan

Source: the New York Times

The experimental turbine from Figure 24 feeds the generated electricity into a nearby supermarket.

One of the objectives of the experiment is to determine the impacts, if any, on wildlife, particularly fish banks, which are monitored by sonar.

If the turbines work properly and there are no environmental impacts or other problems detected, the company that installed the prototypes, Verdant Power (www.verdantpower.com) is planning to apply for permission to install a few hundred turbines around Manhattan waters.

3.8 Wave energy

Wave energy is on the demonstration stage, with some competing technology devices being tested under real conditions. The idea is to use the kinetic energy of waves to generate electricity. Several approaches are being studied and many more suggested. There are two main categories, those floating and those fixed on-shore. On-shore power plants could be installed on breakwaters greatly reducing their cost. No clear leading technology has emerged yet. The potential for wave energy is enormous, and some in the sector speculate this could be the next “big” energy business after wind power.

Figure 25: 2.25MW Pelamis power plant

ABOVE:
Pelamis device to be installed in Portugal.

LEFT:
Prototype Pelamis device during testing.

Ocean Power Delivery Ltd.

Environmental Impacts

Wave energy is still at an early stage for clear environmental impacts to have emerged. However visual impacts of devices such as the Pelamis (Figure 25) are likely to become an issue. Likewise, there is the potential impact on wildlife, and more research is needed.

Table 10: Wave energy summary

Technology	Intermittent	Dispatchable	Modular	Hourly	daily	Seasonal	yearly	Climate Change	Pollution	Wildlife	Health Hazards	Landscape	Location Constraints
Wave energy	Y	N	~	~	Y	Y	~	N	N	~	N	Y	**R**/Shores

3.9 Land fill gas

Landfill gas is not a renewable energy source properly speaking. Landfill gas is one form of biogas that occurs when the organic fraction of waste in a landfill naturally decomposes, generating methane. Ideally landfill gas should not occur because the organic fraction of urban waste would have been separated in origin and treated separately. However, this is not the case, and much biomass ends up in landfills, where it decomposes.

Technically landfill gas is not much different from biogas. Both are derived from decomposition of organic matter. However landfill gas it is treated differently than biogas because landfill emissions would happen anyways, in the form of methane, which is a greenhouse gas 17 times more powerful than CO_2. Just burning the methane already provides an environmental benefit, and extracting its energy content, thus displacing other generation, has a net environmental (and often economic) benefit.

Landfill gas is not pure methane, but it contains a fraction of CO_2, and in some cases other elements. The ratio of methane to CO_2 determines the energy value of the gas, and depends on specific landfill properties, such as composition of the buried waste, temperature, pressure, and age of the landfill. Except in sites with high quality landfill gas, where the gas can be purified and fed into the gas grid or used for other purposes, the preferable approach is to use it for electricity generation.

Environmental Impacts

Using landfill gas for electricity generation has no negative environmental impacts. The environmental impacts of the landfill would occur independently of landfill gas extraction.

Table 11: Landfill gas technology summary

Technology	Intermittent	Dispatchable	Modular	Hourly	daily	Seasonal	yearly	Climate Change	Pollution	Wildlife	Health Hazards	Landscape	Location Constraints
Landfill gas	N	N*	N	N	N	N	N	N	N	N	N	N	S

3.10 Solid Waste Incineration

Municipal solid waste has a high energetic content, mainly in its paper, plastics and organic matter. In those places where residues are incinerated, the excess heat can be used to generate electricity. Solid waste incineration is one of the most contentious "renewable" sources, since environmentalists are generally opposed to it on the grounds that it pollutes with toxins and other pollutants, and that valorization of the energy content of paper and plastic creates disincentives to reduce and recycle, and perverse incentives to generate more waste.

Technology attributes

Waste incineration will generally operate continuously, as base load, or as allowed by emissions regulations. In operational aspects, waste incineration is very similar to a conventional fossil fuel power plant.

Environmental impacts

Waste incineration creates all sort of air and solid pollutants, and emissions of greenhouse gases. Most of the pollutants can be filtered out of the smokestacks, but this is a very costly process. Ashes need to be disposed of in special landfills because of they elevated toxicity.

Table 12: Waste incineration technology summary

Technology	Intermittent	Dispatchable	Modular	Hourly	daily	Seasonal	yearly	Climate Change	Pollution	Wildlife	Health Hazards	Landscape	Location Constraints
Waste Incineration	N	~	N	N	N	~	N	Y	Y	~	Y	~	S/R

3.11 Co-firing and Combined Heat and Power (CHP)

Co-firing and combine heat and power are not renewable energy technologies. However, these technologies are often associated with renewable energy policies and are therefore described here.

Co-firing means using a mix of different fuels. In the case of renewables, it is the combination of biomass, biogas or waste and a conventional fossil fuel to generate electricity. The fuels can be mixed or used successively. Only the electricity equivalent to the renewable energy fraction of the mix is generally considered as renewable electricity. Co-firing can be used as a strategy to cope with seasonality or fluxes in biomass supply. In some cases it is necessary to achieve greater efficiency or for technical reasons.

Combined heat and power (CHP), also know as co-generation, is a conventional energy fuel technology that takes advantage of heat needs to generate electricity as a “byproduct”. It is desirable because of its very high energy efficiency, and generally promoted by governments. It is not a renewable technology, but can be used in combination with biomass to increase energy efficiency.

CHP is relevant to renewables because many of the policies intended to promote renewables are also applied to CHP.

Technology Summary

Table 13: Summary of renewable electricity technologies

Technology	Intermittent	Dispatchable	Modular	Hourly	daily	Seasonal	yearly	Climate Change	Pollution	Wildlife	Health Hazards	Landscape	Location Dependency and Constraints	Other
Wind power	Y	N	~	Y	Y	Y	Y	N	N	Y	N	Y	**S/L**	
Photovoltaics	Y	N	Y	Y	Y	Y	Y	N	~	N	~	~	**R**	
Solar Thermo electric	Y	N	N	Y	Y	Y	Y	N	N	N	N	~	**R/E**	
Hydropower	N	Y	N	N	N	Y	Y	~	N	Y	N	Y	**S/L**	
Geothermal	N	N	N	Y	Y	N	N	N	~	N	N	N	**S/L**	**earthquakes**
Biomass	N	Y	~	N	~	~	~	~	~	~	~	~	**L/R**	
Wave energy	Y	N	~	~	Y	Y	~	N	N	~	N	Y	**R/**Shores	
Landfill gas	N	N*	N	N	N	N	N	N	N	N	N	N	**S**	
Waste Incineration	N	~	N	N	N	~	N	Y	Y	~	Y	~	**S/R**	

S = Specific; L = Local; R = Regional; E = Exclusive use of land

PART II – SUPPORT SCHEMES, POLICIES, MEASURES AND FINANCING STRATEGIES FOR THE PROMOTION OF RENEWABLE ELECTRICITY

Part II describes different support schemes, policies and measures for the promotion of renewable electricity, and is structured in four chapters. Chapter 4 describes market-based support schemes for renewable electricity, including feed-in laws and quota systems, the prevailing policy instruments in renewable electricity promotion. Chapter 5 describes other support policies for renewable electricity, such as tax credits, clean energy funds, direct subsidies and public support for R&D. Chapter 6, describes measures essential for the deployment of renewable electricity technologies, such as grid access provisions, definitions and standards, and administrative streamlining. Chapter 7 describes some strategies used or under consideration for financing the deployment of renewable electricity. This structure is reflected in Table 14.

Table 14: Structure of Part II

Chapter 4: Market-based policies for the promotion of renewable electricity	**Chapter 5: Other policies for the promotion of renewable electricity**
• Feed-in-laws • Quotas • Tendering Systems • Voluntary Markets/Green Electricity	• Tax Credits • Clean Energy Funds • Subsidies • Net metering • Public R&D
Chapter 6: Enabling measures for the deployment of renewable electricity	**Chapter 7: Financing strategies for the deployment of renewable electricity**
• Grid access • Definitions and standards • Administrative Streamlining • Target setting • Awareness and education	• Long-term contracts • Risk Management • REC Futures • Community Ownership

This structure has been chosen because it describes the available instrument for the promotion of renewable electricity while giving an idea of the type of instrument and area of effect. Other authors use other classifications. For example, Gan *et al.* 2005 classify policy instrument as those that help production, capacity or consumption of renewable electricity, while Sawin & Flavin 2004 classify policy instruments as market regulations, financial incentives, and other policies. However, the chosen structure allows for more items to be described.

4 – Market-based policies

Market based policies are those that affect either the demand or the supply of renewable electricity, on the premise that the so-called "market forces" will balance supply and demand, resulting in increased renewable electricity generation. The policies that affect supply are sometimes called "supply-push" policies, while those that affect demand are referred to as "demand-pull" policies. Feed-in laws are a supply-push mechanism, while quotas and green electricity are demand-pull instruments. Tendering is a mix scheme. All these policies are explained next. This chapter is limited to describing the policies and their main features, while Part IV of this dissertation provides an analytical comparison between feed-in laws and quotas.

4.1 – Feed-in-laws

A feed-in law, in essence, guarantees to renewable electricity producers that their electric output is bought at a price above market price for electricity. Feed-in laws comprise two main components: (1) an obligation for the grid operator to buy all renewable electricity produced and (2) a pricing scheme, generally a feed-in tariff or premium:

- Under feed-in tariffs, producers sell their renewable electricity at a pre-set price per kilowatt-hour (kWh). This fixed price, or tariff, is above market price for electricity and guaranteed for a number of years.
- In a premium scheme, producers sell renewable electricity in the spot market, as described in Chapter 1, and a premium, also guaranteed for a number of years, is added to the market price.

It is common in the literature to refer to feed-in laws as feed-in tariffs[11], which can lead to confusion because not all feed-in laws comprise a tariff. In practice, many feed-in laws are neither pure feed-in tariff nor a pure premium scheme, but a hybrid in between.

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[11] Feed-in laws and their variants are referred under many names in the literature and legal texts, including: feed-in tariffs; REFIT (Renewable Energy Feed-In Tariffs); RES-E Tariffs; fixed-price schemes; premium systems; pricing systems; and simply "tariffs".

From a developer's perspective, the key of feed-in laws is to guarantee a revenue for renewable electricity producers sufficient and with enough guarantee to allow investors to invest in renewable electricity generation.

4.1.1 – Advanced feed-in laws

Feed-in laws as just described are very simple. In fact, that description applies only to the basic principles of a feed in laws. But real policies must include other provisions than just the feed-in and pricing clauses. These provisions may address items such as:

- Windfall profits
- Funding
- Equalization and geographical dispersion
- Specific technologies
- Duration and adjustments

Next, a description of windfall profits is provided, as well as examples of how advanced feed-in laws can deal with the items above mentioned.

4.1.2 – Windfall profits

In principle, feed-in law premiums/tariffs are meant to pay for the additional cost of renewable electricity and justified by the positive externalities of renewables, such as energy security, industrial policy, employment creation and reduced environmental impacts, and the negative externalities of conventional power generation. The level of the premium/tariff should be set at a level such that investors can cover their costs, including capital costs and risk, over the lifetime of the project and make a reasonable profit. However, under some circumstances, feed-in laws produce unintended profits for producers, above what is considered as *reasonable profits* (see box). These unintended profits are generally known as windfall[12] profits.

There are three main causes for windfall profits under feed-in laws:

1. Premiums/tariffs are set too high to start with;
2. Tariffs/premiums fail to adjust to rapidly declining technology costs;

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[12] Very appropriate term for wind power, which happens to capture most windfall benefits.

3. In the case of a feed-in law based on market price plus premium, that electricity price increases significantly and the premium is not adjusted accordingly.

REASONABLE PROFITS

The definition of "reasonable profits" is a complicated matter with two different levels of complexity:

1) Investors must obtain profits above the interest rate if they are to invest in renewable energy. How much above the interest rate, i.e., what is "reasonable", is an arbitrary quantity, and defined by a mixture of what is politically acceptable and what are the market conditions in each particular country and period of time. What is acceptable in Germany as a reasonable profit might not be acceptable in the United Kingdom, or what is acceptable in the United Kindom today, might not be acceptable tomorrow.

2) On a more fundamental level, it must be considered that the interest rate upon which the definition of what is acceptable profit is based, reflects a rate of economic growth based on, *inter alia*, the use of fossil fuels, non-renewable resources and pollution. While this consideration has no practical effects for the short-term policy-setting, it is important when planning for the longer term, and additional considerations are necessary on the sustainability of economic growth.

Figure 26 illustrates those three causes. In most cases, windfall profits are due to a combination of those three causes.

Windfall profits are negative for the development of the renewable electricity industry and must be avoided. At first it would seem that windfall profits are good for the renewable electricity industry because they produce additional return on investment, which, provided there are no barriers to entry, should attract additional investment and accelerate renewable electricity deployment. However, this is not the case, with the possible exception of short term gains.

Windfall profits impose an undue burden on electricity consumers and have three main drawbacks for renewables:

1. Excessive benefits for some producers are difficult to justify to the public opinion, particularly when they are the result of a public policy placing a burden on the electricity consumer, and weaken the political support for otherwise necessary incentives to renewable electricity
2. Windfall profits give instruments to those lobbying against policies for the promotion of renewable electricity, mainly fossil fuel advocates and some utilities.
3. Windfall profits increase regulatory uncertainty. Investors understand that such a "good" system cannot last too long, and are concerned about future policy changes, i.e. policy uncertainty.

Figure 26: Windfall profits

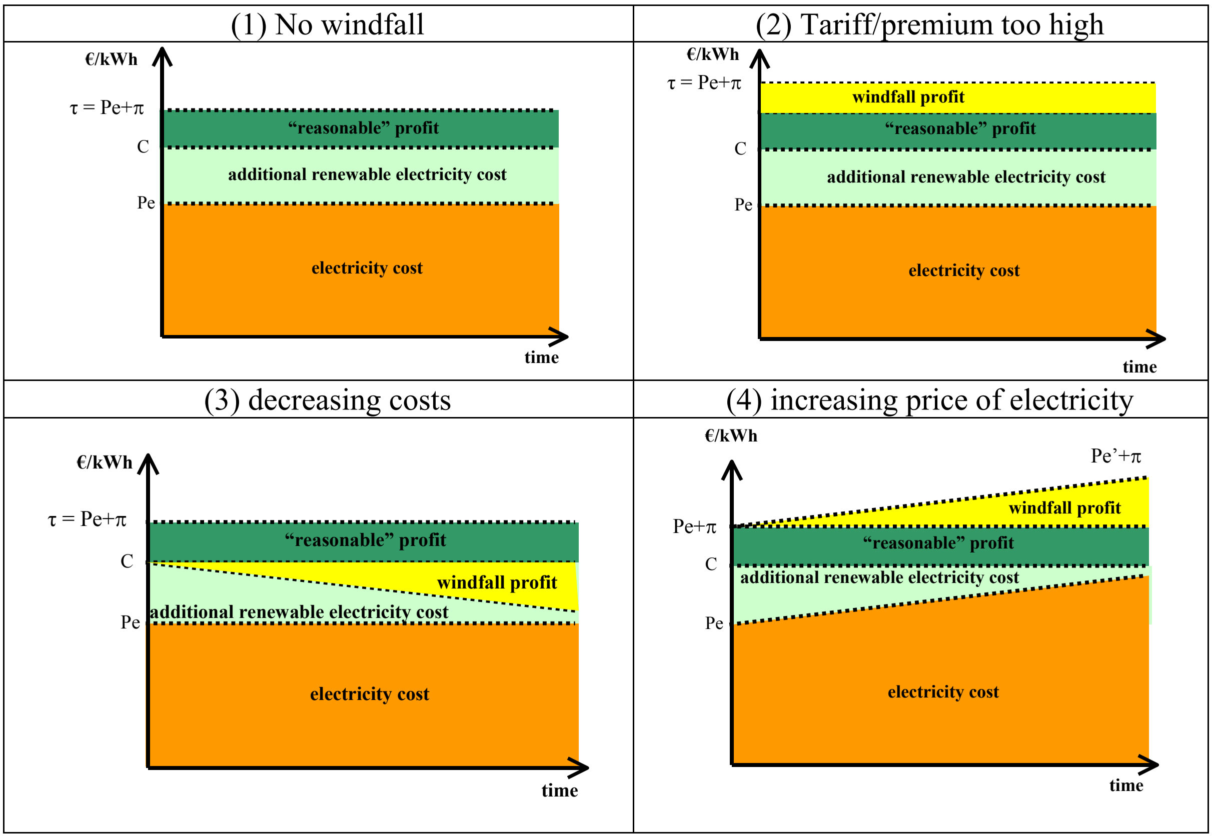

Figure 26: The graphs above show different causes for windfall profits under a feed-in law in a schematic manner. (1) is the case of a perfect feed-in tariff, with a tariff (τ) equal to the price of electricity (P_e) + a premium (π). The premium π covers the extra cost of renewables and a "reasonable" profit for producers. (2) is the case where the tariff is set too high to begin with, and producers capture a windfall profit in addition to the "reasonable" profit. (3) reflects the case of falling costs of renewable, probably due to innovation. (4) depicts the case where electricity prices rise, making renewables more competitive. If the premium is fixed, increases in the electricity price will cause windfall profits.

In order to reduce the impact of windfall profits, premiums/tariffs are not necessarily fixed for the whole period. For example, Germany adopted a degressive feed-in tariff (EGG 2004) where tariffs decrease every year by a fixed percentage in order to reflect technology innovation and foster early deployment. Spain adjusted the premiums to the average electricity price (RD 436/2004 and RD 1432/2002) until 2006. The German and Spanish feed-in laws are explained in detail in Chapter 8.

Chapter 18 proposes and describes the use of a profitability threshold as a means to avoid windfall profits under feed-in premium systems.

4.1.3 – Funding and equalization

Funding of feed-in laws is generally done through a charge in the final consumers. In electrical systems spanning over large regions, or over diverse areas in respect to renewable energy resource base, producers may tend to concentrate their projects in the most attractive areas for renewable electricity deployment. Also, in countries with more than one separate electric system, such as Germany, developers will tend to concentrate on the system with the best resources.

These reasons can cause a geographical imbalance in the deployment of renewables, and also an imbalance on who bears the cost for that deployment. To distribute costs evenly among consumers, a provision know as "equalization" was invented in Germany. Equalization provisions basically pool the costs of feed-in law support and then redistribute them among the different systems, according to their total consumption. The issue of geographical imbalances is addressed in Chapter 15.

4.1.4 – Specific technologies

Feed-in laws can be very easily adjusted by design to provide different levels of support to different technologies. This is done by setting a different tariff/premium for different technologies or groups of technologies.

In practice, all explicit feed-in laws have different support levels for different technologies.

4.1.5 – Duration and adjustments

Feed-in laws are generally guaranteed for a number of years, typically fifteen to twenty, although some countries restrict support to shorter times. For example Italy limits premiums to eight years *(*Lorenzoni 2003*)*, while Germany extends its fixed tariff support from 15 to 30 years (EGG 2004). Sufficiently long legal guarantees are essential to bring confidence to investors, reduce real and perceived investment risk, and lower capital costs.

Adjustment of premiums/tariffs can be necessary. The key idea to retain is that long duration brings certainty about revenues, hence confidence, therefore access to capital and investment. However, adjustment is necessary to keep pace with technological innovation, market conditions, and deployment of renewables.

In Chapter 18 a proposal is made for a possible adjustment mechanism to account for technological innovation.

4.2 – Quotas

Quota systems are support mechanisms that require electricity retailers power suppliers, the transmission grid or consumers (liable entities, Menanteau et al 2003) to include a certain amount of renewable electricity in their resource portfolio. Liable entities can fulfill this obligation by: (a) owning one or more renewable energy power plants; (b) buying the required amount of renewable electricity from someone else; or (c) buying a "guarantee" that some one else has generated the necessary amount of renewable electricity. This "guarantee" is provided in the form of a Renewable Electricity Certificate (REC[13]).

Quotas are a demand side support mechanism, because they create an artificial demand for renewable electricity. The idea is that creating a demand will generate supply. Additionally, because trade provisions are allowed, market forces will, in theory, increase efficiency and achieve an optimal allocation of resources (Sawin and Flavin 2004). Once quota systems are enacted, the government role is limited to monitoring and enforcing compliance.

Thus, a quota system comprises two main components:

1) a quota or target imposed on the electric system; and
2) trade provisions.

The use of market permits for environmental policy was proposed by Baumol & Oates in 1975. Most modern cap-and-trade systems for environmental purposes, including quota systems, are based on the US SO_x cap and trade system, where a trade system was established for sulfur emissions. The SOx cap and trade system has been widely perceived as very successful and credited with sharp reductions in acid rain in the US.

Cap-and-trade systems have been replicated for other environmental purposes, such as controlling greenhouse gas emissions under the Kyoto Protocol. Closer to renewable

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[13] In this dissertation, unless otherwise specified, REC is used as a generic term to refer to Renewable Electricity Certificate and does not necessarily refer to any of the existing schemes that actually use the name REC. Many tradable certificate systems use other names for RECs, such as Green Certificates, Green Labels, Tradable Green Certificates or Renewable Obligation Certificates (ROC). REC is also normally used as an acronym for Renewable Energy Certificate.

electricity, tradable certificate systems have also been under consideration for energy-efficiency and demand-side management measures (Bertoldi & Huld 2006; Langniss & Praetorius 2006).

4.2.1 – Advanced quota systems

Quota systems as just described are very simple. In fact, that description applies only to the basic principles of a quota system. But real policies must include other provisions than just the quota target. These provisions may address items such as:

- REC Market design
- Enforcement
- Administrative issues
- Quota levels
- Existing capacity
- Specific technologies
- Funding

4.2.2 – REC Market design

Under a quota system with tradable certificates, RECs are issued to producers of renewable electricity and a market is created where these certificates can be traded. At the end of the complying period, the liable entities must redeem enough certificates to fulfill their quota obligations.

RECs are initially linked to a physical entity – renewable electricity. However renewable electricity certificates quickly loose their direct relation to a physical entity and become a conceptual good. When renewable electricity is fed into the grid it becomes indistinguishable from electricity generated from fossil fuels or nuclear power. A renewable energy certificate is the guarantee that a certified amount of green electricity, equivalent to the quantity consumed, has been generated somewhere. In tradable certificate systems, RECs can be sold bundled or unbundled with electricity, depending on the design of the system. Therefore when retailers buy renewable electricity, they are buying regular electricity plus the guarantee that an equivalent amount of renewable electricity has been generated somewhere. There are some exceptions where renewable electricity is directly transmitted from source to user, but this is a marginal and no-cost-effective segment of the market (Menges 2003).

If RECs and electricity are unbundled, then RECs can be traded independently of electricity. In this sense, RECs become tradable financial assets (Nielsen & Jeppesen 2003), and a market can be established.

The creation of a successful REC market requires careful design and consideration of many factors.

Certificates should be fraud-proof and credible. Relevant information should be available for each certificate. This information should include the technology used, date and time of generation, total power output and site of the installation. Some REC systems include more information. In the future, RECs might be tracked with geographical information systems (GIS), or other information technologies.

It is also possible that in a REC market renewable electricity producers or other actors would try to game the system to increase their benefits. Particularly troubling would be the creation of cartels withholding renewable electricity generation in order to raise REC prices. These practices would be a perverse effect contrary to the policy objectives of increasing total renewable electricity generation. Appropriate regulation is necessary to avoid those unintended consequences (Lemming 2003).

In a quota driven system market, REC demand is perfectly inelastic, as demand depends on regulation, not on the REC prices. In other words, higher or lower REC prices do not affect demand. In the short term, most renewable electricity producers have very low marginal costs because of non-existent fuel costs and low maintenance costs. Therefore, renewable electricity suppliers sell all their electricity to the grid, because it is always profitable to do so (remember Figure 3 on bidding costs for different technologies). REC supply is directly proportional to the renewable electricity generated. As a consequence, the supply side for REC is also inelastic, at least in the short term, because the availability of certificates does not depend on their price. Additionally, renewable electricity generation – and thus REC supply – fluctuates due to meteorological conditions (wind, rainfall, etc.). These fluctuations can change renewable electricity (and REC) generation seasonally and yearly.

Inelastic demand, plus short-term inelastic supply and supply fluctuations equal high price volatility (Nielsen & Jeppesen 2003). Volatility problems can become acute at the beginning of REC system implementation, when markets are thin. Banking of certificates can alleviate price volatility. If banking provisions are accepted, excess RECs can be carried over from one compliance period to another, allowing producers and consumers of RECs to hedge their risks. Banking can be allowed for a certain number of complying periods or indefinitely. Banking provisions should be gauged carefully because the mechanism can be abused, particularly if quota mandates are not very ambitious and banking is allowed for long periods. For example, in Wisconsin enough RECs have already been banked to comply with quota obligations until 2012 (Glickel 2003). Borrowing mechanisms can also mitigate volatility due to temporary shortfalls in REC supply. Under a borrowing system, the issuing entity issues "virtual" certificates which have to cancelled with real certificates at a later time. An example of borrowing is Japan, which allows utilities to borrow up to 20% of their obligation (METI 2003). Borrowing is in a way similar to having a futures market (section 7.3), but the difference is that, unless a penalty is associated to the borrower, the risks associated to availability of certificates, and the loss of certificate value due to discounting is borne by the lender, in this case the issuing entity.

From the producer point of view, most renewable electricity producers under a quota system will use financial instruments to hedge the risk of REC price volatility risk. This puts at disadvantage small generators because they have comparatively higher cost for the hedging instruments (WWF 2003). Transaction costs for the managing of RECs can be reduced if RECs are traded by brokers in the exchange markets (Nielsen & Jepensen 2003). Several of these broker firms already operate, such as San Francisco-based Evolution Markets.

4.2.3 – Compliance

Most quota systems have a non-compliance penalty. When a liable entity does not comply with the required quota, it has to pay a penalty, or buy-out option. The penalty price effectively acts as a price cap for RECs. Under normal circumstances, no liable entity will buy RECs at a price above the penalty price because paying the penalty is less costly. There is one notable exception in the UK, which is explained in Chapter 8.

Price caps reduce volatility in REC prices, because they give liable entities an idea of the maximum range they will have to pay to support renewables, and reduces potential speculative actions to inflate REC prices.

As example, non-compliance penalties are 55$/MWh for the U.S. State of Connecticut. Figure 27 shows the supply-demand curves for a REC market, and the effects of caps or penalty prices.

Figure 27: Quotas and price caps

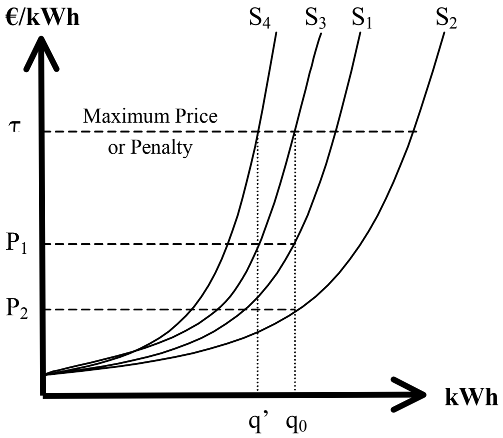

Figure 1: Different supply curves (S) will lead to different REC prices. S_1 and S_2 will result respectively in P_1 and P_2 for a given quota q_0. A maximum price (τ) caps the cost when supply does not meet demand. If price is capped at τ, then $q<q_0$ renewable electricity will be generated for supply curves above S_3, and the quota will not be fulfilled. For example, S_4 will generate $q'<q_0$

A different aspect of compliance is enforcement. If quotas are loosely enforced, then quota systems loose their effectiveness. Which brings up who is in charge of the quota system and other administrative issues

4.2.4 – Administrative issues and funding

When a quota system is set in place, one or several bodies need to be set up, or existing bodies need to be given authority over a number of responsibilities. The responsibilities that need to be assigned include:

(1) definition and implementation of operational rules;
(2) issuance and redemption of certificates;
(3) monitoring of certificates to ensure they correspond to generated renewable electricity and are not duplicated;
(4) registering of RECs and REC transactions;

(5) control of compliance with quotas; and

(6) imposing sanctions.

These responsibilities can be assigned to one or different bodies, which can be but are not limited to the TSO, independent agencies, the ministry of energy or economy or some other body.

The costs of quota systems are normally passed down by the liable entities to the final consumers. Thus, funding for quota systems comes from the final consumer.

A different question is who should bear the administrative costs of policies (Lorenzoni 2003). Should the administrative cost be borne by government? By renewable electricity producers? By consumers? By utilities?

In the case of feed-in laws, administrative costs are easily passed to final consumers as part of the premium or tariff cost. In general, administrative costs will be covered by a combination of public funds, final consumers, and companies operating in the electric system.

Public costs stem among other from staff and overhead costs of any public institutions involved. In some cases, REC transactions are levied to cover for part of those costs, hence the final consumer bears some of the costs. In other cases, the liable entities pay some of the administrative costs. Of those cost, some will be passed down to consumers, but some will simply reduce the profitability of liable entities.

4.2.5 – Quota levels and technology diversity

Under the simplest quota system, a fixed quota is established and liable entities must achieve their quotas by the established deadlines. However, in practice, most quota systems, particularly the most recent ones, have staggered targets, with an increasing quota level over time. Table 15 illustrates a renewable electricity quota with staggered targets for the case of Massachusetts.

In some cases, quotas are fixed for different technologies, in order to promote a specific kind of technology or achieve a desired mix of renewable electricity sources. For instance, in the State of New Jersey (NJ-PJM power pool) there are Class I and Class II certificates for different technologies.

Table 15: Staggered renewable electricity quotas in Massachusetts

Quota	Year
1.0%	2003
1.5%	2004
2.0%	2005
2.5%	2006
3.0%	2007
3.5%	2008
4.0%	2009
additional 1% each year afterward until DOER ends additional requirements	

source: Massachusetts Department of Energy (DOER)

4.2.6 – Existing Capacity

Quota systems must address the coexistence of new an old renewable electricity generation capacity (Lemming 2003). Existing renewable electricity producers have generally benefited from some form of aid in the past or are already competitive. In any case, they already have their operating costs covered by electricity revenues. Including existing renewable capacity into the REC market distorts the REC supply-demand curve as shown in Figure 28. Transition measures and "sunset" clauses are necessary to ensure that quota systems promote additional renewable capacity, and funds are not wasted giving an extra subsidy to already competitive or subsidized technologies.

Figure 28: REC Supply Curve resulting from adding up old and new capacity

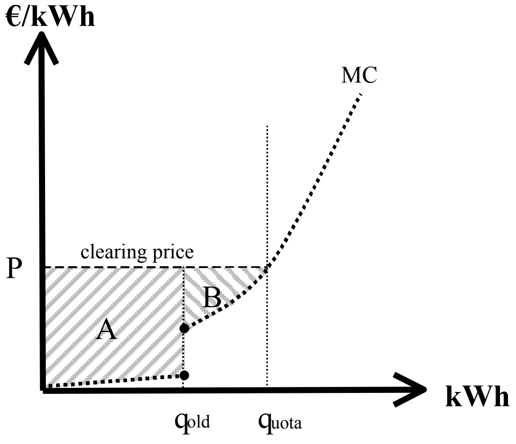

Figure 28: Old renewable electricity power plants will operate at no or negligible marginal cost (MC) because they are already amortized[14]. Under a quota system that does not discriminate between new and old production, old generators will be capturing rent A, while new producers will be subsidized by B. The total cost of the policy will be A + B, but only B will go towards additional capacity.

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[14] With the exception of biomass, which has combustible costs.

4.2.9 – Combination of different Quota systems

Quota systems have the advantage that, in theory, REC markets from different countries can be combined into larger markets, thus promoting greater economic efficiency. To that respect, the European Commission Joint Research Centre (JRC) is developing an Internet Trading research project aimed to design and test reliable, universal, open and inexpensive systems to trade RECs (Bertoldi & Huld 2006). The possibility of harmonization of quota systems in Europe is further discussed in Chapter 8.

The country with more experience in quota systems is the United States, with over 24 US States having enacted a Renewable Portfolio Standard (the US name for quota systems, see Chapter 9 and Figure 58). Each state has its own rules for its quota system, and experience to date suggests that trading of REC between States is very complicated or simply does not work.

4.3 – Tendering Systems

Under a tendering system, the government mandates an amount of renewable electricity capacity to be installed and opens a public bidding process for developers to make their offers. The lowest-price offer wins the competition and a contract is awarded to install the renewable energy units at the bidding price. If multiple projects are needed to meet the tendering offer, then each project is awarded contracts at their bidding prices. A new biding process is started every time, and there can be separate tenders for different technologies. In theory, tendering systems capture elements from both, feed-in laws and quotas. The tendering system allows the government to fix the amount quantity of electricity to be promoted, as in quota systems; guarantees a fixed price for producers, as in feed-in laws; and promotes competition among producers, as quotas (Madlener and Stagl 2005). This, in theory, allows a more cost efficient generation of renewable electricity while controlling the cost and scope of the policy. Unfortunately, existing tendering systems have not yielded the expected results.

The Non-Fossil Fuel Obligation (NFFO) in the United Kingdom (explained in Chapter 8.9) was an early example of a tendering system *(Elliot 1999, Lipp 2001, Sawin & Flavin 2004)*. Tendering lowered contract prices from comparable renewable electricity projects at the time. However, actual installation of new renewable energy facilities was well below expectations *(Quillet 2002)*. Eventually, in 2002, the UK NFFO was changed to a certificate system, the Renewable Obligation, which traded certificates called Renewable Obligation Certificates (ROCs). In 2005 only one country in Europe, Ireland, had a tendering system in place as the main promotion mechanism for renewable electricity, the Alternative Energy Requirement Programme. Nevertheless, feed-in laws replaced the tendering system in Ireland in 2006.

Tendering systems have not proven empirically to be very effective or efficient. The main identified drawbacks of tendering systems include: (1) high transaction costs; and (2) non-implementation.

High transaction costs stem from the fact that potential investors have to prepare elaborate bidding proposals. Those proposals are costly to prepare and amount to a barrier for small investors. Additionally, if the contracts are small, bidding costs become disproportionately high (WWF 2003).

Non-implementation is an even more serious problem. Experience has demonstrated that many of the contract-winning developers in the UK (Quillet 2002) did not actually implement their projects, or faced long delays, resulting in less renewable electricity capacity installed than intended by the policy. In some cases, non-implementation was the result of under-bidding, which reduced the cost of the policy on paper but effectively cut support for projects that would otherwise have delivered the intended renewable electricity.

4.4 – Voluntary Markets – Green Electricity

Voluntary markets, as the name suggests, are markets for renewable electricity that are not explicitly mandated, opposite to quota-driven REC markets or feed-in provisions. Voluntary markets can include direct purchases of renewable electricity or, more commonly, purchases of certificates. These certificates can be “official” certificates from quota systems or certificates issued directly by utilities or third-party organizations.

Schemes by utilities offering renewable electricity to their costumers on a voluntary basis are also known as green pricing (Bird et al 2004, Wiser et al 2004)

The demand for voluntary markets can come from business and industry seeking to comply with ISO14001 and other environmental or energy-efficiency standards, from business and industry seeking a more environmentally-friendly image, from institutions and organizations such as universities, municipalities and stadiums, or from private consumers.

Voluntary markets can and do co-exist with quota systems. Voluntary markets can also co-exist with feed-in law schemes, but their effect in promoting renewable electricity is less certain. It is important to ensure the additionality of purchases under voluntary markets, particularly in those jurisdictions where a quota or other obligation already exist requiring a fraction of renewable electricity production. For example, it has been noted (Friends of the Earth 2004) that most U.K. consumers purchasing under utility voluntary schemes for renewable electricity where simply subsidizing the utility's requirement to buy ROCs (the U.K. renewable energy certificate under the UK quota system).

Voluntary markets are most extended in the United States, where the Green-e Renewable Certification Program is the leading voluntary certification and verification programme (EPA 2004). It is estimated that the total voluntary market in the US in 2003 was 3.9 million MWh (Holt & Bird 2005). To put this number in context, this quantity is roughly half the electricity consumed by Luxembourg in 2006, or 1‰ (0.001) of electricity consumed in the United States in 2006 (IEA 2006)

Table 16 shows prices for voluntary RECs offered by a variety of companies for residential consumers in the US. It is difficult to assess wholesale prices because the price of most transactions is often not disclosed.

Table 16: US prices for voluntary RECs (2004)

Company	Product Name	Resource Mix	Residential Price Premium
3 Phases Energy Services	Green Certificates	100% wind	2.0¢/kWh
Aquila Inc.	Aquila Green Credits	100% wind	Nonresidential only
Bonneville Environmental Foundation (BEF)	Green Tags	≥98% wind, ≤ 1% solar, ≤ 1% biomass	2.0¢/kWh
Community Energy	New Wind Energy	100% wind	2.5¢/kWh
EAD Environmental	100% Wind Renewable Energy Certificates	100% wind	1.5¢/kWh
	Home Grown Hydro Certificates	100% small hydro (<5MW)	1.2¢/kWh
Green Mountain Energy	TRCs	100% renewable	Nonresidential only
Maine Interfaith Power & Light/BEF	Green Tags (supplied by BEF)	≥98% wind, ≤ 1% solar, ≤ 1% biomass	2.0¢/kWh
Maine Interfaith Power & Light	First Wind of Maine	100% wind	4.0¢/kwh
Maine Power Options	MPO MaineMade Certificates	50% hydro, 50% biomass	Nonresidential only
Mass Energy/ People's Power and Light	New England Wind	100% wind	5.0¢/kWh
Mainstay Energy	Fossil Free 100% Renewable	100% renewable	2.0¢/kWh
	Fossil Free 100% Wind	100% wind	2.5¢/kWh
	Fossil Free 100% Solar	100%solar	20¢/kWh
NativeEnergy	WindBuilders	100% wind	1.0¢/kWh $10/ton of CO2
	CoolHome	Biogas and wind	1.0¢/kWh $10/ton of CO2
	WindBuilders Business Partners	100% wind	Nonresidential only
NUON Renewables Ventures	PVUSA Solar TRCs	100% solar	nonresidential
Pacific Renewables, Inc	Green Tags	100% biomass	~3¢/kWh
PG&E National Energy Group	PureWind Certificates	100% wind	4.0¢/kWh
Pepco Energy Services	PES Green TRC	100% renewables	Nonresidential only
PPM Energy	Green Tags from Wind Energy	100% wind	Nonresidential only
Renewable Choice Energy	American Wind	100% wind	2.0-4.0¢/kWh
Sterling Planet	Green America	45% wind, 50% biomass, 5% solar	1.6¢/kWh
Sun Power Electric	ReGen	99% landfill gas, 1% solar	3.6¢/kWh
Waverly Light & Power	Iowa Energy Tags	100% wind	2.0¢/kWh
WindCurrent	Chesapeake Windcurrent	100% wind	2.5¢/kWh - 3.0¢/kWh
Viking Wind	Green Energy Tags	100% wind	Nonresidential only
Vision Quest	Green Energy	100% wind	Nonresidential only

Source: Holt & Bird 2005

Sweden also has a voluntary market based on the green label system, "*Bra miljöval*", created by the environmental non-government organization (NGO) Swedish Society for Nature Conservation (SSNC).

Figure 29: Green Certificate

SPECIMEN

Certificat d'électricité verte

Green-Access certifie que

la 10e session du groupe de travail I du GIEC du 29 janvier au 1er février 2007,
pour la conférence et l'hébergement des participants

a consommé 224 MWh d'électricité renouvelable,
produite par la centrale hydroélectrique de Poses (Eure).

Ces MWh, injectés dans le réseau et consommés en 2007,
ont été certifiés d'origine renouvelable par Observ'ER
sous les N° 30277000421060050506000[XXXXXXX](1)
inscrit dans la base de données RECS.

GREEN-ACCESS
Promoteur d'Électricité Verte

Observ'ER

(1) Les numéros exacts seront attribués après la conférence.

Miquel Muñoz, January 2007

Figure 29 shows an actual green electricity certificate. In this case it was used to guarantee that electricity consumption at the Intergovernmental Panel on Climate Change (IPCC) meeting held in Paris on January - February 2007 was provided by renewable electricity. The actual power from the certificate comes from the Hydroelectric power plant of Poses, in the Seine river, about a 100km from Paris. Nothng in the certificate guarantees that the scheme does not subsidize an already existing and profitable facility.

Voluntary markets are based on choice by consumers. As noted, the drivers for such a choice can be several, and for business it usually involves image issues or compliance with some sort of standard. On the other hand, consumer choice for green electricity comes in most cases from ethical moral or religious grounds. It must be noted, however, that consumers have long been accustomed to receive electricity from a monopolistic utility, with no room or need for making choices (and no responsibility over the energy sources). Given the opportunity (and obligation) to choose, many consumers find consumer choice overwhelming (Fuchs *et al* 2002).

In some occasions markets will be described as "voluntary", but other factors are driving the demand. Such was the case in the Netherlands in 2001, when consumers had a tax incentive of 6c€/kWh (Menanteau *et al* 2003).

5 – Other policies

This section describes other policies to promote renewable electricity which are not market mechanisms in the sense that they affect demand and supply of renewable electricity, but have financial implications for renewable electricity producers.

5.1 – Tax Credits

Tax credits are a generic term to designate schemes under which renewable electricity producers get financial support in the form of tax relief.

Tax incentives can be investment credits or production tax credits (PTC). Investment credits directly reduce the cost of investment. A developer can deduct part of his or her investment on the renewable energy project from his/her tax payments. Investment credits were used in California during the 80's, and are credited for giving a big push to the wind power industry in its early stages (Sawin 2001). However, if not linked to proper standards and performance requirements, investment credits can be used as tax loopholes and lead to installation of substandard equipment. Some of the wind farms installed in California that received tax incentives never produced a kWh of renewable electricity (Sawin 2001).

Production Tax Credits (PTC) grant tax deductions proportional to the amount of renewable electricity actually produced. In general, production tax credits are preferable to investment credits, because they promote the ultimate goal of the policy: production of renewable electricity. While investment credits may be more attractive to industry, they do not necessarily promote the social optimal levels of investment (Sawin & Flavin, 2004).

Tax incentives are regressive, since they tend to benefit people and industries with higher incomes and revenues, who can deduct more out of their taxes (Sawin & Flavin 2004). In addition, tax credits tend to concentrate investment at the end of fiscal year, creating "pulses" in demand for equipment. Irregular patterns of investment are generally less beneficial for the components industry than steady investment.

Tax measures can be combined with accelerated depreciation provisions. Accelerated depreciation allows to amortize the costs of equipment more quickly, hence reducing tax payments in the earlier years.

5.2 – Clean Energy Funds

Clean energy funds are funds established to promote the deployment of clean energies. These funds are generally funded through a levy on electricity, and can vary in range and scope. Most existing funds promote energy efficiency and renewables. The specifics of the funding mechanism and its objectives change from fund to fund. Clean energy funds are popular in the United States.

5.3 – Direct Subsidies

Subsidies are financial handouts that directly contribute to the renewable energy project. Two types of direct subsidies are direct payments and rebates. Direct payments cover part of the installation costs. There are a variety of direct payments plans. They range from a small percentage to the totality of installation costs, and can be given to individuals, business, communities, etc. Direct payments can be part of national programs, but very often come from regional or local policies. Due to the vast number, scope, type, and mixing of regional and local subsidies to all sorts of things, including renewable electricity, it is difficult to calculate the costs, efficiency or effectiveness of such subsidies. Direct payments may stem from a specific renewable energy policy, like programs in the Navarra and Castilla-la-Mancha regions of Spain, or may be part of social or electrification policies, like the program *"Luz Para Todos"* ("light for all") in Brazil (Decreto 4873).

Rebates are similar to direct payments but the developer gets a payment after he or she has made the investment.

Unlike tax-credits, under rebates or direct payments all income-level investors benefit the same. Rebates and direct payments, if available on a continuous basis, promote steady investment over time. Thus, benefit for the industry is greater than with tax benefits and the “end-of-fiscal-year” effect. For those reasons some analysts (Sawin & Flavin 2004) argue that payments and rebates are generally preferable to tax credits.

Other forms of subsidy are low interest loans and loan guarantees to reduce the cost of initial capital. This is of particular importance for renewable technologies, which need a significant upfront investment. In most cases renewable technologies are considered “risky” investments by the financial markets, resulting in higher capital costs. With loans and loan guarantees, the subsidy comes in the form of the state assuming part of the risk associated to renewable electricity. In most countries, the government has to set aside some money in a fund when offering loans and loan guarantees, so these measures imply an economic cost.

In some contexts and some actors consider all support provided by support policies as a subsidy. Under this interpretation, subsidies are classified as on-budget and off-budget. On-budget subsidies appear in national accounts as government expenditures. Off-budget subsidies include tax exemptions, credits, regulatory support mechanism, and other measures.

It is very difficult to quantify the amount of on-budget subsidies, and even more complicated to account for off-budget support, since there is no comprehensive official record of historical and current energy subsidies. Nonetheless, some attempts have been made to obtain figures. And it is estimated that in 2001, the EU spent € 0.6 billion in on-budget measures and € 4.7 billion in off-budget subsidies for renewable energy (EU 2004, REN21 2005)

5.4 – Net metering

Net metering is a popular measure for owners of small renewable electricity installations, mainly grid-connected photovoltaics. In essence, net metering is a feed-in law scheme where renewable electricity is priced at the same price as retail electricity.

Under net metering, the renewable electricity generator is a consumer and producer at the same time. The electricity meter runs in both directions, and electricity produced is subtracted from electricity consumed. At the end of the billing period, the consumer pays the utility for the difference between consumed and produced electricity. If the consumer generated more than he or she consumed, then depending on the scheme, either the utility compensates for the excess electricity at retail price, or just keeps the excess production for free.

Figure 30: Net Metering

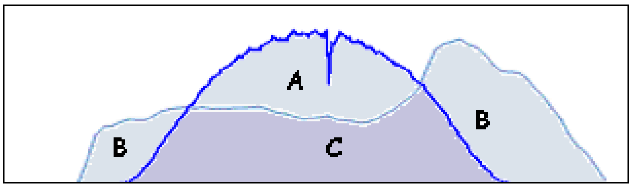


Figure 30 shows an example of net metering, superimposing a demand curve from the U.K. (in light blue), with a PV production pattern (in dark blue). In this case, the domestic consumer has steady electric consumption during the day and increased consumption in the evening, while photovoltaic generation, peaks in the midday hours. In the morning and evening, consumption is higher than production, and the grid is supplying electricity (area B). During the day hours, consumption (area C) is supplied by the photovoltaic installation and there is a surplus (area A) which is fed into the grid. If B>A, then the domestic consumer is a net consumer from the grid and pays the difference. If A>B, then the home is a net generator, and the meter runs backwards.

For practical purposes, net metering is the equivalent of using the grid as a storage facility for renewable electricity produced. In the case of photovoltaics, both the grid and the domestic consumer benefit.

The consumer benefits in the sense that he or she can store the generated electricity for free, without need to invest on costly battery systems.

The utility benefits because it keeps the margins between peak-demand (i.e. expensive) electricity supplied by the photovoltaic system and lower-demand (i.e. less expensive) electricity supplied to the consumer.

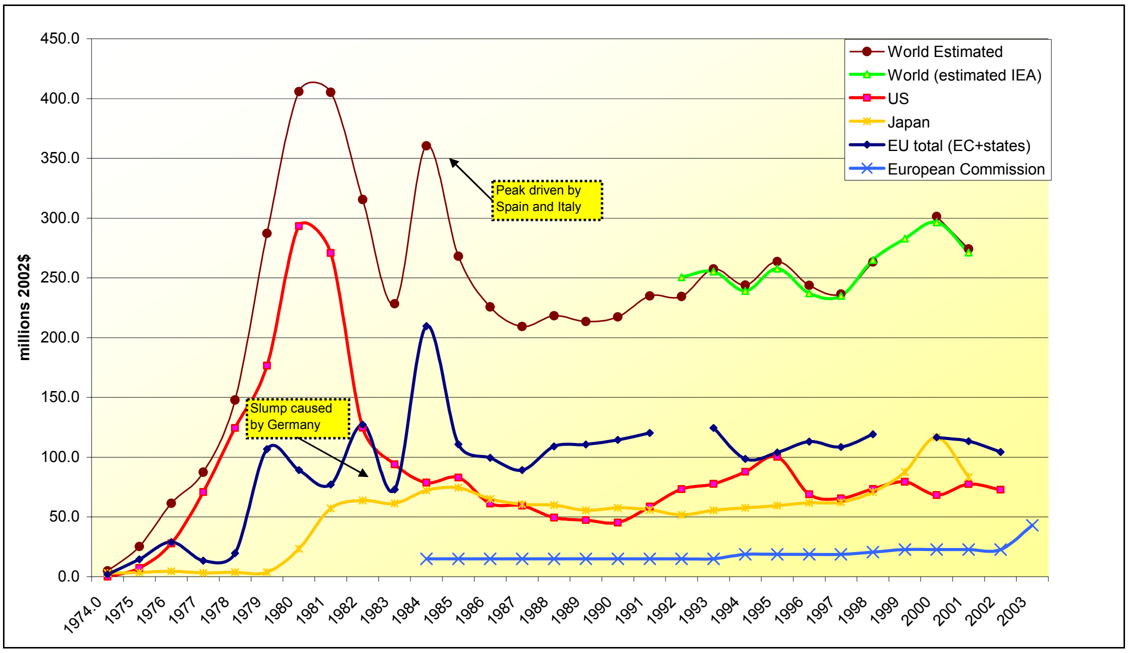
5.5 – Public R&D

Public investment in research and development (R&D) is arguably one of the main contributors to the development of renewable energy technologies.

Public investment in energy R&D was greatly boosted in developed countries as a result of the first and second oil crisis, in the 1970´s. Public R&D investment in the OECD reached its peak at the beginning of the 1980’s. It is a well known fact, that, with the collapse of oil prices in 1984 and a subsequent decade of relatively low oil prices, investment in energy R&D declined.

The general trend in energy R&D investment also affected renewables. Next the example of PV is used to illustrate public R&D in renewables. Figure 31 reflects estimations of OECD total investment in photovoltaic R&D.

Figure 31: OECD public R&D on PV



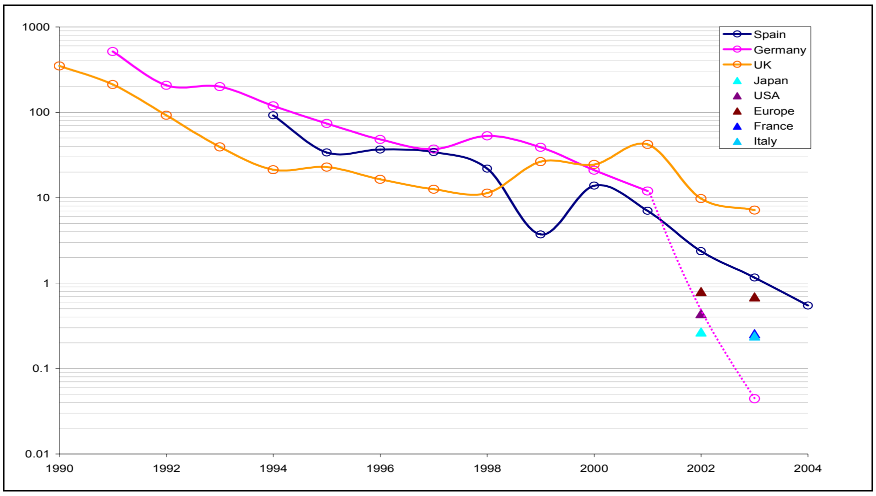
Data sources: IEA/OECD, European Commission

Figure 31 shows the evolution of public R&D in photovoltaics for different countries and two world estimates. One world estimate, provided by the IEA, ranges from 1992 to 2001 (green line). The other estimate (brown line) is obtained by adding up the R&D expenditures of USA, Japan, EU countries and EC. The match between the two estimates is remarkable, since the original data is extracted from different databases. The discontinuities in the lines are years where data is not available.

In addition to the general trend in diminishing R&D investment in the energy sector, there seems to be a shift in support, from R&D to market-based deployment support. This trend is better reflected Figure 32.

Figure 32 illustrates the shift in relative public incentives forrenewables from public investment in R&D to market incentives. This shift is quite dramatic (note the logarithmic scale) and can be explained in part by the reduction in general RD&D in energy, and in part by the massive increase of market support for renewables in Germany, Spain and Japan (for PV).

Figure 32: Market support vs. R&D for PV



data sources: Mitchell & Connor 2004, Comisión Nacional de la Energía, IEA, Schaeffer *et al.* 2004, PV-Trac, PVPS

Figure 32: The vertical axis represents R&D/Deployment support, and is expressed in a logarithmic scale. R&D is measured as public expenditure and deployment support is measured as the market support mechanisms. In the case of the longer series, market support for Germany is the different feed-in laws, in Spain for the “Regimen Special” and in the U.K. the NFFO and after 2003 the ROC. Single points are given for countries where data is only available for a particular year, mostly 2002 and 2003.

6 – Enabling measures

This chapter describes a series of measures essential, although not necessarily sufficient, for the success of renewable electricity promotion strategies. These measures generally do not have direct financial implications.

6.1 – Grid access

Guaranteeing grid access is an essential step for any renewable electricity policy to be effective. In order to access electricity markets, renewable electricity must physically enter the grid. Renewables often face discriminatory access from transmission companies based on their technical features (intermittency, non-dispatchability) or simply because they are latecomers and do not have historical rights to transmission lines (Sawin 2004). Renewable energy producers are frequently forced to assume the costs of not only the necessary technical adaptations, but also of grid extension, upgrades, or reinforcement investments. Some countries like France and Germany have laws that distinguish between connection costs and cost related to grid extension and reinforcement, allocating the first to renewable electricity producers and the later to grid owners or operators. In the case of Belgium, independent renewable power producers bear disproportionate costs for grid connection (WWF 2003).

It is notable that transmission lines, access to grid and sharing of grid related costs is one of the most relevant problems faced by liberalized electric systems. Under a deregulated electricity system neither producers nor consumers have incentives to invest in grid maintenance, or grid upgrading and expansion. As a result electric grids have become the bottleneck of national electric systems. Congestion and grid obsolescence are increasingly common problems in deregulated systems.

Feed-in laws, by definition, have a feed-in provision that guarantees access to the grid and purchase of all electricity generated. This is one of the key elements for success of feed-in laws.

Another access-related issue is the degree of the deviations allowed for intermittent renewable sources, and the length of the time gap between the bidding process and actual delivery in the electricity market. Deviations are the difference between programmed electricity deliveries and actual delivery. Different electric systems deal differently with deviations, but normally there is a secondary market, the balance market, to cover deviations, and generators who do not meet (or exceed) their programmed supply above a certain threshold are penalized or required to compensate the difference. How deviations are treated by the TSO particularly affects intermittent technologies such as wind power and photovoltaics.

Clear guidelines on deviations an biding gaps are needed to ensure both grid efficiency and that regulations designed for other technologies do not become barriers to renewable electricity deployment.

6.2 – Definitions and Standards

Definitions and standards are essential for the well-functioning of markets, to avoid fraud and the use of substandard technology, and to guarantee safety and environmental protection. Standards for renewable electricity include technology standards, project sitting standards, grid connection standards and building codes (Sawin & Flavin 2004).

For example, currently in the European Union different Member States allow different energy sources and renewable technologies to qualify or not for their renewable electricity support schemes. Directive 2001/77/EC provides a definition of renewable energy sources (wind, solar, geothermal, wave, tidal, hydropower, biomass, landfill gas, sewage treatment plant gas and biogases), however, it does not require Member States to adopt those definitions, nor does it indicate which technologies require support. This is relevant, for instance, in the case of hydropower. Generally large hydropower is not supported and small hydropower is. The definition of what constitutes large or small hydropower changes from one Member State to another. Other areas that need clear definitions are (1) waste-related processes; (2) combinations of renewable and fossil fuels (co-combustion) and/or co-generation; and (3) small domestic installations.

National policies for the promotion of renewable energies must clearly define which technologies are allowed to benefit from its provisions. Criteria to define the "greenness" of electricity should be clear, transparent, and objective. In some circumstances it makes sense to qualify the technologies as renewable energy sources because of social or environmental considerations.

Definitions also need to be long-lasted. For example, in the Netherlands, definition of technologies that qualified for its support schemes changed over the years. In 1997 waste co-combustion was excluded. In 1998 hydropower over 15MW was excluded. In 2002, hydropower was excluded altogether. In 2003, with the new feed-in tariff, landfill gas and biogas were excluded, but hydropower (of national origin) was re-included. However, this inclusion is symbolic, since the Netherlands, being flat, has no hydropower potential.

Standards are needed to guarantee safety and efficiency, to meet environmental and other criteria, and to avoid deployment of sub-optimal equipment. In addition, agreement on standards promotes industrial development and helps with the creation of markets for renewable electricity technology and components.

From a longer-term perspective, the setting of international standards and definitions can have significant impacts on future rulings regarding WTO-compatibility of renewable electricity promotion measures (Howse 2005). This applies to the physical trade of electricity, or, more plausibly, the international trade of renewable electricity technology, components, and related financial instruments (RECs, carbon credits, etc). In this respect, the European Union, with leading companies in most renewable technologies, is in a privileged position to shape international definitions and standards.

As discussed, grid access can be a significant problem for renewable electricity producers. Grid operators and utilities hostile to renewables often employ abusive technical or safety requirements in order to prevent renewable electricity from being connected to the grid. For example, in the late 1990's Spain and Germany had equivalent feed-in-law premiums for photovoltaics. However, while the German photovoltaic market was booming under the 100.000 Roof Program, the Spanish sector remained stalled under the RD2818/1998 law. The reason was that Spanish law-makers did not include connection codes in the law, and utilities prevented individuals from being connected for "technical reasons." Concise connection codes are necessary to avoid situations like the one described from happening.

Standards are not necessarily set by governments or official institutions. In many cases standards are set by private, semi-private, supra-national or independent entities, like the EMA or ISO, or industry groups, which act autonomously of government agencies.

Building codes can also play a significant role in the development of some renewable technologies, particularly solar. Requirement for architectonic integration and pre-installation of solar equipment in new-construction buildings can dramatically reduce the costs of renewable electricity.

6.3 – Administrative Streamlining

The administrative burden on renewable energy projects can be quite high. The permitting procedures found within state of Massachusetts can be seen as an excellent example of the administrative burden that is also found within many other states and countries. Table 17 summarizes the permitting steps that a renewable electricity facility might face in Massachusetts.

For small projects transaction costs associated with permitting and planning are disproportionately high (Sonntag-O'Brien & Usher 2004). Permission procedures and planning should be streamlined. A "one-stop-shop" permitting procedure should be established, especially for small projects, to help reduce total costs for small renewable electricity producers, and bolster the number of installations.

In general, the fewer the permits necessary the better from the promotion of renewables perspective. Also, the simpler and more automated the permitting process, the smaller the uncertainty associated to the licensing process and the lower the cost of financing.

Table 17: Permit Requirement for Renewable Electricity projects in Massachusetts

	SOLAR PV	WIND	HYDRO	WAVES	FUEL CELLS	BIO-MASS
Local Level						
Permits and Approvals	X	X	X	X	X	/
Solar Access Laws	X	/	O	O	O	O
State Level						
Energy Facilities Sitting Board	O	/	O	O	O	O
Environmental Policy Act	O	/	/	/	O	/
Department of Environmental Protection	O	/	/	/	O	X
Coastal Zone Management Office	O	X	O	X	O	O
Natural Heritage Program	O	X	X	X	O	O
Department of Public Safety	O	O	O	O	/	/
Executive Office of Transportation and Construction	O	O	O	O	/	/
Historical Commission	/	O	/	O	O	O
Federal Level						
Environmental Policy Act	O	/	/	/	O	O
Army Corps of Engineers	O	/	/	/	O	O
Federal Aviation Administration	O	X	O	O	O	O
Emergency Management Administration (FEMA)	O	O	X	X	O	O
Interconnection and Sales						
Distribution Company	X	X	X	X	X	/
ISO New England	O	/	/	O	O	O
Net Metering	X	X	X	X	X	/
Distribution Company	X	X	X	X	X	/
Bilateral Power Purchase Agreement	O	/	/	/	O	O
Wholesale to ISO-NE Spot Market	O	/	/	/	O	O

X very likely **/** possible **O** unlikely

Adapted from: *(DOER 2001)*

6.4 – Target setting

Support policies for the deployment of renewable electricity have are commonly linked to targets. For example, the EU has the goal of generating 21 % of renewable electricity by 2010 (Directive 2001/77/EC); the German 1991 1000 Solar Roofs Programme and the 1994 Japan 70.000 Solar Roofs Programme had the objectives of deploying 1.000 and 70.000 solar roofs respectively, and the California Solar Initiative has the goal of deploying 3000MW of solar power by 2017.

Policy objectives and their scope should be clear and well-defined. Clear objectives allow for assessment, policy-learning and improvement. Clear goals also indicate to industry leaders what to expect from policies and what is expected from them, helping to create the necessary confidence for long-term investments in renewable energy technologies.

Targets should be long term (without precluding additional short-term targets) to maintain confidence. Announcing new targets and goals provides temporary boost to renewables industry, "the announcement effect" (Isoard & Soria 2001). However long-term stability and policy-predictability (Madlener and Stagl 2005) is more important for the deployment of renewables.

Targets can be decided based on numerous criteria, other targets, and any combination between them, including but not limited to national potentials, tendency curves, energy needs, carbon emissions, energy intensity, job creation, costs, and a long etc. Targets should clearly distinguish between installed capacity and generated electricity.

Chapter 18.3 makes specific policy proposals regarding linkages between targets and policy mechanisms.

At least 42 countries, including all European Union countries have targets for renewable electricity. These targets are illustrated in Table 18, below. It can be observed that the targets are a percentage of electricity (e.g. Malta), a percentage of primary energy including electricity (e.g. Thailand), an installed capacity of renewable electricity (e.g. the Dominican Republic), certain total output of renewable electricity (e.g. Australia), a certain output of renewable energy, including electricity and heat (e.g. Switzerland), or a combination of relative and fixed targets (e.g. Korea).

Table 18: Renewable electricity targets in different countries

Country	Target	Year	Notes
Australia	9.5 TWh/yr .	2010	
Austria	78.1%	2010	See Table 21
Belgium	6.0%	2010	See Table 21
Brazil	3.3 GW added	2006.	wind, biomass, small hydro
Canada	3.5-15%, other		province targets
China	10% power capacity	2010;	(~60 GW)
Cyprus	6%	2010	See Table 21
Czech Republic	8%	2010	See Table 21
Denmark	29.0%	2010	See Table 21
Dominican Republic	500 MW wind power	2015.	
Egypt	3% 14%	2010 2020	
Estonia	5.1%	2010	See Table 21
Finland	31.5%	2010	See Table 21
France	21.0%	2010	See Table 21
Germany	12.5%	2010	See Table 21
Greece	20.1%	2010	See Table 21
Hungary	3.6%	2010	See Table 21
India	10% added power capacity	2003–2012.	(~10 GW)
Ireland	13.2%	2010	See Table 21
Israel	2% 5%	2007 2016.	
Italy	25.0%	2010	See Table 21
Japan	1.35% of electricity ()	2010	excluding geothermal, large hydro
Korea	7% 1.3 GW	2010	Including large hydro grid-connected solar PV
Latvia	49.3%	2010	See Table 21
Lithuania	7%	2010	See Table 21
Luxembourg	5.7%	2010	See Table 21
Malaysia	5%	2005	
Malta	5%	2010	See Table 21
Netherlands	9%	2010	See Table 21
Norway	7 TWh	2010	heat and wind
Philippines	4.7 GW	2013	
Poland	7.5%	2010	See Table 21
Portugal	39%	2010	See Table 21
Slovakia	31%	2010	See Table 21
Slovenia	33.6%	2010	See Table 21
South Africa	10 TWh	2013	final energy
Spain	29.4%	2010	See Table 21
Switzerland	3.5 TWh	2010	electricity and heat
Sweden	60%	2010	See Table 21
Thailand	8%	2011	primary energy
United Kingdom	10%	2010	See Table 21
United States	See Table 45	2000-2025	

Sources: REN21 2005, Directive 2001/77/EC, Annex II to the Accession treaty

Targets are also used as upper limits for support schemes. Many support schemes are tied to the final goal, and contain sunset clauses that make the support scheme expire once the goal is reached. In that regard, targets are often used to limit the economic cost of a policy, rather than because the intention is to achieve a goal.

As mentioned in the introduction, what the targets should be is a discussion beyond the limits of this dissertation. The optimal level of renewables is a political decision, that can be informed by science and stakeholders, but in the end, will depend on the decision-making process.

6.5 – Awareness and education

Lack of awareness on renewable technologies can be a barrier to greater market penetration. The best policy, perhaps, to combat unawareness is education. Education can be targeted toward many different actors and provided at many levels: for the general public, for decision-makers, for policy-makers, for industry leaders, for investors and financial players, and for shareholders.

Education should be focused on different aspects of renewable energy technologies, depending on the target audience. For example, in the financial sector, a good information program will bring more awareness about the technical potentials and opportunities of renewables, thus increasing confidence. Increased confidence among the financial community often results in lower interest rates and cheaper capital, which is so necessary for the renewables sector.

Consumer education generally increases support for renewable energies and acceptance of additional electricity costs. It may also facilitate voluntary systems, explained in Chapter 4, where consumers generate a demand for certified renewable electricity.

Shareholder education campaigns carried out by non-profit organizations can lead to unexpected results. For example, in 2000 Greenpeace leaded a shareholder action during a campaign for a large scale solar PV manufacturing plant, which involved buying 500,000 shares of Royal Dutch Shell (Greenpeace 2000). This action was probably one of the first large shareholder actions. Although it did not achieve its stated goal of gathering sufficient votes to force Shell to consider the PV manufacturing plant, it was deemed a success by analysts, and opened the door to many shareholder actions to follow on different environmental areas, most notably climate change. For example, in 2004, shareholder proposals forced US utilities *American Electric Power* and *Cinergy* to report publicly their response to growing pressures to reduce greenhouse gas and other emissions.

Sharing information and disseminating success stories is very important to increase confidence in the sector and to avoid *reinventing the wheel* each time (Sawin & Flavin 2004). Environmental NGOs play very important roles in the dissemination of information. NGOs have a large potential to promote renewable electricity mechanisms because they enjoy greater credibility than businesses among the public, and can reach large audiences through their membership.

Sharing information can also be done at the policy maker level. For example, the governments of Germany, Slovenia and Spain have set up the feed-in cooperation (www.feed-in-cooperation.org) in order to promote the exchange of experiences so as to improve the feed-in system design in each country.

7 – Financing strategies

Renewable electricity projects are generally capital intensive, have lower operating costs than conventional energy and medium payback periods (Nielsen & Jeppesen 2003). Therefore, facilitating access to capital for renewable electricity developers should be an essential part of policies aimed at promoting the generation of renewable electricity. This chapter explores different financing incentives, including the role of long-term contracts, risk management strategies, REC futures and community ownership.

7.1 – Long-term contracts and REC futures

Long-term contracts are an essential component for project financing. Long-term contracts guarantee an income stream over an extended period of time, access to credit and increase the possibility of investment by investor funds. Feed-in-laws are in many regards equivalent to a long-term contract, because they guarantee a fixed price or premium over long periods of time. However, most quota systems lack such a guarantee. This is one of the reasons why access to capital is easier under fixed price schemes than under quota policies.

There is an inherent problem with quotas, REC markets and long-term contracts. Renewable electricity is still a new player in the electricity markets. Although deployment rates have been impressive over the last decade, there is still much policy-learning happening, and uncertainty about the rates of renewable energy deployment over the next decade. Hence, future prices for REC are a large unknown and few potential consumers are willing to take the risk for long-term REC contracts. This fact is compounded by uncertainty regarding the continuation of most policies for the promotion of renewable electricity.

Aware of the problem of lack of long-term contracts under quota systems, some policy and decision makers are considering innovative approaches. For instance, the Massachusetts Renewable Energy Trust is considering acting as a broker and issuing long-term contracts to producers. The Massachusetts Renewable Energy Trust would sign long-term contracts with producers and acquire the RECs. Then, it would sell RECs to the market at market price. To determine the price for the long-term prices the Massachusetts Renewable Energy Trust would use projections of future REC demand and supply. The trust would assume the risk. Any losses would be covered by the Massachusetts Renewable Energy Trust, which would be acceptable because the trust's mission is to promote renewable energies (*www.mtpc.org*).

Nonetheless, in some cases long-term contracts are included in the quota system design, as is the case in Texas. The availability of long-term contracts, together with an excellent wind resource, burgeoning electricity demand, and the mentality of "everything is big in Texas" are generally credited for the success of Texas in deploying renewables. Texas is one of the few successful quota systems.

In countries or regions with quota systems, selling of futures or forward contracts on RECs is a possibility to finance projects. Some cases of forward REC selling have been reported (Green-e 2005, Holt and Bird 2005), however these are done on a project-by-project basis and the practice is not common or extended. There are no common guidelines for forward sales of RECs, although some have been proposed (e.g. Green-e 2005) and more are likely to follow, particularly in the US market.

There are a few drawbacks to REC futures that need to be addressed if those are to be used as a financing mechanism, including: non-delivery risk; discounting; policy risk; and variability in renewable electricity supply.

Forward contracts have an inherent risk of non-delivery, that is, the buyer pays today for RECs to be delivered in the future by a, in most cases, un-existing yet power plant. The risk of the plant never coming into operation or not producing enough RECs to fulfill its obligations needs to be covered. This could be done, for instance, with a guarantee from a different renewable electricity plant or buying RECs in the market (Holt and Bird 2005).

A question in setting the price of RECs is how to address discounting. If the price is not discounted, then buyers would be paying an extra, while if they are discounted, generators will receive less revenue than they otherwise would.

The concerns about continuity of quota policies can also undermine forward sales of RECs. In particular, there is a strong feeling that if REC prices get too high or there is a widespread scarcity of them that damages industry, quota requirements would not be enforced or relaxed.

A different concern about REC futures arises from the seasonal cycles of renewable energies, and the capacity to fulfill obligations. Besides the daily oscillations in wind power, yearly oscillations are also observed, with some years windier than others. The same is true for rain, which affects mini-hydro and biomass output. Therefore, in a scarce year, generators might not be able to generate enough RECs to fulfill their futures contracts. Precisely in those years REC prices would spike, making buyers more apprehensive about having the contracts fulfilled and prone to legal actions. Conversely, in resource plentiful years, since renewable electricity operates on baseload basis, an excess of RECs might be produced and prices collapse, which would make REC futures worthless. Lemming 2003 argues that due to the stochastic nature of REC supply, forward contracts would have a negative impact on the project financial risk.

7.2 – Risk Management

Traditional risk management tools are generally not appropriate to gauge financial risk associated with renewable electricity. As a result, renewable electricity projects are commonly penalized with excessive risk premiums. Risk associated to renewables comes from different potential problems like technology, solvency, regulatory framework, permitting and environmental impacts. Policies aimed at promoting the development and deployment of renewable electricity technologies should address these risks.

Technological risk is inherent to any new technology. Financial markets are averse to new things and risk. The main technological risks are performance and costs, both of installation and operation. Performance should be guaranteed through standards and contracts with component manufacturers to take risk away from investors. A different risk, to some extent technological, is posed by problems associated to grid access.

Bankruptcy is another risk to potential investors on renewable electricity projects. On one side, confidence in the future solvency of the renewable power plant company is necessary to guarantee future revenues and return on investment (ROI). But solvency of buyers is also a requisite. For example, in the case of quota and certificate systems, solvency of utilities who are mandated to redeem RECs is essential. In the United Kingdom it is estimated that the defaults of two utilities (TXU Europe and Maverick) in year 2003 caused the price of UK's renewable obligation certificates (ROC) to drop by approximately 2-3 £/MWh (Platts 2004).

Environmental risks are another category of risk that cannot be neglected. Although beneficial on the large scale, renewable electricity projects can have local environmental impacts. The early wind turbines had problems with bird collisions and noise. These problems have largely been solved thanks to the lower rotation speed of newer, larger wind turbines, plus more careful sitting. In most places, hiring an ornithologist is a requirement for the wind farm planning phase. However, new problems can also appear and threaten operation and revenue. For instance, in the case of wind power, a new wildlife impact seems to be bat collision with wind turbines, particularly some endangered species in North America. Industry, government and conservationists have already started working together to study the impacts and find a solution to the bat problem (AWEA News release 03/04/2004).

Risk also comes from unforeseen interactions with other land or space uses. For example, the Town of Hull, in Massachusetts, installed a wind turbine in 2001 (see Figure 33). Given the satisfactory results, the town of Hull was considered installing a second wind turbine. However, concerns about radar interference with the Logan International Airport in Boston almost paralyzed the project. Eventually, in 2006, Hull got its second wind turbine (www.hullwind.org) A similar case happens in the United Kingdom, where the development of several wind power projects is threatened by military demands of a large exclusion zone in the Dumfriesshire area (Platts 2004). The Ministry of Defence is concerned that infrasound impact of wind farms will interfere with one of its underground nuclear monitoring test centers, used to seismically detect nuclear explosions around the world. Fueled by reality or not, unexpected problems and opposition always increase costs and uncertainty.

Figure 33: Wind turbine in Hull, Massachusetts

Source: www.hullwind.org

Risk can also play in favor of renewable's development. For example, there are studies comparing current costs of renewable electricity under long-term contacts, mainly wind power, and future contracts for natural gas and natural gas price projections (Bolinger *et al* 2004), and studies addressing price risk from the portfolio point of view which show the advantages of including renewable electricity in the generating mix (Awerbuch 2003).

It has also been suggested to use renewable electricity from wind power as a price hedge for natural gas power plants (Berry 2005).

7.3 – Community Ownership

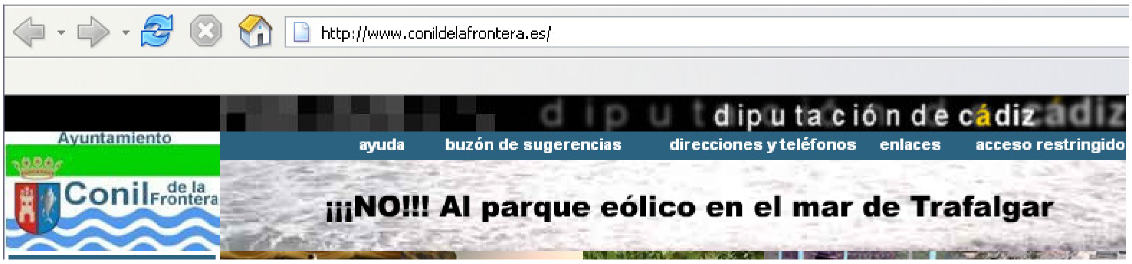
Community ownership is a possibility for developing and funding projects. Communities may include agricultural co-operatives, small towns or city public utilities. Community ownership offers several advantages over the common venture capital approach. Community projects generally mean empowerment and participation in the decision-making process. As a result, people have stakes and feel involved in the project. Awareness is raised. Permitting and other administrative steps are usually accelerated because all parts are involved. Community involvement also makes policy more resistant by involving everyone.

An example of community ownership is the one mentioned above of the town of Hull, Massachusetts (Figure 33).

Nonetheless, the trend of deployment on renewable electricity projects tends to be towards larger and more capital-intensive projects, only available to large companies. This trend is particularly acute in wind power farms, but also in large PV projects, such as large PV roofs or façades in corporate or public buildings.

Unfortunately, as wind farms become larger and local involvement decreases, more and more cases of the "not in my back yard" (NIMBY) effect are observed. Local public opposition and or concern about wind power seems to be mounting in most countries.

Figure 34: Public opposition in a town in the South of Spain



¡¡¡NO!!! Al parque eólico en el mar de Trafalgar

Figure 34 shows a case of local opposition to a marine wind park off the Southern coast of Spain, near the Gibraltar Strait. What is significant of Figure 34 is that it is a snap shot of the official web-site of the Municipality of Conil de la Frontera, in the province of Cádiz. Local opposition and NIMBY is not confined to local non-profits, lobbysts and NGOs, but can also include public institutions.

PART III – COUNTRY CASE STUDIES

Part II has described the main support policies, measures and strategies to support, deploy and finance renewable electricity. In Part III the cases of the European Union, including some selected countries (Chapter 8), and the United States (Chapter 9) are studied.

Renewable electricity policy is a booming field, with an increasingly fast pace of developments. Almost every week some policy announcement is made somewhere in the world, and the inauguration of 100MW+ wind farms and multi-megawatt solar PV installations, which made the headlines (of the specialized press) a few years ago, now are too many to track.

Therefore it is not the intention of this section to give a comprehensive recount of existing renewable electricity policies and the status of renewable electricity deployment in different countries, but rather to illustrate evolution in several key countries. For more descriptions, case studies, and comparisons of quota systems, feed-in-laws, and other support schemes, see for example ADMIRE REBUS 2003, Held et al. 2005, Lauber 2004a, Menanteau et al. 2003, Ragwitz et al. (2006, 2005), REN 21 (2005, 2006, 2007), and Sawin 2004(a,b).

8 – Europe

This chapter describes the situation regarding renewable electricity in the European Union and its Member States. First there is a review of the history and legislation concerning renewable electricity at the EU level, followed by description of renewable electricity in selected Member States. Hence, chapter 8 is organized as follows:

- European Union
- Germany
- Spain
- Denmark
- France
- Ireland
- The Netherlands
- Sweden
- United Kingdom

The selection of countries was broadly made for the following reasons: Germany and Spain because they illustrate successful feed-in systems upon which the proposals in Part V of this dissertation are based; Denmark because it is also one of the pioneers of wind power and feed-in laws and illustrates the negative effects of policy changes; France because it illustrates a system hostile to renewables; the Netherlands because it is an example of multiplicity of policies; Ireland because it is an example of tendering systems; Sweden as an example of voluntary markets and green taxes; and the United Kingdom as an example of tradable systems.

8.1 – EU - European Union

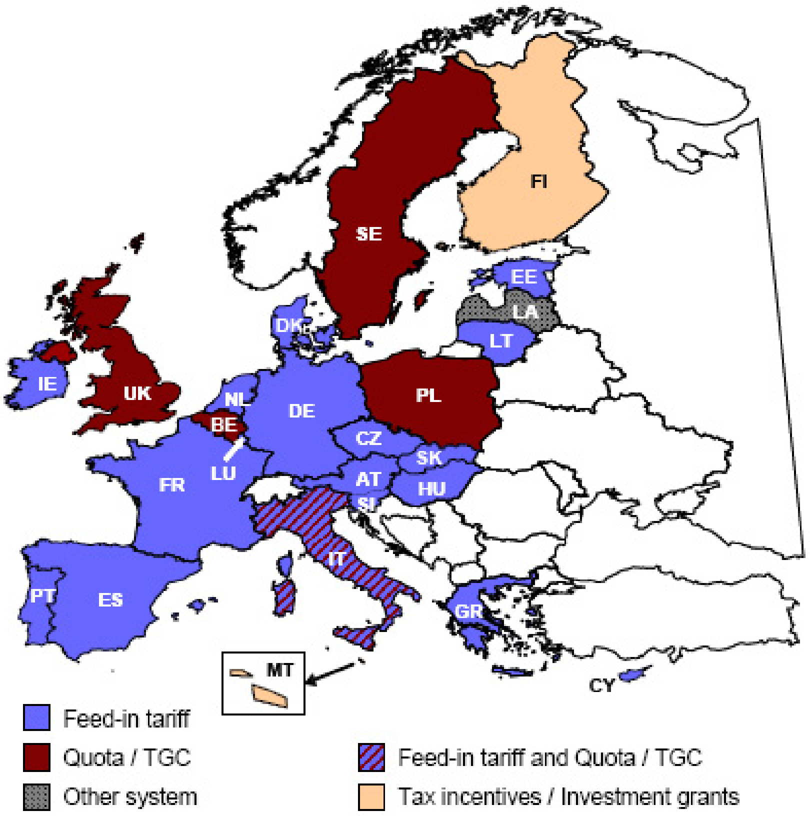
Increasing the share of renewable energy sources, and in particular the share of electricity from renewable energy sources (renewable electricity) is a stated goal of the European Union, which aims to have 21% of renewable electricity by 2010, as formulated in Directive 2001/77/EC on the promotion of electricity produced from renewable energy sources.

Table 19: European Union Key Indicators

EU-25 Key Indicators (2004)		**Pop**: 301.023 million
		Area: 4,422,773km^2
GDP: 6345.27 billion €	**Per capita**	**Per GDP**
Total **Primary Energy** Supply: 1140.88 Mtoe	3.79 toe/capita	0.18 toe/1000€
Electricity Consumption:3179.04 TWh	10560 kWh/capita	0.50 kWh/€
Energy-related **CO_2 Emissions**: 3863 Mt CO_2	8.40 tCO_2/capita	0.60 $kgCO_2$/€
		Sources: DG Tren 2006

This Directive, as amended by the Accession Treaty (Annex II, Part 12, 1802-04), sets national indicative targets on renewable electricity and obliges EU Member States to take appropriate steps toward those targets. All EU Member States have introduced policies and support schemes for the promotion of renewable electricity in compliance with Directive 2001/77/EC. Support schemes include feed-in laws, quotas, and, to a lesser extent, tendering and tax incentives. Figure 35 shows the different policies in different EU member states.

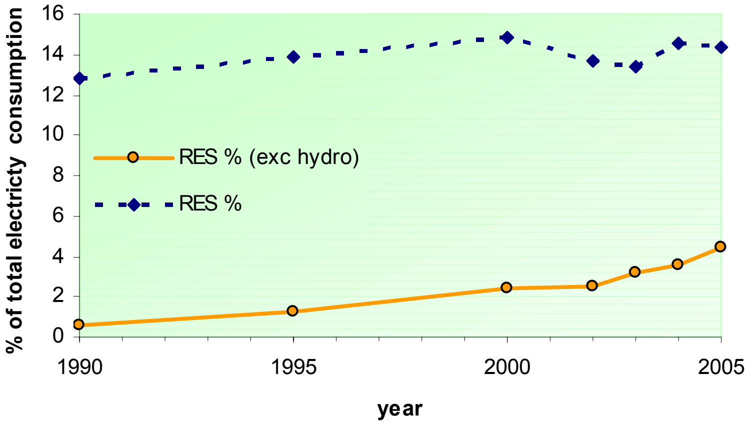
Figure 35: Renewable Electricity promotion schemes in the EU



Source: adapted from Ragwitz et al 2006

Figure 36 reflects the relative generation of renewable electricity versus the total consumption in the EU for the period 1990-2005, showing the non-hydro component. This share, being a relative quantity, takes into consideration the increase in electricity demand over time.

Figure 36: Renewable electricity share in the EU-15



Source: IEA2006b

Next I provide the context for evolution of support schemes for renewable electricity in Europe and the formulation of Directive 2001/77/EC, an outline of the legislative framework with emphasis on Directive 2001/77/EC, and an overview of the status of implementation of Directive 2001/77/EC and the different support policies uses in the EU Member States. This last point will be expanded for selected countries in the next sections.

8.1.1 – Context, and historical background to Directive 2001/77/EC

The European Union policy objectives on renewable energy were established in the white paper *Energy for the future: renewable sources of* energy (COM(97)599). The white paper states that renewable energy sources should be promoted for environmental, security, and socio-economic reasons. Environmental reasons primarily mean the EU's commitment to reduce greenhouse gas emissions[15] and emissions of other noxious

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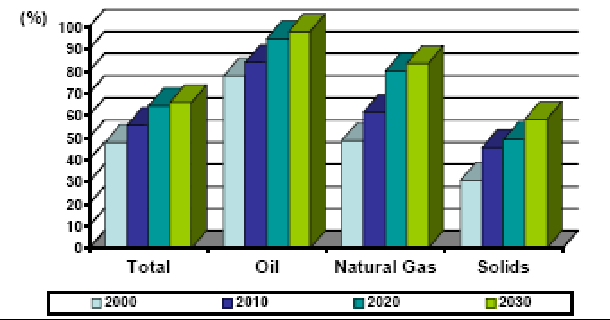
[15] At the time of the white paper the Kyoto conference of the parties to the United Nations Framework Convention on Climate Change (UNFCCC) still had to happen. Initially during the Kyoto negotiations the EU had a more ambitious target of 15% greenhouse gas emissions reductions respect to 1990 levels. During

compounds and air pollutants, such as heavy metals from coal combustion or smog and acid rain precursors. Security reasons focus on reducing the EU dependency on fossil fuel imports. Forecasts based on consumption trends estimate that in 30 years 70% of primary energy and 90% of oil consumed in the EU will be imported (COM(2002)321). Figure 37 shows current and projected dependency of the EU on fuel imports.

Figure 37: Fossil fuel imports and forecasts for the EU



	2005	2030
Natural Gas	57%	84%
Oil	82%	93%
Coal/Solids	39%	59%

Source: EU 2007a

Socio-economic reasons include employment creation, industrial policies and rural revitalization.

Creation of employment stems from the fact that renewable electricity is in general more labor intensive than conventional technology. For example, a study for the European Union (Ecotec 2002) showed that renewable energy had the potential to create over 900,000 new jobs in the EU by 2020. Table 20 illustrates estimations of direct jobs in electricity production for different technologies. Other analysts (REN21 2005) estimate that direct jobs from the renewable energy sector, including manufacturing, installation and operation and management, exceeded 1.7 million in 2004, including 900.000 from bio-fuels production. Kammen *et al* (2005) found that renewable electricity consistently generates more jobs per unit of installed capacity, unit of electricity produced or amount of investment than fossil fuel technologies.

The European Union has the world's top wind turbine manufacturers, as well as many of the main solar photovoltaic panel producers, and exports renewable electricity technology (REN21 2005). For example, it is estimated that 20.000 jobs in Denmark and 31.900 jobs in Germany, as well as €2.51billion in turnover in Germany are due to

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the Kyoto negotiations reductions were brought down for the EU "bubble" to 8% during the 2008-2012 compliance period. The EU ratified the Kyoto Protocol on May 31, 2002. The Kyoto Protocol entered into force on 16 February 2005.

exports of wind power technology (COM(2006)yyy). Therefore, promotion of renewable electricity makes sense as a national or European industrial policy.

Table 20: Direct jobs in energy production

Fossil Fuels & Nuclear		Renewable Energy	
Sector	**Jobs year/ TWh** (fuel production + power generation)	**Sector**	**Jobs year/ TWh** (fuel production + power generation)
Petroleum	260	Wood Energy	733-1,067
Offshore Oil	265	Hydro	250
Natural Gas	250	Minihydro	120
Coal	370	Wind	918*
Nuclear	75	Photovoltaics	29,580*
			*low estimate

source: (Goldemberg 2004)

Rural economies can benefit directly and indirectly from renewable electricity. Indirectly from employment, and directly from fees, local taxes and direct revenues for land owners. For example, it is estimated that wind power compensations to US farmers range from 3000$ to 5000$ per wind turbine per year (AWEA). Since most land is still available for other practices such as grazing or planting, this practice is known as “double cropping”.

Directive 2001/77/EC converted the policy objectives of the white paper into numeric targets for individual Member States, and provided some guidelines and criteria to be used regarding renewable electricity. Next section gives and overview on the objectives and main provisions of Directive 2001/77/EC.

8.1.2 – Directive 2001/77/EC Overview

Objective: The stated purpose of the Directive (Article 1) is to promote and increase the contribution of renewable energy sources to electricity production in the European Union and to create a basis for a future Community framework for renewable electricity. Community framework means harmonization, which will be addressed in the next subsection.

Definitions: In its Article 2, the Directive defines renewable energy sources as:

- Wind
- Solar
- Geothermal
- Wave
- Tidal
- Hydropower
- Biomass
- Landfill gas
- Sewage treatment plant gas
- Biogases
-

Targets: The directive 2001/77/EC sets indicative targets on renewable electricity for Member States. These targets are summarized in Table 21, which also includes the targets for accession countries after the 2004 European Union enlargement. These targets were the result of though negotiations in 2001, and again for the 2004 enlargement countries.

The Directive requests Member States to take the necessary steps to encourage consumption of renewable electricity, to establish national targets in accordance with those in Table 21, and to report periodically to the European Commission on success in meeting the national targets. The Directive further requests the Commission to assess Member State's progress and empowers the Commission to make proposals based on these assessments to the European Parliament and Council, including on mandatory targets.

Table 21: EU Renewable Electricity Consumption Indicative Targets 2010

Country	Renewable Electricity 1997 (TWh)	Renewable Electricity share (%)1997	Renewable Electricity share % 2010
Austria	39.05	70.0	78.1
Belgium	0.86	1.1	6.0
Cyprus	0.002	0.05	6
Czech Republic	2.36	3.8	8
Denmark	3.21	8.7	29.0
Estonia	0.02	0.2	5.1
Finland	19.03	24.7	31.5
France	66.00	15.0	21.0
Germany	24.91	4.5	12.5
Greece	3.94	8.6	20.1
Hungary	0.22	0.7	3.6
Ireland	0.84	3.6	13.2
Italy	46.46	16.0	25.0
Latvia	2.76	42.4	49.3
Lithuania	0.33	3.3	7
Luxembourg	0.14	2.1	5.7
Malta	0	0	5
Netherlands	3.45	3.5	9.0
Poland	2.35	1.6	7.5
Portugal	14.30	38.5	39.0
Slovakia	5.09	17.9	31
Slovenia	3.66	29.9	33.6
Spain	37.15	19.9	29.4
Sweden	72.03	49.1	60.0
United Kingdom	7.04	1.7	10.0
Community-15	338.41	13.9	22

Sources: Annex II to the Accession treaty, Directive 2001/77/EC

8.1.3 - Towards EU Harmonization?

Directive 2001/77/EC does not indicate a preferred support mechanism for renewable electricity, but its Art 4 mandates that the European Commission had to report and assess by the end of year 2005 the success of the different national support schemes. Additionally, Art 4 entitles the Commission to propose a ‘‘Community framework with regard to support schemes’’, i.e., to propose harmonization of renewable electricity support schemes. Such a proposal according to Art 4, should: contribute to the achievement of national targets; be compatible with the principles of the internal EU electricity market; consider the different sources, technologies and geographical characteristics of renewable electricity; be simple, effective and cost-efficient; and include sufficient transitional periods of at least 7 years.

When Directive 2001/77/EC was first proposed, the European Commission objective was to establish a harmonized support mechanism for renewable electricity. At the time of drafting the Directive, harmonization was mostly understood to be harmonization of a quota system with EU-wide tradable certificates (Rowlands, 2005). Quota support schemes were favored by DG Competition (Lauber, 2004b), and often seen as more cost-efficient and in line with the EU single electricity market objectives than feed-in laws (Reiche 2005). Even an industry association was set up in 2001, RECS International, to experiment with renewable electricity certificates (RECs), establish standards and serve as an embryo for a future mandated European-wide certificate-based system. However, strong opposition by Germany and Denmark, who had feed-in laws, stalled negotiations . The Commission was opposed to feed-in laws on the grounds that they were against EU competition rules. The argument was that feed-in-laws were a form of state aid conflicting with EU competition laws. In a landmark ruling, *PreussenElecktra vs. Schleswag*, critically timed during the Directive negotiations in 2001, the European Court of Justice declared the German feed-in law consistent with competition rules (European Court of Justice 2001). This ruling, together with the success of existing feed-in laws, the inexistence of successful quota systems, and the weight of Germany made it impossible for the European Commission to impose its will. A compromise solution –which amounted to not deciding anything– was reached. The resulting Directive postponed the decision on harmonization of support mechanisms to 2005, and only *if necessary*. In any case, the transition period is mandated to be 7 years (Article 4.2.d). Consequently, no harmonized EU policy could be enforced before 2012.

On December 2005, the European Commission issued its report on the support of renewable electricity, COM(2005) 627 Final. Two main conclusions can be extracted from this Communication regarding the effectiveness and cost-efficiency of quotas and feed-in laws. First feed-in laws have proven so far to be more effective than quotas in promoting deployment of renewable electricity generation capacity. This was expected because the largest increases in renewable electricity generation (mostly wind power) happened in two Member States (Germany and Spain) with active feed-in laws, while

Member States with quota systems have so far shown little progress in additional renewable electricity generation.

Second, and this was unexpected, feed-in laws have proven so far to be the most cost-efficient support scheme for renewable electricity. This is clearly illustrated for the case of wind power in Figure 64, in chapter 10, which explains in more detail effectiveness and cost-efficiency of quotas and feed in laws.

These findings effectively put an end to any short-term plan for European harmonization of quotas as renewable electricity support schemes. In its conclusions from report COM(2005) 627 Final, the European Commission does not regard a harmonized European system appropriate at this stage, focusing instead on optimization of existing systems and co-operation among member states with similar support systems (that is cooperation among countries with quotas and cooperation among countries with feed-in laws). These conclusions are supported by the results of model-based prospective analyses, which suggest that the most significant efficiency gains can be achieved simply by strengthening and improving national support schemes (Ragwitz et al., 2006).

Given the seven-year time gap, plus the recent recommendations from the European Commission, harmonization does not seem too immediate. Part V of this dissertation proposes an innovative approach towards harmonization of feed-in laws.

Notwithstanding, any harmonization, be it of feed-in laws, of quota systems or of some other hybrid system, would need to satisfy some requirements and overcome some obstacles, such as which are the admissible technologies, regional distribution (among Member States and among sub-national regions), technology distribution, definition of targets and market inefficiencies.

Which technologies should be eligible for a harmonized system? As discussed in Chapter 6 this is a controversial issue. During Directive 2003/77/EC negotiations the definition of renewable electricity was the source of heated debate (Lauber 2004b). Each Member State tried to promote its indigenous renewable energy sources. For instance, the Netherlands did not want hydro-power recognized because their only realistic renewable resources are biomass and wind power (Dinica & Arentsen 2003), and have virtually no hydro resource (Boots 2003, Reijnders 2002). The UK wanted urban waste incineration recognized as renewable because of their waste management system (Reiche 2001). Which sources are included in each country's renewable energy certificate scheme depends largely on national interests and objectives. Different actors within countries also have different opinions regarding which technologies should be accepted. For instance, UK environmentalists are likely to oppose definition of waste incineration as an acceptable green technology. Reaching an agreement on eligible technologies requires much negotiation at the national and supranational level. In the end, the political definition was stated in Article 2§a "'*renewable energy sources' shall mean renewable non-fossil energy sources (wind, solar, geothermal, wave, tidal, hydropower, biomass, landfill gas, sewage treatment plant gas and biogases)"*. However, this definition is not binding for national policies, and any harmonized system would need to explicitly state so.

8.2 – Germany

Germany in Figures.

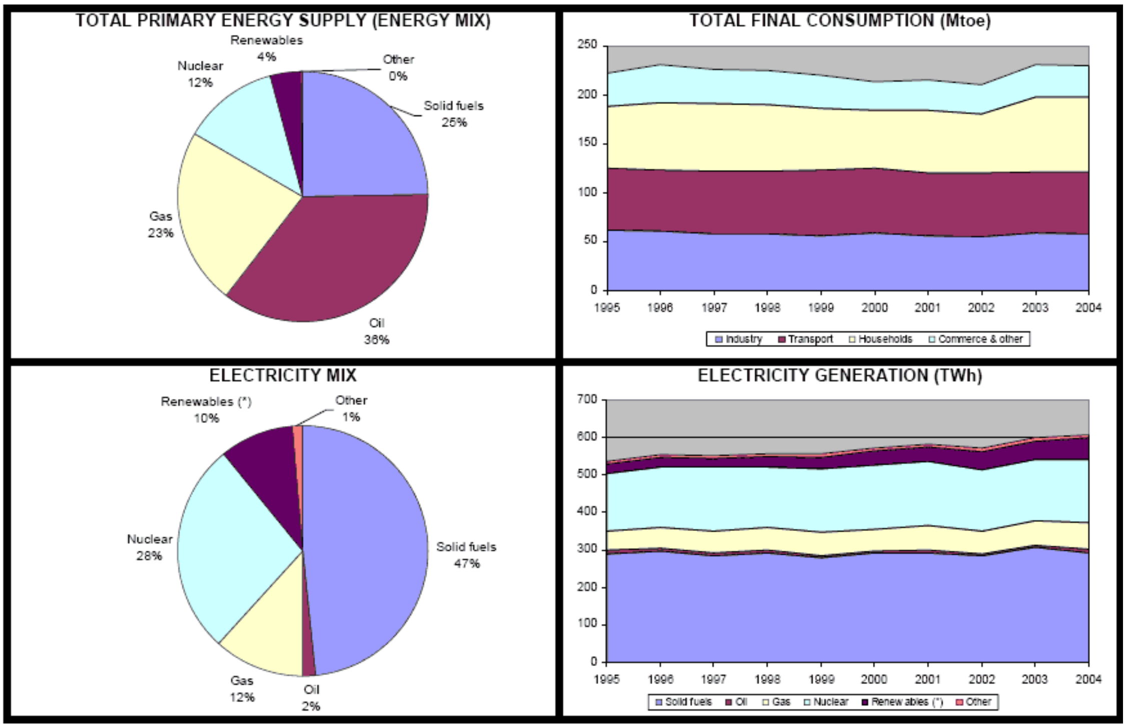
The previous and following tables and graphs outline the energy situation in Germany. Table 22 summarizes key energy indicators for Germany such as primary energy consumption, electricity consumption, and carbon dioxide emissions related to energy, in absolute terms and per capita and per unit of GDP. GDP is expressed both, in absolute terms (translated to year 2000 US$) and in power purchase parity corrected (PPP) GDP, which reflects the different costs of things in different countries when accounting for country output.

Table 22: Germany Key Indicators

GERMANY Key Indicators (2004)		**Population**: 82.5 million **Area**: 357,021 km^2
GDP: 1952.70 / 2160.03* billion US$	**Per capita**	**Per GDP/PPP GDP**
Total **Primary Energy** Supply: 348.04 Mtoe	4.22 toe/capita	018 / 016* toe/1000$
Electricity Consumption:579.98 TWh	7030 kWh/capita	0.28 /0.27* kWh/$
Energy-related **CO_2 Emissions**: 848.60 Mt CO_2	10.29 tCO_2/capita	0.43 / 0.39* kgCO_2/$
*PPP (power purchase parity) calculated, all $ refer to year-2000 US$ Sources: IEA 2006a, CIA		

Figure 38 shows the energy mix for both primary energy and electricity in Germany. It is significant that almost half of electricity generated in Germany originates from coal, and nearly one third from nuclear power. Germany's plans to phase out nuclear energy were widely publicized. However, after a change in government and two successive supply cuts from natural gas from Russia in the winters of 2005 and 2006, the political support for the nuclear phase out seems to be weakening.

Figure 38: Energy and electricity “mix” in Germany 2004



Source: European Commission 2007a

Renewable Electricity deployment and production

In 2005 Germany was the world’s leader in wind power, with an installed capacity of 18,430MW (REN21 2006). In 2005 Germany was also the world’s leader in solar photovoltaics, with 1,400MWp of installed capacity (REN21 20066).

Table 23 shows the progression of installed capacity for different renewable electricity technologies in Germany.

Table 23: Renewable electricity installed capacity (MW) in Germany 1990-2004

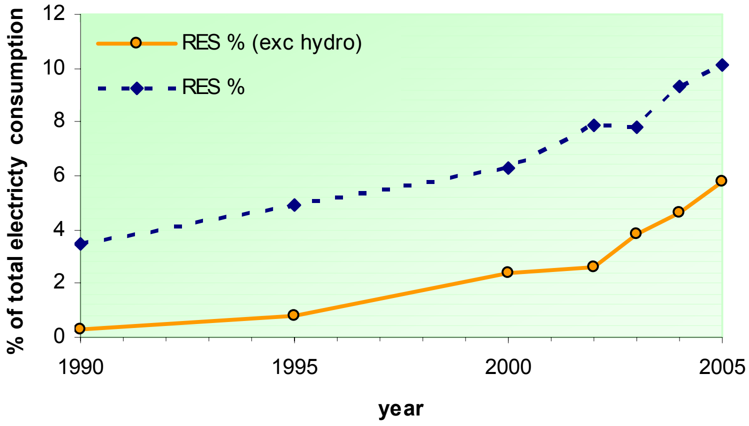
	Hydro	PV	Wind	Waste	Solid Biomass	Gas from Biomass	Liquid Biomass
1990	6851	2	48	550		229	
1995	8876	18	1137	509	79	229	
2000	8982	114	6095	585	129	345	
2002	9499	260	12001	585	285	580	
2003	8256	388	14609	585	500	599	12
2004	8271	708	16629	585	810	654	12

Source: IEA2006b

Wind power shows the most spectacular growth, with a 15-fold increase during the 10-year period 1995 to 2004. Solar photovoltaics growth rate is even higher, albeit from a smaller starting point. Solid biomass and biogas also experiment significant growths.

Figure 39 reflects the time-evolution of the share of renewable electricity in Germany. This figure differs from Figure 38 because Figure 38 reflects the absolute production of electricity while Figure 39 reflects the relative generation of renewable electricity versus the total consumption. Therefore, Figure 39 takes into consideration the increase in electricity demand.

Figure 39: Renewable electricity share in Germany



Source: IEA2006b

The interesting line in Figure 39 is the lower line, which represents the share of renewable electricity excluding hydro, or the “new renewables”. Particularly interesting is the acceleration of production of renewable electricity after 2002, when the effects of the feed-in tariff explained below started showing up.

Renewable Electricity Policies: the EEG

Deployment of renewables in Germany has been largely due to strong support policies, particularly its feed-in tariff law, embodied in the Renewable Energy Sources Act. The 2004 German Renewable Energy Sources Act (known as EEG, the German acronym for *Erneuerbare-Energien-Gesetz*) was a major revision of the 2000 Renewable Energy Sources Act, which in turn replaced the 1991 Electricity Feed law (StrEG). For a review of renewable energy policy history and evolution in Germany, see Jacobsson and Lauber 2006.

The EEG has three core elements:

- grid access and priority of renewable electricity
- degressive tariff
- nation-wide equalization.

Grid access and priority of renewable electricity:

The EEG regulates renewable electricity plants' grid access as well as renewable electricity's priority of purchase and transmission. The Transmission System Operators (TSOs) are mandated to connect renewable electricity plants to the grid. The costs of grid extension are allocated to renewable electricity plant operators, and grid upgrading costs are allocated to the TSO. TSOs can reflect upgrading costs due to renewable electricity in transmission charges, provided those costs are properly documented. TSOs are also obliged to buy and transmit all renewable electricity generated by power plants in their grid. Exceptions are allowed under mutual agreement between TSOs and renewable electricity generators in order to improve efficiency and/or functioning of the grid.

Degressive tariff

The EEG guarantees a feed-in tariff to renewable electricity producers for a period of 20 years[16].

Table 24 summarizes the tariffs for different technologies and installed capacities. One of the innovations of EEG is the use of degressive tariffs. Each renewable electricity plant is guaranteed the tariff at the level of the year it was commissioned, but for new installed plants that tariff level declines a certain percentage every year. The objective of the degression clause is to account for technological innovation and to promote early deployment of renewables.

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[16] with the exception of hydropower, with tariffs lasting from 15 to 30 years, depending on the installed capacity

Table 24: Feed-in law in Germany (EEG)

		Tariff 2004[a]	Degression	Remarks
Hydropower				
≤ 500kW		9.67 c€/kWh	0	
>500kW ≤5MW		6.65 c€/kWh		
>5MW≤150MW	Δ≤500kW	7.67c€/kWh		only plant modernization or existing structures only additional capacity Δ counts -1%/yr, only until 2012 ecological limitations
	Δ≤10MW	6.65 c€/kWh	-1%/yr	
	Δ≤50MW	4.56 c€/kWh		
	Δ>50MW	3.70 c€/kWh		
Landfill gas and sewage biogas				
≤ 500kW		7.67 c€/kWh[b]	-1.5%/yr	
>500kW≤5MW		6.65 c€/kWh[b]		
Biomass				
≤150kW		11.5 c€/kWh[b,c,d]	-1.5%/yr	
>150kW ≤500kW		9.9 c€/kWh[b,c,d]		
>500kW ≤5MW		8.9 c€/kWh[b,d,e]		
>5MW ≤20MW		8.4 c€/kWh[b,d]		
Geothermal				
≤5MW		15 c€/kWh	-1%/yr	
>5MW ≤10MW		14 c€/kWh		
>10MW≤20MW		8.95 c€/kWh		
>20MW		7.16 c€/kWh		
Wind Power				
on shore		5.5 c€/kWh[f]	-2%/yr	minimum yield 60%
off-shore		6.19 c€/kWh[g]		
Solar				
Any		45.7 c€/kWh	-5%/yr	only until 2015
≤30kW		57.4 c€/kWh[h]		integrated on buildings or noise walls
>30kW≤100kW		54.6 c€/kWh[h]		
>100kW		54.0 c€/kWh[h]		

a: Figure indicates basic tariff without complements.
b: +2 c€/kWh if biogas is refined to natural gas standards or generation equipment meets certain technical standards
c: +6 c€/kWh if fuel is untreated plants, manure, or vinasse
d: +2 c€/kWh for combined heat and power
e: +4 c€/kWh if fuel is untreated plants, manure, or vinasse
f: +3.2 c€/kWh first five years for 150% yield, time (months) increasing with decreasing yield: time=60-8*(150-yield)/3
g: if installed before 2010, +2.91 c€/kWh during 12 years (additional 0.5month for each mile beyond 20 nautical miles from coastline and additional 1.7 month for each meter of depth beyond 20m)
h: +5 c€/kWh if not integrated in the roof or the roof itself but it forms substantial part of the building

Equalization and other provisions

The EEG includes an explicit nation-wide equalization scheme (Art§14) to distribute evenly among different regions the costs associated with the renewable electricity feed-in tariff.

The EEG also contains provisions for (1) energy intensive consumers (Art§16) which are granted reduced cost from renewable electricity obligations; (2) transparency and publicly available data (Art§15); and (3) guarantees of origin (Art§ 17), as mandated by Directive 2001/77/ EC.

Regional Support

In addition to federal support from the EEG, renewable electricity in Germany also received support from the federal regions (Länder). Estimations of this support are reflected in Table 25. Quantification of regional support such as the one in Table 25 is difficult and public data does not exist for most countries.

Table 25: support by Länder to renewable electricity in million €

	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	1991-2001
wind	13.2	16.4	40	46.7	39.9	27.1	31	20.4	14.9	7.7	2.4	259.7
hydro	4.9	4.7	8.2	5.8	5.4	3.7	3.8	4.7	3.9	2.6	2.2	49.9
PV	5.4	10.5	9	9.9	9	14.6	19.6	15.6	19.4	22.8	27.9	163.7
Biomass	2.8	7	18	17.6	38.9	30.6	38.6	37.8	28.2	38.4	37.1	295
Education	1.5	1.7	1.4	1.6	3.2	4.3	6.8	5.1	3.9	6.2	6.2	41.9
R&D	12.5	20.5	28.1	27.1	27.1	21.8	30	53.2	53	38	23.1	334.4
Other	49.5	48.4	48.7	46.5	28	23.3	26.8	15.7	8.8	23.6	29.7	349
Total	**89.8**	**109**	**153**	**155**	**152**	**125**	**157**	**153**	**132**	**139**	**129**	**1493.6**

(data from: IEA 2004)

8.3 – Spain

Spain in Figures.

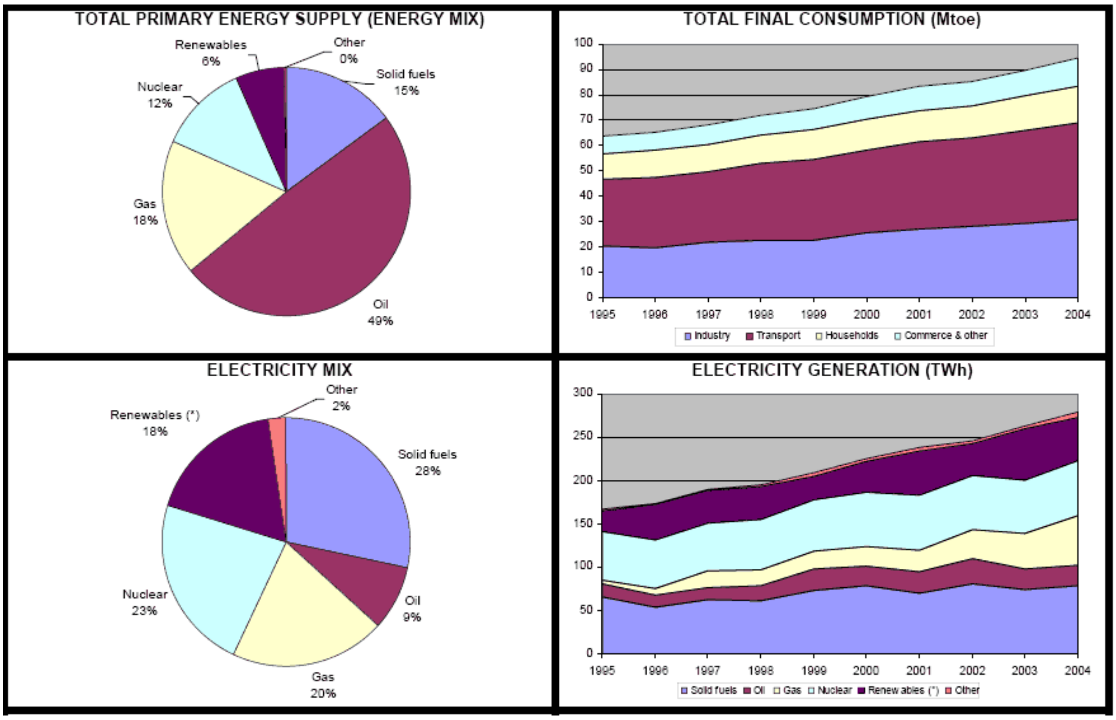
The previous and following tables and graphs outline the energy situation in Spain. Table 26 summarizes key energy indicators for Spain such as primary energy consumption, electricity, consumption, and carbon dioxide emissions related to energy, in absolute terms and per capita and per unit of GDP and PPP GDP.

Table 26: Spain Key Indicators

SPAIN Key Indicators (2004)		**Population**: 42.7 million
		Area: 504,782 km^2
GDP: 655.6 / 957.97* billion US$	**Per capita**	**Per GDP/PPP GDP**
Total **Primary Energy** Supply: 142.2 Mtoe	3.33 toe/capita	0.22 / 0.15* toe/1000$
Electricity Consumption: 252.91 TWh	5924 kWh/capita	0.39 /0.26* kWh/$
Energy-related **CO_2 Emissions**: 329.77 Mt CO_2	7.72 tCO_2/capita	0.50 / 0.34* $kgCO_2$/$
*PPP (power purchase parity) calculated, all $ refer to year-2000 US$ Sources: IEA 2006a, CIA		

Figure 40 shows the energy mix for both, primary energy and electricity in Spain. About half of Spain's primary energy is provided by oil. In 2004 23% of electricity was generated by nuclear energy and 18% by renewables. However, this figure can be misleading, as hydropower shows a great year-to-year variability. For example, 2004 was a particularly dry year in Spain. Therefore, it can be more informative to look at the time series, also in Figure 40, to see the contribution of renewables to total electricity generation, or to observe the contribution of renewables except hydropower, as depicted in Figure 41. In 2005, 7.9% of electricity generated in Spain was from renewable origin (excluding hydro).

Figure 40: Energy and electricity "mix" in Spain 2004



Source: European Commission 2007a

Renewable Electricity deployment and production

In 2005 Spain ranked second in the world in installed wind power capacity (10030MW), and was among the top three in new installed wind capacity (REN21 2006). In addition, as many as 20 solar thermo-electric projects, totaling 1000MW and 4000m€ in investment are being considered (Boletín de Energías Renovables).

Table 27 reflects the increases of renewable electricity installed capacity from 1990 to 2004. Particularly outstanding is the growth rate of installed wind power capacity, which grew 83-fold during the 1995-2004 decade.

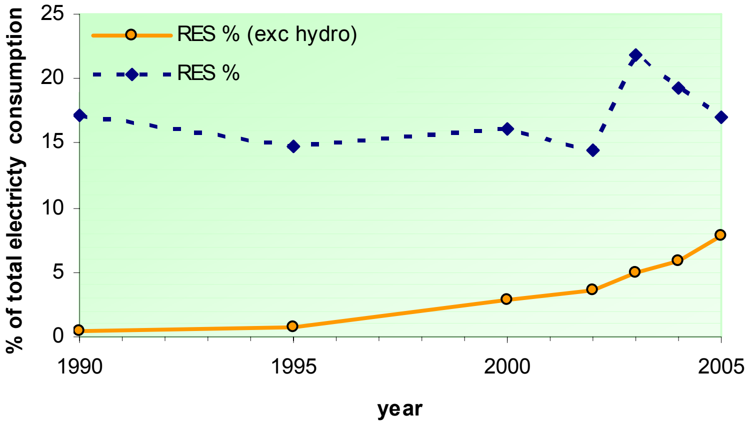
Table 27: Renewable electricity installed capacity (MW) in Spain 1990-2004

	Hydro	PV	Wind	Waste	Solid Biomass	Gas from Biomass
1990	16231	3	2	27	115	
1995	16784	7	98	69	126	
2000	17960	12	2206	94	150	50
2002	18068	20	4891	94	285	73
2003	18043	27	5945	94	329	125
2004	18118	36	8220	189	670	238

Source: IEA2006b

Figure 41 shows the time-evolution of the share of renewable electricity in Spain. With a 7.9% share of non-hydro renewable electricity in 2005, Spain ranks among the first countries on share of renewable electricity other than hydro, after Iceland and Denmark, both countries much smaller than Spain.

Figure 41: Renewable electricity share in Spain



Data from: IEA2006b

The sharp oscillations on renewable electricity share in 2003 show the great variability introduced by rain from one year to another.

Renewable Electricity Policies: RD 436/2004:

Investment in renewable electricity in Spain has been largely driven by its feed-in law, which is particularly beneficial for wind power. Spain's feed-in law was first enacted in 1998 (RD 2818/1998) and modified in 2004 (RD 436/2004).

The Spanish feed-in law offers two modalities for renewable electricity producers to choose: (a) a fixed tariff, and (b) market price plus a premium plus an incentive to participate in the market. Given current prices for electricity, most producers choose the market price plus premium option. Premiums, tariffs and the incentive are calculated as a percentage of a reference yearly electricity tariff[17]. A separate Spanish bill (RD

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[17] RD 7/2006, approved in 2006, de-linked the premium from the reference tariff. The new mechanism to establish the premium is still under negotiation at the time of writing, but it is expected to be related to

1432/2002) establishes the methodology used to calculate the reference yearly tariff. This reference tariff is also used for many purposes unrelated to renewable incentives. The incentive to participate in the market is 10% of the reference yearly tariff, amounting to 0.7 c€/kWh in 2005. The premiums and feed-in tariffs are shown in Table 28.

Under RD 436/2004 premiums must be revised every four years. RD 436/2004 also includes many technical provisions. Among them are (1) compensation for reactive power (Art§26); (2) calculation of deviation costs (Art§31); and (3) specific compensation for wind power installations equipped to cope with tension gaps.

Table 28: Feed-in law in Spain (RD 436/2004)

		Option a) Fixed Tariff					Option b) Market Price + Premium*	MAX** (MW)
		year 1-5	5-15	15-20	20-25	25+		
Solar Photovoltaic	≤100kW	575% (42.15c€/kWh)				460%	260%(19.06c€/kWh) 210% (after 25yrs)	150
	>100kW	300% (21.99c€/kWh)				240%		
Solar Thermoelectric		300% (21.99c€/kWh)				240%		200
Wind Power On/off-shore	≤ 5 MW	90% (6.57c€/kWh)				80%	50% (3.67c€/kWh)	13000
	> 5 MW	90% (6.57c€/kWh)		85%		80%		
Geothermal	≤ 50MW	90% (6.57c€/kWh)			80%		50% (3.67c€/kWh)	
Hydropower	≤10MW	90% (6.57c€/kWh)				80%	50% (3.67c€/kWh)	2400
	>10MW ≤ 25MW	90% (6.57c€/kWh)			80%		50% (3.67c€/kWh)	
	>25MW ≤ 50MW	80% (5.86c€/kWh)					40% (2.93c€/kWh)	
Energy crops / biomass residues / sludge / biogas		90% (6.57c€/kWh)				80%	50% (3.67c€/kWh)	3200
Forestry/farming industry		80% (5.86c€/kWh)					40% (2.93c€/kWh)	

- Tariff and premium expressed as a percentage of reference yearly tariff. Rounded prices for 2005 (reference yearly tariff= 7.3304c€/kWh) are included in brackets.

* includes market incentive of 10% of reference yearly tariff

** indicates maximum installed capacity under this support provision

National Renewable Electricity Objectives

In August 2005 Spain established new goals on renewable energy, more ambitious than the previously existing ones. Those goals were stated in the "Plan de Energías Renovables en España" (Spain's Renewable Energy Plan), also known as PER (IDAE 2005)

The PER establishes a general objective for renewables to supply 12.1% of primary energy consumption and 30.3% of electricity generation. The PER establishes specific

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internal rate of return and contain upper and lower bands to limit windfall profits and guarantee minimum retribution.

targets for renewable electricity, thermal applications of renewable energy (i.e. space and water heating) and use of biofuels.

Regarding renewable electricity, Table 29 shows Spain's targets for each technology for 2010.

Table 29: Spain's Renewable Electricity objectives 2010

	2004		2010 (objective)	
	MW	GWh	MW	GWh
Hydropower >50MW	13.521	25.014	13.521	25.014
Hydropower >10MW <50MW	2.897	5.794	3.257	6.480
Hydropower <10MW	1.749	5.421	2.199	6.692
Biomass power plant	344	2.193	1.317	8.980
Biomass Co-combustion	0	0	722	5.036
Solid Urban Waste.	189	1.223	189	1.223
Wind Power	8.155	19.571	20.155	45.511
Solar Photovoltaic	37	56	400	609
Biogas	141	825	235	1.417
Solar thermoelectric	-	-	500	1.298
Total Electricity	27.032	60.096	42.494	102.259

Source: Plan Energías Renovables (IDAE 2005)

The PER also includes goals region by region for each technology, which are not reproduced here.

Numerous regions in Spain (Comunidades Autónomas) have different schemes to promote renewable energies in general and renewable electricity in particular. As mentioned in the section from Germany, an official compendium and quantification of all existing policies at regional level and their total contribution does not exist.

Greenpeace published a guide listing regional policies for solar photovoltaics in 2003 (Guía Solar). Nevertheless, due to the number of regions and frequency of changes in regional policies, such compendia rapidly become obsolete.

8.4 – Denmark

Denmark in Figures.

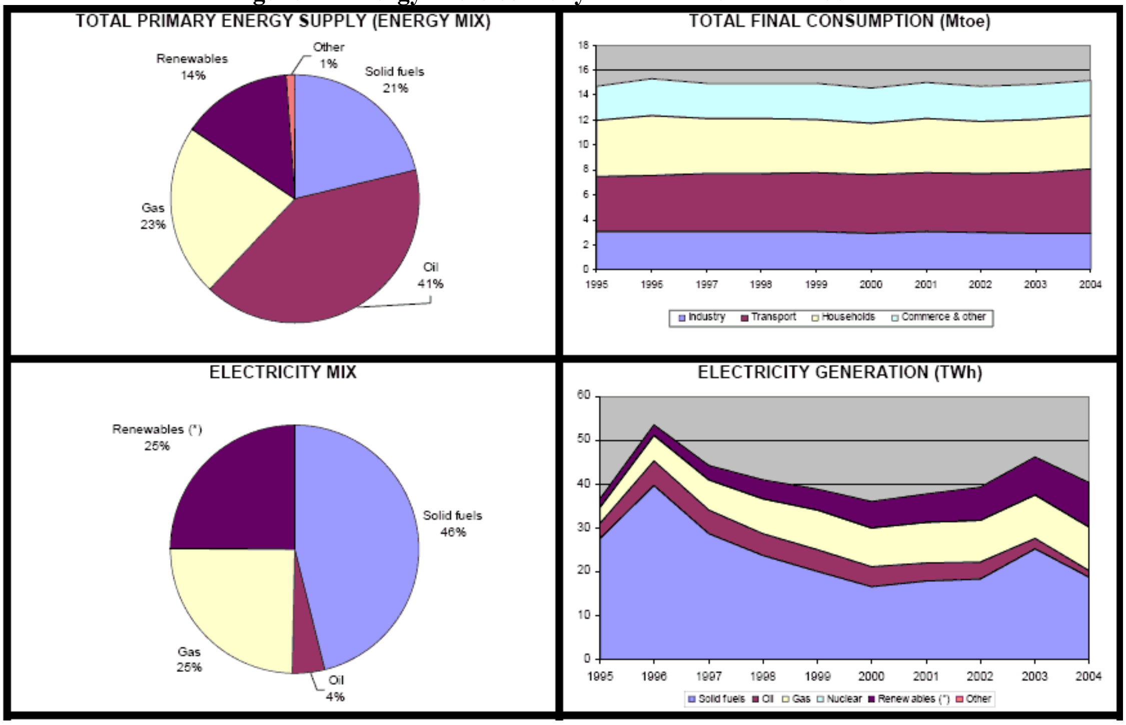
The previous and following tables and graphs outline the energy situation in Denmark. Table 30 summarizes key energy indicators for Denmark such as primary energy consumption, electricity, consumption, and carbon dioxide emissions related to energy, in absolute terms and per capita and per unit of GDP and PPP GDP.

Table 30: Denmark Key Indicators

DENMARK Key Indicators (2004)		**Population**: 5.4 million **Area**: 43,094 km^2
GDP: 166.40 / 159.81* billion US$	**Per capita**	**Per GDP/PPP GDP**
Total **Primary Energy** Supply: 20.07 Mtoe	3.72 toe/capita	0.12 / 0.13* toe/1000$
Electricity Consumption: 35.82 TWh	6633 kWh/capita	0.22 /0.22* kWh/$
Energy-related **CO_2 Emissions**: 50.92 Mt CO_2	9.43 tCO_2/capita	0.31 / 0.32* kgCO_2/$
*PPP (power purchase parity) calculated, all $ refer to year-2000 US$ Sources: IEA 2006a, CIA		

Figure 42 shows the energy mix for both, primary energy and electricity in Denmark. Denmark has no nuclear power, and one fourth of its electricity is produced from renewable energy sources.

Figure 42 Energy and electricity "mix" in Denmark 2004



Source: European Commission 2007a

While generation of electricity from gas and renewable energies have experienced an increase over the 1995-2004 decade, electricity generation from coal has significantly reduced.

Renewable Electricity deployment and production

With the exception of Iceland, a small country with population under 300.000 (CIA 2006) and exceptional hydro power and geothermal resources, which has a 100% renewable electricity system, Denmark is the country with highest share of renewable electricity generation excluding hydro, as reflected in Figure 43. This is due mainly to the contributions of wind power and biomass.

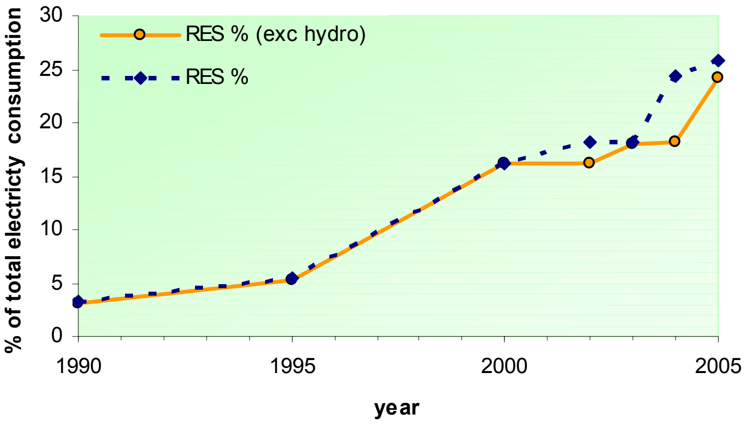
Table 31: Renewable electricity installed capacity (MW) in Denmark 1990-2004

YEAR	Hydro	PV	Wind	Waste	Solid Biomass	Gas from Biomass
1990	9		343		40	20
1995	10		616	150	110	23
2000	10	1	2417	230	86	41
2002	11	2	2886	270	512	53
2003	11	2	3115	285	311	58
2004	11	2	3124	312	474	63

Source: IEA2006b

It must be noted that Denmark has very efficient district-heating systems based on biomass co-generation, so the electric component of biomass is only a fraction of the energetic use of renewable biomass. The use of biomass and waste incineration seems to have reached a saturation point in Denmark (Hvelplund 2005).

Figure 43: Renewable electricity share in Denmark



Source: IEA2006b

Renewable electricity policies

During the decade of the 1990's, Denmark had a feed-in tariff promotion scheme for renewable electricity. Up until 1999 economic conditions for wind power were very favourable, with a feed-in tariff of 8¢€/kWh (European Commission 2004). However, the feed-in tariff was financed through the Treasury, and increasing share and production of renewables, as shown Figure 43 and Table 31, caused an increased burden in public finances.

After a change of government in 2001, Denmark abolished its previous feed-in scheme and proposed to replace it with a tradable green certificate system. However, implementation of the tradable certificate market was postponed, initially until 2003, and transition rules were established for the interim period, which included market electricity price plus a fixed bonus (IEA 2004). The result of the policy change was a dramatic drop in investment and deployment of new wind power projects. In 2001 the only projects that were built were those already in the pipeline .

In the end the tradable certificate was never started nor implemented, and a new agreement between government and opposition was reached in 2004, establishing a feed-in premium system (Com(2005)637). Momentum was gained again for renewables, as can be observed in Figure 43, for the last period with data available, 2004-2005.

There are different versions of why the certificate market was initially delayed and eventually not implemented. One of the suggested reasons for non-implementation of the certificate market was waiting for a European Trade scheme to be in place, as it was initially thought it would be the outcome of Directive 77/2001/EC (IEA 2004). Another suggested reason was the strong opposition and lobbying against the certificate system by the renewables industry and by NGOs (Meyer and Koefoed 2003). It must be kept in mind that the world's leading wind turbine company, Vestas, is Dane, and that exports of renewable and energy efficient technologies in 2003 was around €4.800million, €2.400 million only in wind turbines. In fact, the green energy industry in Denmark accounted for most of Denmark's current account surplus of €5.500 in 2003 (Hvelplund 2005).

Another explanation is offered by Hvelplund 2005, who notes that owners of renewable electricity plants had formed a sales association, and therefore the competition was lacking. In the light of the situation, the Government might have changed its approach. Beyond the effects for Denmark, if the argument is correct, it would be the first documented case of a cartel of renewable electricity producers in a quota-driven market for renewable electricity certificates.

8.5 – France

France in Figures.

The previous and following tables and graphs outline the energy situation in France. Table 32 summarizes key energy indicators for France such as primary energy consumption, electricity, consumption, and carbon dioxide emissions related to energy, in absolute terms and per capita and per unit of GDP and PPP GDP.

Table 32: France Key Indicators

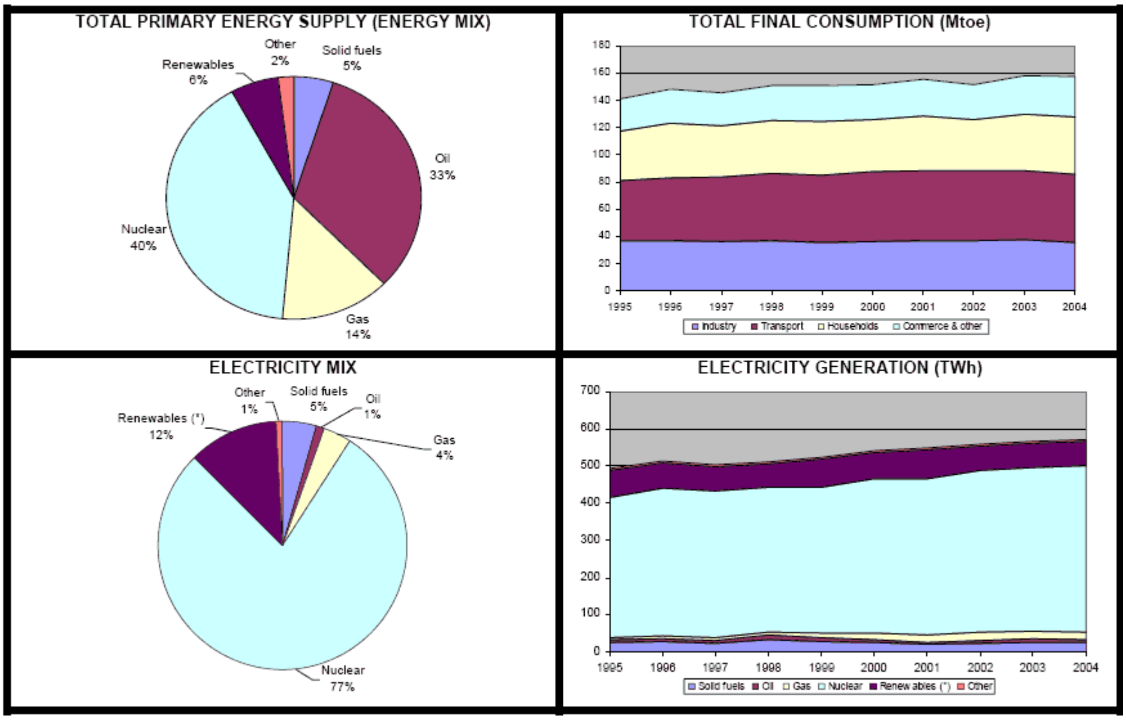
FRANCE Key Indicators (2004)		**Population**: 62.2 million **Area**: 545,630** km^2
GDP: 1414.80 / 1678.33* billion US$	**Per capita**	**Per GDP/PPP GDP**
Total **Primary Energy** Supply: 275.17 Mtoe	4.43 toe/capita	0.19 / 0.16* toe/1000$
Electricity Consumption: 478.10 TWh	7689 kWh/capita	0.34 /0.28* kWh/$
Energy-related **CO$_2$ Emissions**: 386.92 Mt CO$_2$	6.22 tCO$_2$/capita	0.27 / 0.23* kgCO$_2$/$

*PPP (power purchase parity) calculated, all $ refer to year-2000 US$
**refers mainland France. With overseas territories: 640,053km^2
Sources: IEA 2006a, CIA

France electricity system is a large centralized system based on nuclear power. The main player in the French electric system is Electricité de France (EDF), which is state-owned and operates in monopolistic conditions, with a market share of 90%, with the second player, Compagnie National de Rhône, accounting for 3% market share. (Grotz 2005).

Figure 44 shows the energy mix for both, primary energy and electricity in France. The defining feature for France's electricity system is its heavy reliance on nuclear power, nearing 80% of electricity supply. The rest of generation is provided by a mix of hydropower, coal and natural gas.

Figure 44: Energy and electricity "mix" in France 2004



Source: European Commission 2007a

Renewable Electricity deployment and production

Table 33 and Figure 45 illustrate evolution of installed renewable electricity and renewable electricity share in France respectively. Having France more wind potential than Germany, it is striking to see a mere 357 MW of installed capacity in 2004.

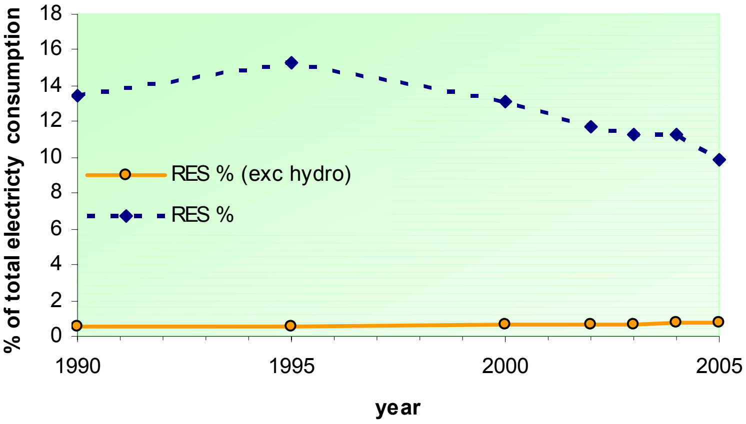
Table 33: Renewable electricity installed capacity (MW) in France 1990-2004

	Hydro	PV	Tide, Wave, Ocean	Wind
1990	24747			
1995	24987	1	240	3
2000	25215	3	240	57
2002	25311	5	240	133
2003	25235	8	240	222
2004	25235	10	240	357

Source: IEA2006b

Figure 45 clearly illustrates that the contribution of renewable electricity other than hydro the total electricity generation is negligible in France. And most of it is attributable to a single power station, the Usine Maremotrice de la Rance, described in Chapter 3 and shown in Figure 23.

Figure 45: Renewable electricity share in France



Source: IEA2006b

The decline in total renewable electricity share of consumption is due to an increased demand, with hydropower generation remaining more or less constant.

Development of renewables in France has been mainly for off-grid applications in remote areas, the numerous islands, overseas territories, as illustrated in Figure 46.

Figure 46: Off-grid PV installation: France

Glenan Islands, France, Miqel Muñoz August 2004

Renewable electricity policies

France has a hybrid feed-in law policy, with a feed-in tariff for installations under 12MW and a tendering system for installations larger than 12MW. Despite significant resources of wind, biomass and geothermal energy (European Commission 2004) the promotion scheme has failed to achieve significant development of those resources.

The level of the tariff is sufficient, at least when compared to other systems such as Germany or Spain (see Figure 64), however, prospective developers face strong administrative and grid barriers.

Grid barriers come from a largely centralized system and from a lack of will to accommodate renewable electricity. For example, the grid operator estimates that no more than 4000MW can be absorbed by the existing grid (Grotz 2005).

Administrative barriers include local and regional regulations, as well a lack of interest by EDF, the monopolistic state-owned electricity company.

It almost seems as if France was doing its best to block independent power producers from generating renewable electricity. While this idea cannot be found in writing, it's not uncommon to hear in private conversations that the French government is trying to prevent more mature German and Spanish wind power companies from taking over the untapped renewables market in France.

To add to the negative climate for renewables in France, in many regions there is a strong "not-in-my-backyard" effect, with local population opposing or being concerned about possible development of wind power. Figure 47 shows local media attention to wind power in a small rural village in France.

Figure 47: Local concern at wind power

Bretagne, France, August 2004, Miquel Muñoz

8.6 - Ireland

Ireland in Figures.

The previous and following tables and graphs outline the energy situation in Ireland. Table 34 summarizes key energy indicators for Ireland such as primary energy consumption, electricity, consumption, and carbon dioxide emissions related to energy, in absolute terms and per capita and per unit of GDP and PPP GDP.

Table 34: Ireland Key Indicators

IRELAND Key Indicators (2004)		**Population**: 4.06 million **Area**: 70,280 km^2
GDP: 118.20 / 134.49* billion US$	**Per capita**	**Per GDP/PPP GDP**
Total **Primary Energy** Supply: 15.21 Mtoe	3.75 toe/capita	0.13 / 0.11* toe/1000$
Electricity Consumption: 25.10 TWh	6182 kWh/capita	0.21/0.19* kWh/$
Energy-related **CO_2 Emissions**: 41.40 Mt CO_2	10.20 tCO_2/capita	0.35 / 0.31* $kgCO_2$/$

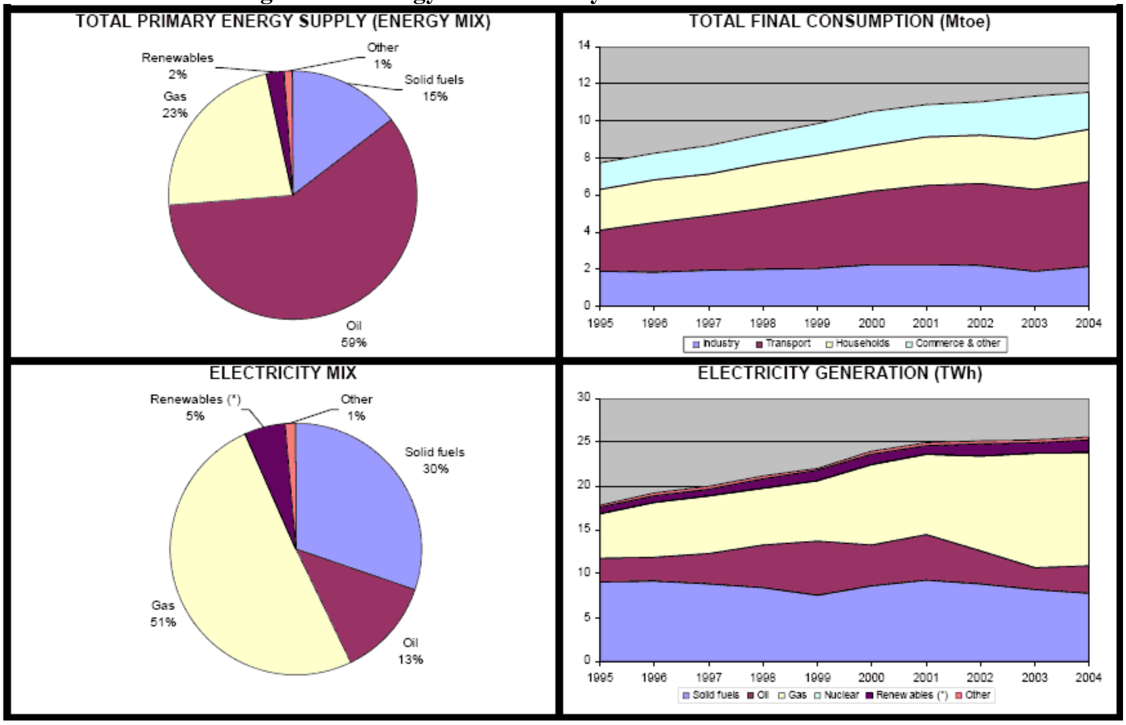
*PPP (power purchase parity) calculated, all $ refer to year-2000 US$

Sources: IEA 2006a, CIA

Figure 48 shows the energy mix for both, primary energy and electricity in Ireland. Ireland's energy system is largely dependent on oil and gas imports. Half the electricity is generated by gas, and one third by solid fuels, which include coal and peat.

Perhaps one of the most significant features of Ireland's electric system is the large increase in demand experienced in the 1995-2000 period.

Figure 48: Energy and electricity "mix" in Ireland 2004



Source: European Commission 2007a

Renewable Electricity deployment and production

Table 35 and Figure 49 illustrate evolution of installed renewable electricity and renewable electricity share in Ireland respectively.

Table 35: Renewable electricity installed capacity (MW) in Ireland 1990-2004

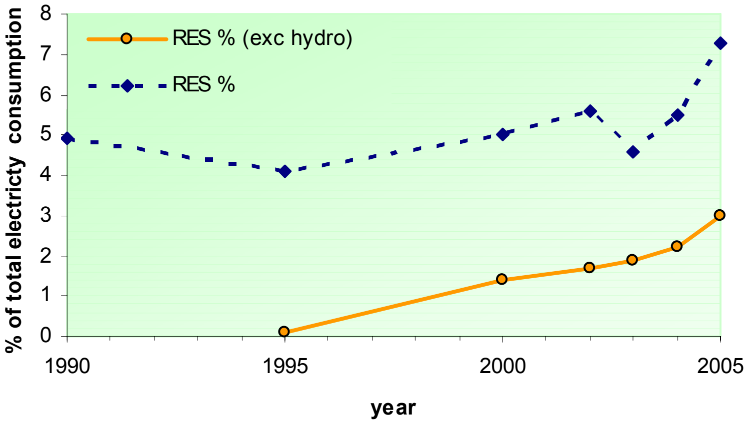
	Hydro	Wind	Gas from Biomass
1990	513		
1995	517	6	
2000	528	116	15
2002	532	189	19
2003	532	249	15
2004	532	378	19

Source: IEA2006b

Wind power has experienced some growth in the last years, and is expected to grow significantly over the next years. Ireland has a large wind energy resource potential, estimated at more than 5000MW and 15TWh, 50% of national consumption (Kellet 2005)

Ireland also has large wave energy potential, but as discussed in Chapter 3, this technology is not mature yet and not expected to contribute to renewable electricity generation in the near future.

Figure 49: Renewable electricity share in Ireland



On addition to being an island, Ireland is an electrical island, with very little interconnection capacity. There are only two interconnectors, one with Northern Ireland

and one with Scotland (Komor & Bazilian 2005). This makes balancing of fluctuations from intermittent sources more technically complex and costlier. The lack of balancing capacity is a factor to take into consideration when integrating intermittent resources such as wind into the system.

Renewable electricity policies

Until 2004 Ireland had a tendering scheme into place, the Alternative Energy Requirement (AER). Under the AER, the winner of a tendering process is awarded a Power Purchase agreement for 15 years. The additional cost of the contracts is cross-subsidized by electricity consumers.

Six competitions were held under the AER between 1995 and 2004 (IEA 2004). The AER led to relatively poor quality equipment because the lower cost offers won the bids (European Commission 2004). Poor quality wind power is an issue because of the electric island feature of Ireland's system mentioned before. For such a system, slightly more expensive turbines equipped to sustain voltage dips and not to disconnect at high wind speeds are more appropriate.

Tender requirements, such as wind farm limit, might also have led to inefficiencies in project design (European Commission 2004). That is, where a 23MW wind farm was the optimal option (from a technical and economic point of view), maybe the tender only called for a 10 MW farm, thus leading to inefficiencies.

In 2006 Ireland established a feed-in tariff.

8.7 – The Netherlands

The Netherlands in Figures.

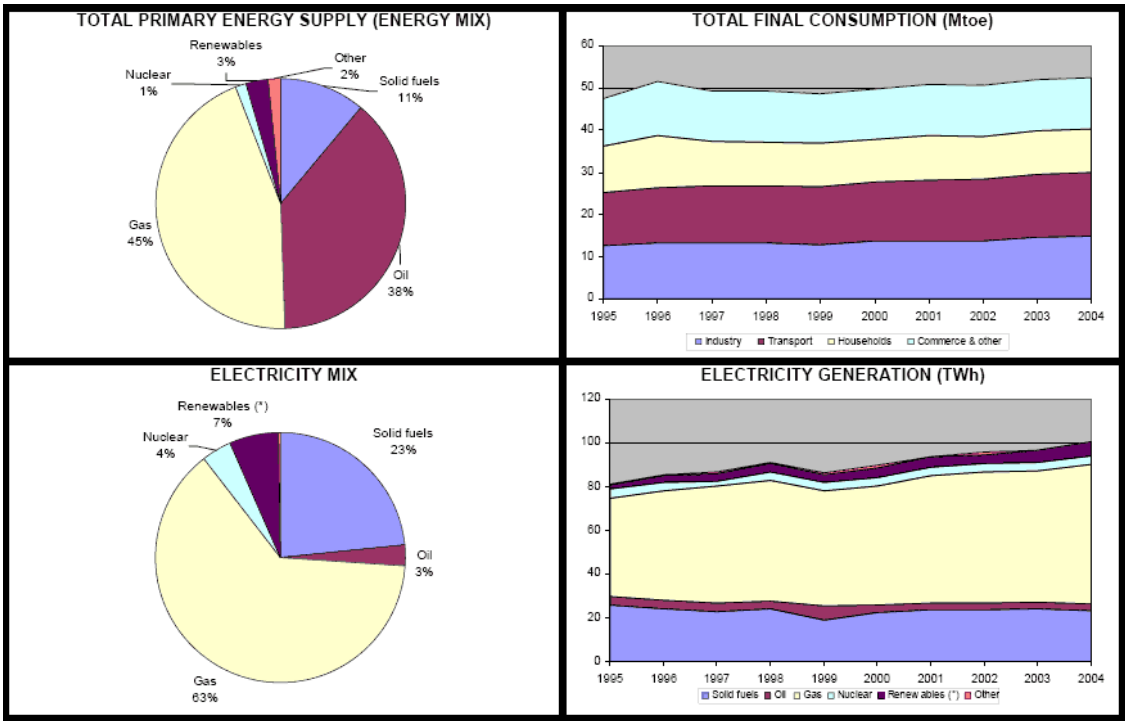
The previous and following tables and graphs outline the energy situation in the Netherlands. Table 36 summarizes key energy indicators for the Netherlands such as primary energy consumption, electricity, consumption, and carbon dioxide emissions related to energy, in absolute terms and per capita and per unit of GDP and PPP GDP.

Table 36: The Netherlands Key Indicators

THE NETHERLANDS Key Indicators (2004)		**Population**: 16.27million **Area**: 41,526 km^2
GDP: 398.50 / 467.45* billion US$	**Per capita**	**Per GDP/PPP GDP**
Total **Primary Energy** Supply: 82.15 Mtoe	5.05 toe/capita	0.21 / 0.18* toe/1000$
Electricity Consumption: 112.66 TWh	6924 kWh/capita	0.28 / 0.24* kWh/$
Energy-related **CO_2 Emissions**: 185.75 Mt CO_2	11.42 tCO_2/capita	0.47 / 0.40* kgCO_2/$
*PPP (power purchase parity) calculated, all $ refer to year-2000 US$ Sources: IEA 2006a, CIA		

Figure 50 shows the energy mix for both, primary energy and electricity in the Netherlands. The Netherlands has natural gas fields in its territory, and this is reflected in its energy and electricity mix, with natural gas accounting for nearly two thirds of electric generation.

Figure 50: Energy and electricity "mix" in the Netherlands 2004



Source: European Commission 2007a

Renewable Electricity deployment and production

The Netherlands is a flat country, therefore its hydro potential is basically nil. In addition, the Netherlands is a very densely populated country, with many restrictions in land use, which make permitting procedures are particularly complex. Most of the wind potential is for off-shore wind, where there is less competition for land-use.

Table 37 shows the evolution in installed capacity for different technologies in the Netherlands. Wind growth in 2003 and 2004 is mainly due to off-shore wind farms. The renewable technology experiencing a fastest growth is solid biomass.

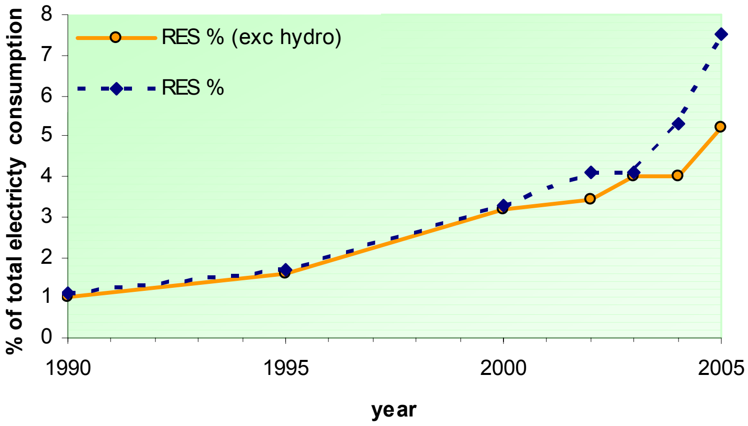
Table 37: Renewable electricity installed capacity (MW) in the Netherlands 1990-2004

	Hydro	PV	Wind	Waste	Solid Biomass
1990	37	1	52	196	6
1995	37	2	280	277	6
2000	37	13	502	414	72
2002	37	26	784	414	232
2003	37	46	1055	414	160
2004	37	50	1254	414	439

Source: IEA2006b

Figure 51 shows the evolution of the share of electricity production generated from renewable energy sources. In the case of the Netherlands, the hydro component (blue line) is due to electricity imports, since national hydro generation is negligible.

Figure 51: Renewable electricity share in the Netherlands



data adapted from: IEA2006b

Renewable electricity policies

The Netherlands has seen many types of support schemes for the promotion of renewable electricity. Lack of policy stability has been highlighted as one of the main barriers to renewable electricity in the Netherlands (Reiche 2005)

From 1991 to 2001 renewables in The Netherlands were promoted through voluntary agreements between the government and the electric industry.

In 1996 an energy "ecotax" was introduced for small and medium consumers (Gan et al 2005). The tax exempted renewable electricity, with the goal of fostering its deployment. The "ecotax" exemption expired in 2005.

In 1998, a voluntary "green label" system promoted by utilities was established.

When electricity sector was liberalized in 2001 the government established a voluntary green certificates system, which replaced the utility-sponsored voluntary green label. The government provided a three year period during which consumers could only switch companies if the switched to one providing green electricity. In 2004 the electric system was fully liberalized and consumers could chose any utility (Reiche 2005)

The main driver for the green certificates system was an exemption from the ecotax, so consumers redeeming those certificates could avoid an energy tax.

Initially imports of renewable energy did not qualify for the ecotax exemption, but after lobbying from the distribution companies, imports were also included in the tax exemption (Gan et al 2005). As a result, the system was overwhelmed by imports of electricity from existing hydropower in neighboring countries. This caused a loss of tax income for the government, estimated at 205 million € for 2001 (Hughes 2004), no investment in renewable electricity generation in the Netherlands, and no additional renewable power capacity abroad (van Rooijen & van Wees 2006).

In 2003 the green certificate system was changed to a feed-in tariff, the MEP. The MEP was linked to national goals of 10 % of final consumption originating from renewable energy in 2020, 9% electricity in 2010, and specifics of 1500MW of wind power and 500MW of biomass co-firing in 2010. The MEP was based on the German EEG, but with a fixed premium instead of a fixed tariff. That is, producers received a premium on top of electricity price, with technology-specific tariffs and no degression. Table 38 shows the premiums for renewable electricity.

Table 38: MEP Premiums 2006 - Netherlands

Wind onshore	65 €/MWh
Wind offshore	97 €/MWh
Biomass co-firing (wood)	61 €/MWh
Biomass co-firing (mixed)	25 €/MWh
Biomass CHP	97 €/MWh
Biomass CHP bio-oil	60 €/MWh
Solar-pv, small hydro	97 €/MWh

Data from: 3rd feed-in law cooperation

On August 18th 2006, the MEP was closed to new projects, as it became evident that the target would be reached. Without a new target, the MEP could not be extended, but with elections due on November 22nd 2006, no new mandate or budget was on sight. The resulting effect is a gap in the promotion policies.

With three different support schemes in force in less than five years, there is not enough stability or confidence in future stability for investors to plan. The changes affect support schemes as well as definitions of qualifying technologies. In addition, the policy failure to get renewed due to the reaching of the target caused another bust in the renewables deployment, and apparently renewed lost of faith of investors in the Dutch renewables market.

8.8 – Sweden

Sweden in Figures.

The previous and following tables and graphs outline the energy situation in Sweden. Table 39 summarizes key energy indicators for Sweden such as primary energy consumption, electricity, consumption, and carbon dioxide emissions related to energy, in absolute terms and per capita and per unit of GDP and PPP GDP.

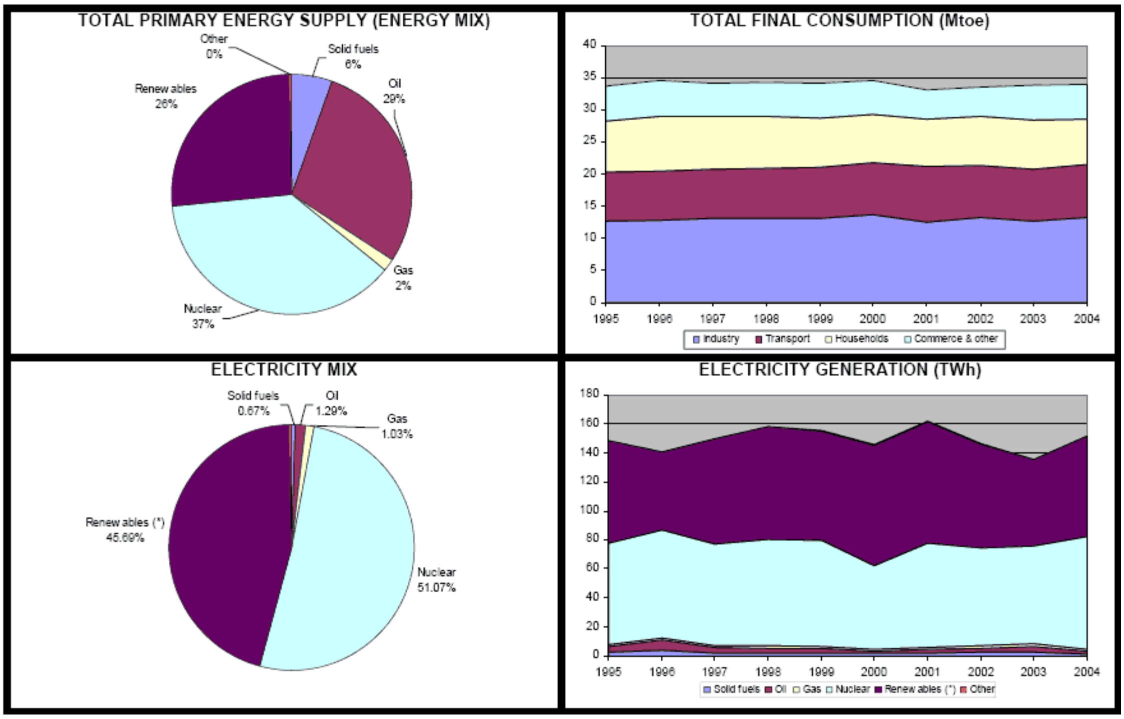
Table 39: Sweden Key Indicators

SWEDEN Key Indicators (2004)		**Population**: 8.99 million
		Area: 449,964 km^2
GDP: 263.2 / 262.16* billion US$	**Per capita**	**Per GDP/PPP GDP**
Total **Primary Energy** Supply: 53.94 Mtoe	6.00 toe/capita	0.20 / 0.21* toe/1000$
Electricity Consumption: 138.69 TWh	15427 kWh/capita	0.53 /0.53* kWh/$
Energy-related **CO_2 Emissions**: 52.16 Mt CO_2	5.80 tCO_2/capita	0.20 / 0.20* kgCO_2/$
*PPP (power purchase parity) calculated, all $ refer to year-2000 US$ Sources: IEA 2006a, CIA		

Figure 52 shows the energy mix for both, primary energy and electricity in Sweden. It can be observed that nuclear and renewables provide close to two thirds of primary energy and nearly all of electricity supply.

The structure of the Swedish energy mix helps understanding how Sweden plans to be the first “oil-free” economy. The electricity system, based on nuclear and hydro is already oil-free. The 29% primary energy consumption of oil in 2004 was mainly due to transport and heating. In both cases, Sweden plans to replace oil by biomass and biofuels, taking advantage of Sweden’s large biomass (read forests) resources.

Figure 52: Energy and electricity “mix” in Sweden 2004



Source: European Commission 2007a

Renewable Electricity deployment and production

Table 40 and Figure 53 illustrate de evolution of renewable electricity in Sweden. For most of the 1990’s no significant increase in non-hydro renewable electricity was observed, and the increases barely kept the share of renewables in total consumption.

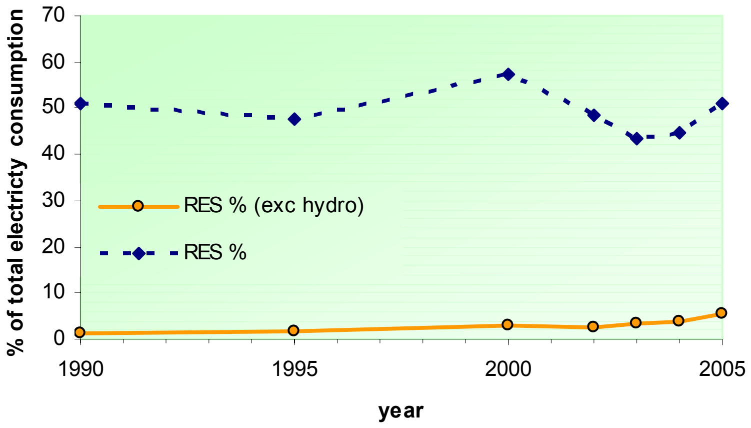
Table 40: Renewable electricity installed capacity (MW) in Sweden 1990-2004

	Hydro	PV	Wind	Waste	Solid Biomass	Gas from Biomass
1990	16331		8	30	1200	
1995	16152	2	67	76	1200	
2000	16525	3	209	74	1490	18
2002	16232	3	357	170	1670	20
2003	16143	3	399	170	1670	20
2004	16345	3	452	264	1670	20

Source: IEA2006b

In the 2000’s growth in waste incineration and wind power began outpacing growth in demand, explaining the slight increase (yellow line) at the end of Figure 53.

Figure 53: Renewable electricity share in Sweden



Source: IEA2006b

Renewable electricity policies

Sweden has traditionally used taxation as a policy instrument, and has a long history of taxes for environmental purposes. Act 1776, into force since 1994, provides tax exemption for renewable electricity.

Voluntary markets also played an important role in Sweden. Sweden's main environmental NGO, the Swedish Society for Nature Conservation created a widely recognized green label for electricity (BRA MILJÖVAL).

In 2002 a green certificates system was approved by the Swedish Parliament. The system entered into force in May 2003 (European Commission 2004, Körner 2005,). The quota system was not very effective in fostering investment in new capacity. An assessment by the Swedish Energy Agency in 2004 found that no new production capacity had been added for the first year of the green certificates system. In addition, from the final cost to consumers of the certificate system, only 49% went to renewable electricity producers. The rest was used to pay administrative costs (17%) and government taxes (20%) and fines (14%) (Gan *et al* 2005).

Swedish Society for Nature Conservation has publicly opposed the quota system, accusing it of just being a covert taxation system, and noting its inability to meet the established targets (Gan *et al* 2005).

8.9 – United Kingdom

United Kingdom in Figures.

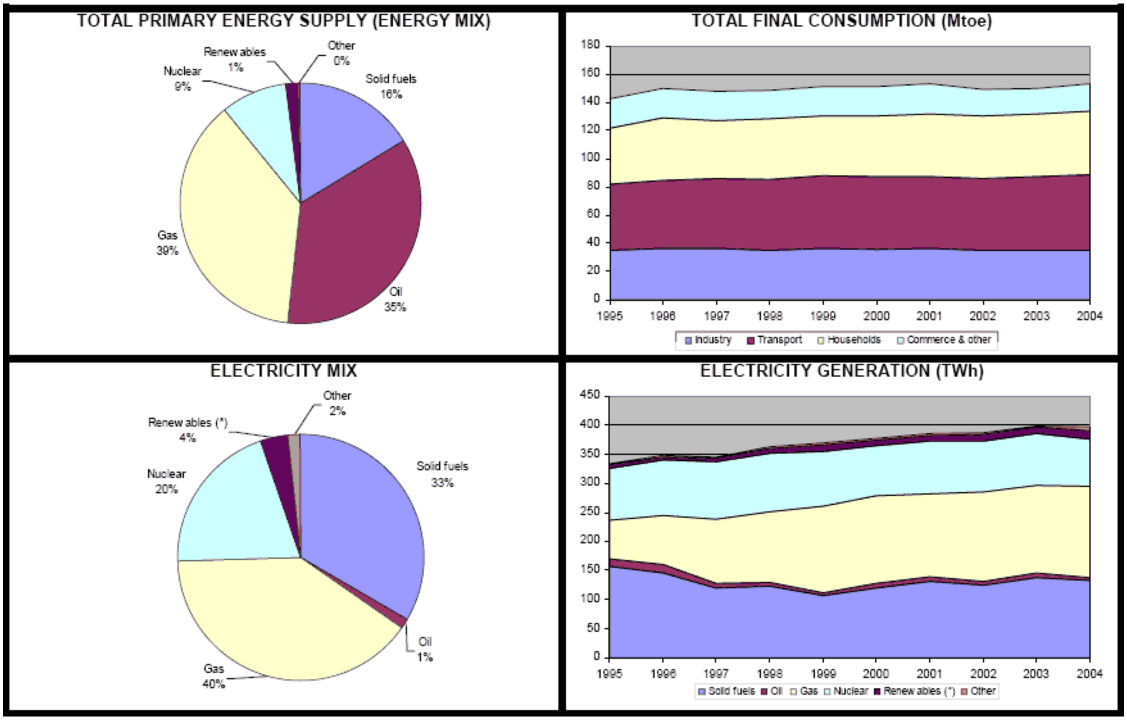
The previous and following tables and graphs outline the energy situation in the United Kingdom. Table 41 summarizes key energy indicators for the United Kingdom such as primary energy consumption, electricity, consumption, and carbon dioxide emissions related to energy, in absolute terms and per capita and per unit of GDP and PPP GDP.

Table 41: United Kingdom Key Indicators

UNITED KINGDOM Key Indicators (2004)		**Population**: 59.8 million **Area**: 244,820 km^2
GDP: 1591.1 / 1661.29* billion US$	**Per capita**	**Per GDP/PPP GDP**
Total **Primary Energy** Supply: 233.69 Mtoe	3.91 toe/capita	0.15 / 0.14* toe/1000$
Electricity Consumption: 371.31 TWh	6205 kWh/capita	0.23 /0.22* kWh/$
Energy-related **CO_2 Emissions**: 537.05 Mt CO_2	8.97 tCO_2/capita	0.34 / 0.32* $kgCO_2$/$
*PPP (power purchase parity) calculated, all $ refer to year-2000 US$ Sources: IEA 2006a, CIA		

Figure 54 shows the energy mix for both, primary energy and electricity in the United Kingdom. Electricity generation in the UK is dominated by fossil fuels, natural gas and coal. However, there has been a process of substitution of gas for coal, with coal losing market share, particularly when compared to the 1980's decade, already outside the graph in Figure 54.

Figure 54: Energy and electricity "mix" in The United Kingdom 2004



Source: European Commission 2007a

Renewable Electricity deployment and production

Table 42 and Figure 55 illustrate evolution of installed renewable electricity and renewable electricity share in the United Kingdom respectively.

Renewable electricity plays a minor role in electricity generation in the U.K., less than 4% of total consumption, less than 2.5% if hydro power is excluded. The United Kingdom has one of the best wind resources in Europe (Mitchell & Connor 2004), so despite a four-fold increase in wind power during the 1995-2004 decade, this can be considered a poor result, particularly in light of wind power development in other countries.

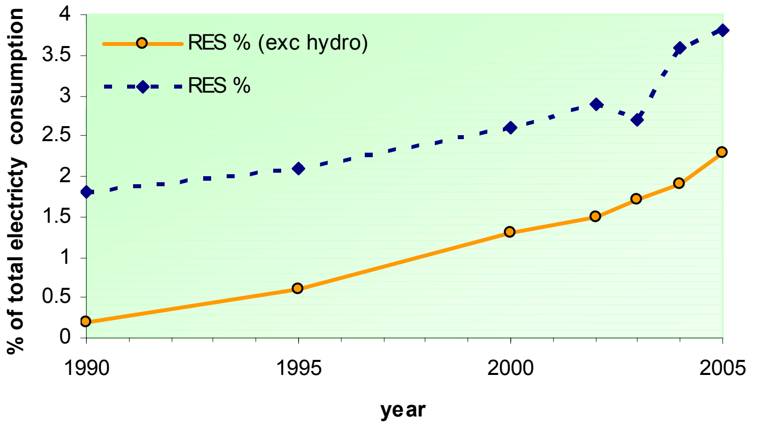
Table 42: Renewable electricity installed capacity (MW) in the United Kingdom 1990-2004

	Hydro	PV	Tide, Wave, Ocean	Wind	Waste	Solid Biomass
1990	3897			10	31	
1995	4220			200	87	46
2000	4273	2	1	412	184	133
2002	4391	4	1	534	203	144
2003	4256	6	1	742	217	163
2004	4248	8	1	811	223	163

Source: IEA2006b

Wave energy potential is also considerable in the UK (Mitchell & Connor 2004). Table 42 reflects some wave energy capacity, which stems from a few wave energy experimental plants, including a 500kW prototype in Scotland.

Figure 55: Renewable electricity share in the United Kingdom



Source: IEA2006b

Renewable electricity policies

During the 1990's, the UK had a tendering system as the promotion scheme for renewable electricity, called the Non-Fossil Fuel Obligation (NFFO). The NFFO was in force from 1990 to 1998.

Under NFFO tenders, a total of 3639 MW of contracts were awarded for renewable electricity. However, only 1034 of those were in operation in 2004 (Dinica 2005)

In 2000 the UK changed its support scheme to a quota and certificate system, the Renewables Obligation. Table 43 shows the enacted quotas in England, Wales and Scotland, and those proposed for Northern Ireland. Those quotas are binding.

Table 43: Renewable Obligation Quotas in the United Kingdom

year	England, Wales, Scotland	Proposed Northern Ireland
2003	3.0	
2004	4.3	
2005	4.9	
2006	5.5	2.5
2007	6.7	2.6
2008	7.9	2.8
2009	9.1	3.0
2010	9.7	3.5
2011	10.4	4.0
2012	11.4	5.0
2013	12.4	6.3
2014	13.4	-
2015	14.4	-
2016	15.4	-

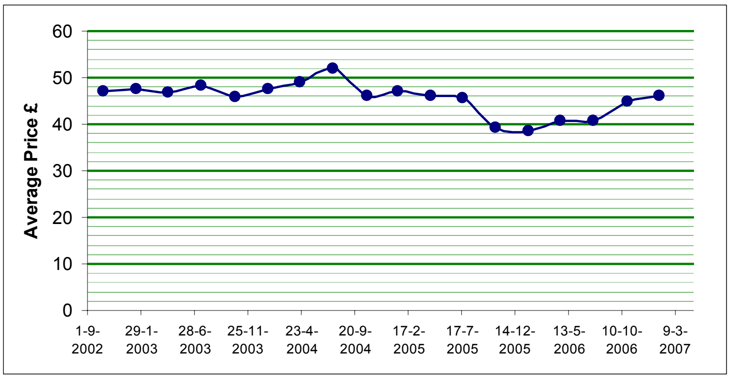
adapted from (Dinica 2005)

Together with the quota, a market for certificates was established. The certificates in the U.K. are called Renewable Obligation Certificates (ROCs). The Renewables Obligation has a buy-out provision, which allows utilities to pay a certain "fine", the buy-out quantity, and not comply with the ROC provision. The buy-out price was initially set at 30£/MWh. This provision, in effect, sets a cap price for compliance with the Renewables Obligation.

What is innovative in the UK quota system, is that it was designed as a revenue neutral policy. The proceedings from the buy-out revenue are recycled and distributed among the ROC owners, in proportion to how many ROCs they redeemed, therefore reducing the cost of compliance.

The effect of this policy has been that ROCs have been actually worth more than the buy-out price for the entire period since the Renewables Obligation has been in force. This is clearly reflected in Figure 56, which shows ROC average prices from ROC auctions from October 2002 to January 2007. The prices in Figure 56 are above the initial 30£/MWh and current 35£/MWh buy-out prices.

Figure 56: ROC Prices: Oct 2002 – Jan 2007



Data adapted from: Non-Fossil Purchasing Agency Limited

In addition to the Renewables Obligation, an energy tax, the Climate Change Levy, was implemented in April 2001. The Climate Change Levy is imposed on industrial, commercial and public-sector electricity consumers. Renewable electricity, however, is exempt from the Climate Change Levy. This exemption is exercised through specific certificates, different than the ROCs.

In addition to the Renewables Obligation and the Climate Change Levy exemption, there are voluntary green tariffs for consumers who choose to consume renewable electricity. These are offered by utilities at a premium price for green consumers. However, as already noted in Chapter 4, it has been pointed out (Friends of the Earth 2004) that consumers purchasing under the voluntary green schemes offered by utilities might be simply subsidizing the utility's requirement to buy ROCs, and therefore those voluntary schemes should be linked to buying ROCs and withdrawing them from the market.

The UK is the leading example of a functioning quota system. The financial incentive provided by ROCs, illustrated in Figure 56, has been so far the highest financial incentive for any mechanism in the European Union, as shown in Figure 64. Nevertheless, the Renewables Obligation has so far not proven sufficient to achieve the UK's renewable electricity objectives or to foster significant development of the UK's abundant renewable resources. One of the problems faced by developers, particularly wind developers, is the difficulty to finance projects due to the uncertainty in future ROC supply and future ROC prices.

9 – United States of America

Table 44 provides some key indicators for the United States of America. The United States of America was the pioneer in policies for the promotion of renewable electricity with the introduction in 1978 of the Public Utilities Regulatory Policy Act, best know as PURPA. Since then, support for and deployment of renewables in the US has experienced numerous swings, from being world leader to lagging well behind other developed countries to a renaissance in the last years.

Table 44: U.S. Key Indicators

UNITED STATES OF AMERICA Key Indicators (2004)		**Population**:293.95million
		Area: 9,826,630 km^2
GDP: 10703.9* billion US$	**Per capita**	**Per GDP***
Total **Primary Energy** Supply: 2325.89 Mtoe	7.91 toe/capita	0.22 toe/1000$
Electricity Consumption: 3920.61 TWh	13338 kWh/capita	0.37 kWh/$
Energy-related **CO_2 Emissions**: 5799.97 Mt CO_2	19.73 tCO_2/capita	0.54 $kgCO_2$/$

*GDP = GDP PPP (power purchase parity) calculated, all $ refer to year-2000 US$
Sources: IEA 2006a, CIA

This chapter begins with a historical background of renewable electricity policies and developments in the United States, followed by a description of the main support mechanisms, at the federal and at the state level. Finally, the current state of deployment and perspectives of future are discussed.

10.1 – Historical Background

The United States was pioneer in the enactment of renewable electricity policies. The Public Utilities Regulatory Policy Act, best know as PURPA, was enacted in 1978. The PURPA can be considered as the first feed-in law, and the successful feed-in laws existing today in Germany, Spain and other countries can be considered the policy daughters or granddaughters of PURPA.

In broad lines, PURPA mandated utilities to purchase electricity from "qualifying facilities", which included renewable electricity generators and combined heat and power (co-generation). The prices to be paid by utilities to producers under PURPA was supposed to be based on avoided costs of generation. To calculate avoided costs many factors were considered, including projections on fuel costs. PURPA was a federal law, but the specifics of its implementation were left to each state to regulate.

The State of California had the most attractive PURPA implementation rules for renewable electricity producers. In particular, under a figure know as “Standar Offer 4” contracts, producers were offered a long term purchase contract with fixed tariffs for the first ten years of operation. These contracts lasted from 15 to 30 years.

It is estimated that, in combination with tax incentives, PURPA stimulated deployment of 12000MW of renewable power in the US, including geothermal, mini hydro, solar thermoelectric and wind power, including 6100MW in California (Martinot et al 2005)

PURPA never expired, but as it will be seen, it gradually became irrelevant, or worse, a symbol of regulatory burden and market inefficiency.

PURPA was designed in the late 1970’s, at a time when electricity markets were vertically integrated monopolies, with utilities controlling generation, distribution and retail of electricity. It was also designed at a time of rapidly escalating oil prices, when a significant amount of electricity generation was still based on fuel-oil and other oil derivatives, and when energy security was at the top of the political agenda.

Most deployment under PURPA happened during the 1980’s. However, by the beginning of the 1990’s the situation had changed significantly. Regarding costs, there was an ample supply of electricity from nuclear plants that had been long delayed as a result of policies following the Three Mile Island nuclear accident and which finally came into operation, In addition, natural gas prices had dropped more than four-fold, making natural gas-based power generation very cheap.

PURPA was based on avoided costs[18]. The calculations of avoided costs included projections of escalating fossil fuel costs. These price increases not only did not materialize, but, on the contrary, prices plummeted. As a result, PURPA prices based on avoided costs also declined, making PURPA contracts unattractive. For example, the average price paid to renewable electricity generators under PURPA in California was 12.79¢$/kWh, while avoided costs dropped to 2-3¢$/kWh in the 1990's.

The 1990's also saw another major development in electricity markets in the US: restructuring. This is the transition process from the "natural monopolies" of vertically integrated utilities to liberalized electricity markets as described in Chapter 1. The restructuring sector was marked by large uncertainties, as the rules that would regulate the unregulated electricity markets where far from clear. This uncertainty, combined with generation surpluses inherited from the regulated era, hindered investment in energy generation (of all kinds) for some years. The deregulation process was mostly completed by the late 1990's but its "growing" pains and adjustment continued into the early 2000's. The (in)famous 2001 California energy crisis, for example, was mostly a result of power companies (including also (in)famous Enron) gaming the new "deregulated" system for profit.

In general the 1990's saw a stagnation of renewable electricity developments in the US (Martinot et al 2005). The United States went from being the world leader in renewables to lagging behind Europe and Japan, who benefited from the earlier investment in the US. As the US market faltered for windpower and photovoltaics, Denmark, Germany and Japan took over.

In the mid 1990's a new post-PURPA generation of policies began being discussed. At the federal level, the Production Tax Credit was created. At the state level, some states began experimenting with quota systems (know as renewable portfolio standards, RPS, in

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[18] Avoided costs meant avoided operation and investment costs for utilities, and did not take into account climate change, sulphur emissions or other externalities.

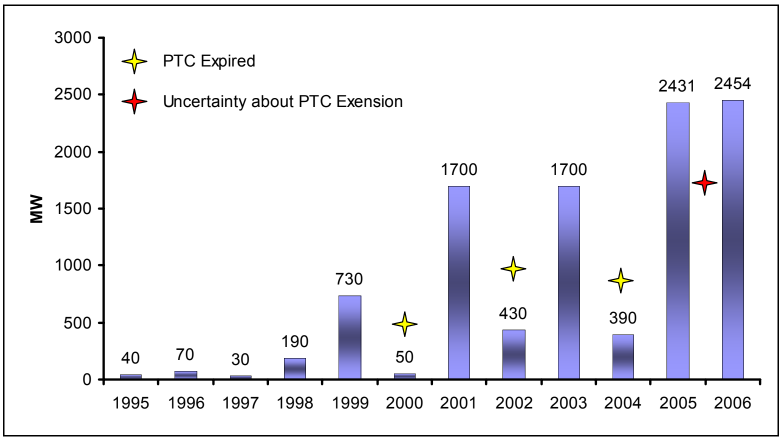
the US), net-metering provisions and clean energy funds. All these policies are discussed next.

11.2 – Production Tax Credit.

The production tax credit (PTC) was created in 1994. It basically consist on a tax exemption based on renewable electricity production. The exemption began at 1.5¢$/kWh, and was later updated to 1.8¢$/kWh and to 1.9¢$/kWh in 2006. The PTC effectively works as a feed-in tariff, and it has been dubbed by some as the "feed-in tariff of the rich", because it can only be used as a tax deduction.

The PTC has proven very influential for the deployment of renewable electricity in the US. Unfortunately, not for the positive influences one could expect of such a feed-in law, but rather because of its inconsistency over time, which has caused a severe boost-boom effect in the US renewables industry. The PTC is not a permanent measure, but needs to be renewed by the Congress. The Congress has renewed the PTC most times for one year, some times for two. But in three cases, on years 2000, 2002 and 2004 the Congress let the PTC expire before renovating it. This causes severe busts in the renewables energy sector, which in the case of wind power can clearly be observed in Figure 57.

Figure 57: Installed wind power capacity in the US



Data sources: Martinot *et al* 2005, AWEA

Figure 57 displays the installed wind power capacity for the period 1995-2006. The years when the Production Tax Credit (PTC) was left to expire are market with a yellow star. From the moment that wind power started showing significant deployment (1998) there is a clearly observable correlation between expiration of the PTC and lower deployment rates. Renewal of the PTC for 2006 was stalled till the very last, causing a reduction into forecasted installation above 3000MW.

The PTC has in a way become a symbol of the perverse effects of inconsistent policies. The PTC alone is not sufficient to stimulate growth in renewables, but its absence or uncertainty about its renovation is sufficient to significantly hinder renewables deployment. The PTC has been applied to more than 5.4GW of wind power in the US from 1995 to 2005 (REN21 2005).

It is been estimated by the American Wind Energy Association (AWEA) that renovation of the PTC is necessary at least 8 months in advance in order not to cause a slowing down of the technology markets.

12.3 – State Policies

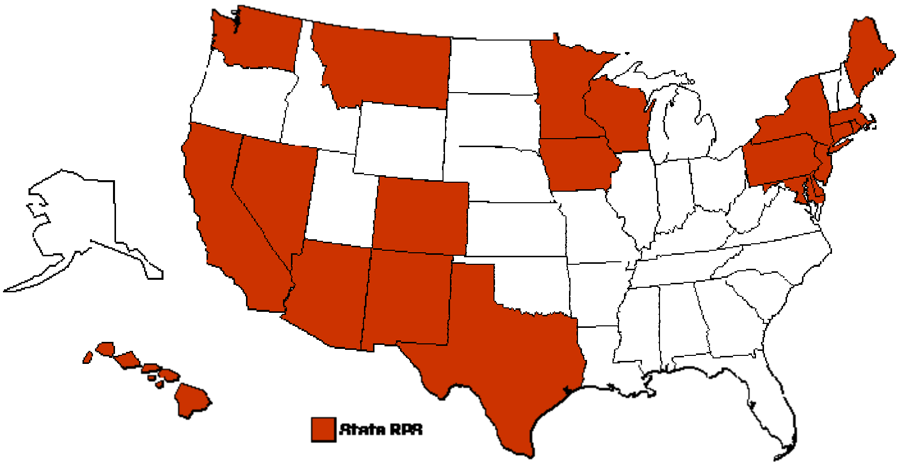
Federal support for renewables in the US vanished in the early 1990's, and deployment stagnated. However, the void left by the federal government was partially filled by States, who started enacting a whole range of policies to support renewables. Three of the most popular types of policies are Renewable Portfolio Standards, Clean Energy Funds and Net Metering, discussed next.

It must be stressed that, even though the policy types are similar, each state designs its own policy, and that RPS from different states are as similar or different among them as different quota systems or feed-in laws in European countries.

9.3.1 – Renewable portfolio standards

Renewable Portfolio Standards are the instrument of choice by US States to promote renewable electricity. RPS are the US terminology for quota systems, some times linked to REC markets and some times not. A total of twenty-four states have enacted RPS as of the end of 2006. These states are reflected in Figure 58 and in
Table 45.

Figure 58: Renewable Portfolio Standards in the US



Data source: DSIRE 2007

Table 45: RPS in US States

State	Target	Year	State	Target	Year
Arizona	15%	2025	Montana	10%	2015
California	20%	2010	Nevada	20%	2015
Colorado	10%	2015	New Jersey	20%	2020
Connecticut	10%	2010	New Mexico	10%	2011
Delaware	10%	2019	New York	25%	2013
Hawaii	20%	2020	Pennsylvania	18%	2020
Iowa	105MW	1999	Rhode Island	16%	2019
Maryland	7.5%	2019	Texas	5880 MW	2015
Maine	30%	2000	Washington D.C.	11%	2022
Massachusetts	4%	2009	Washington	15%	2020
Minnesota	25%	2025	Wisconsin	10%	2015

Source: DSIRE

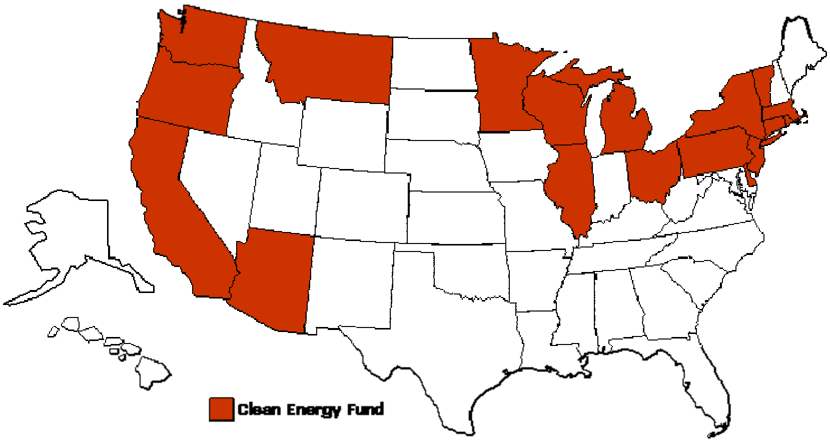
Besides being a quota system, RPS greatly differ from one State to another, and no generalizations can be made (Rickerson & Grace 2007). Of those systems that have tradable certificates(RECs), the RECs are generally not tradable from one state to another.

In 2003 and 2004 there was talk about a US-wide renewable portfolio standard as part of the energy bill discussions. A major problem with a US-wide RPS is the distributional issue discussed in the European case. The Southern states, with poor endowment of cheap renewable energy sources worry that they might face high costs to comply with a national renewable portfolio standard. For that reason, a US-wide RPS seems unlikely to gather enough political support to pass the Congress. Nonetheless, in 2006, renewable electricity lobbyists are still pushing for a US-wide RPS legislation. The shift seems to have changed from a US-wide RPS to a federal mandate thateach state has a RPS and facilitating the exchange of RECs between states.

9.3.2 – Clean Energy Funds

A total of 18 states and Washington D.C. have established clean energy funds, mostly through some sort of levy on electricity. These funds are used in different ways for the promotion of renewable electricity, and in most cases also energy efficiency and sustainable energy technologies such as fuel cells. An example is the Massachusetts Renewable Energy Trust, which is funded by electricity consumers in Massachusetts through a small charge in the electricity bill (www.mtpc.org). Figure 59 shows which states have enacted clean energy funds, and Table 46 shows estimations (DSIRE) of the total amount to be collected from those funds from 1998 through 2017.

Figure 59: US States with clean energy funds



Data sources: DSIRE, CESA 2006

Figure 59 illustrates US States with enacted clean energy funds. With the exceptions of Texas and Florida, arguably all major US States have clean energy funds.

It is estimated that clean energy funds in the US collect US$ 300 million per year (Bolinger et al 2004). Existing US funds in 2002 were expected to raise USD 3.5 billion from 1998 to 2012 (Wiser et al 2002). Existing funds in 2006 are expected to have raised USD 4.7 billion by 2017 since 1998 (DSIRE).

Table 46: Estimated US Clean Energy Funds 1998-2017

State	Fund (m$)	State	Fund (m$)
California	2048	New York	85
Connecticut	338	Pennsylvania	80
Delaware	11	Ohio	20
Illinois	127	Oregon	95
Massachusetts	383	Rhode Island	10
Michigan	1122	Vermont	36
Minnesota	111	Washington D.C.	10.5
Montana	10	Wisconsin	22
New Jersey	279		
Total: 16 States + D.C. $4787million			

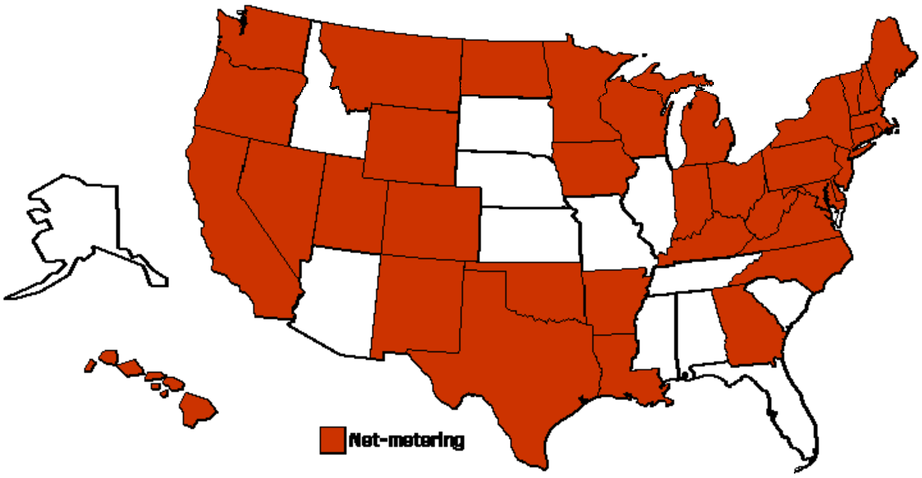
How these funds are used depend on each particular fund. Typical measures include grants, low-interest debt, guarantees, training, buy-down programs, project facilitation and technical assistance.

In 2004, 707MW of renewable electricity capacity had been funded through clean energy funds, and 1548MW were in the pipeline (Bolinger et al 2004).

9.3.3 – Net metering

Most US States have introduced net metering provisions, explained in section 5.4. The number of states with such provisions is reflected in Figure 60.

Figure 60: US States with net metering provisions



Data source: DESIRE 2007

Figure 60 shows US States with net-metering provisions. States where some utilities have voluntary net-metering schemes have not been included. These are Florida, Idaho, Illinois and Arizona.

These net-metering rules range from some states such as Wyoming allowing small installations of up to 20kW to use net metering to others such as New Mexico and

Colorado in the Megawatt order or as Ohio with no limit in system size. Most states also have different net-metering provisions for residential or commercial producers. Other differences among net metering provisions is whether they affect all utilities or just a certain range of electric companies and/or types of contracts.

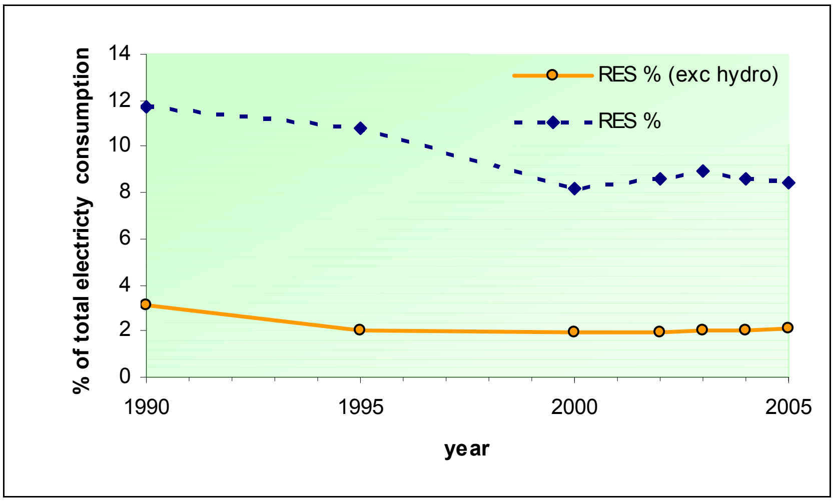
9.4 – Renewable electricity production and deployment

Table 47: Renewable electricity installed capacity (MW) in the United States 1990-2004

	Hydro	Geo-thermal	PV	Solar Thermal	Wind	Waste	Solid Biomass	Gas from iomass	Liquid Biomass
1990	92360	2669		339	1911				
1995	100060	2968	67	333	1731				
2000	98881	2793	139	419	2377	3265	6129	880	
2002	93994	3012	212	202	4531	3222	6151	958	
2003	96352	3036	275	388	6121	3133	6115	1030	35
2004	96699	3094	365	388	6522	2741	6446	1004	65

Data source: IEA2006b

Figure 61: Renewable electricity share in the USA



Data Source: IEA2006b

PART IV – COMPARISON BETWEEN FEED-IN-LAWS AND QUOTA SYSTEMS

Part II of this dissertation described support schemes for the promotion of renewable electricity. Part III compared policies and their results in different countries. Part IV analyzes some aspects of those policies more in detail, in particular by providing a comparison between feed-in laws and quota systems. This comparison is in regards to several aspects, including:

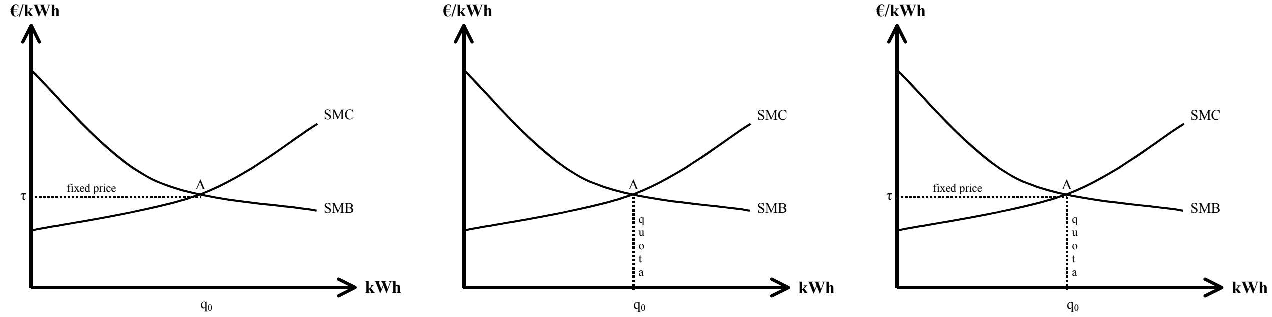
- efficiency
- effectiveness
- innovation
- uncertainty
- funding
- regulatory risk

The comparison between feed-in laws and quota systems is a reflection of a much older debate in economic policy, at least 30 years old, the debate of prices vs. quantities (Weitzmann 1974). As it will be discussed, at a very basic level, under perfect market conditions, pricing systems such as feed-in laws and quotas systems should achieve the same results. However, perfect market systems seldom exist, and each particular policy has its own characteristics that make one system preferable to another under certain circumstances. There are examples of quota systems in the past that have been applied to environmental policy, such as the sulfur cap and trade system in the US to address acid rain. Nonetheless, in the case of renewable electricity, I argue that feed-in laws are superior policy instruments than quotas.

From a purely economic perspective, the optimal production of renewable electricity is set by the intersection of the social marginal benefit curve and the social marginal cost curve (Kolstad 2000). Such optimization should be seen as a heuristic construction rather than a computable quantity. Both fixed prices and quotas can theoretically achieve the optimal point under market conditions (see Figure 62).

Quotas are “demand-pull” incentives, and feed-in-laws “supply-push” incentives. Under feed-in law mechanisms, the cost-per-kWh produced is initially known, but the total installed capacity that will result is not. Under quota systems, the final quantity of renewable electricity generated is known, but costs are not.

Figure 62: Social Optimum, Prices and Quotas



(a) Fixed prices (b) Quota (c) Fixed prices vs. Quota

Figure 62: The social optimum (point A) is defined by the intersection of social marginal cost (SMC) and social marginal benefit (SMB) curves. SMB is the change in benefit to society contributed by an additional unit of renewable electricity. Likewise, SMC is the change in cost to society contributed by an additional unit of renewable electricity. The curves used in this figure are only illustrative, and the shapes can greatly vary. Chapter 12 provides a more detailed discussion on the SMB and SMC of renewable electricity. Under perfect market conditions both policies, a fixed price (a) or a quota (b), can yield the optimal result A (c).

In theory, under perfect market conditions (perfect foresight and information, no externalities, no monopolies), if well-gauged, both quotas and fixed prices can achieve the optimal point. However, markets are seldom perfect, and never in the electricity sector. In addition, does the optimal point exist and if so, can it be known? For an optimal point to exist as described, that is as the intersection of the social marginal cost and social marginal benefit curves, it has to be possible to make an economic valuation in monetary terms of costs and benefits of items such as climate change and energy security. These kind of exercises tend to derive into philosophical and often acrimonious debates about the value of life, happiness and future generations. For example, controversy on methodologies used to valuate human life in developed and developing countries nearly derailed negotiations of the Intergovernmental Panel on Climate Change in 2001 for the Third Assessment Report (TAR).

Even if it is accepted that eventually all impacts and benefits can be reduced to monetary terms from a philosophical standpoint, there is still the issue of uncertainty and lack of knowledge regarding the actual social benefit and social cost curves.

In the next chapters, quotas and feed-in laws are compared in terms of efficiency, effectiveness, technological innovation, performance under uncertainty, funding and regulatory risks.

13 – Efficiency and effectiveness

Efficiency and effectiveness are two terms often used indistinctly in common language but with very definite and different meanings.

(1) Efficiency refers to how much output is obtained per unit of input. An energy-efficient compact fluorescent lamp (CFL), for example, will use less energy than a regular light bulb to produce the same amount of light[19]. When referring to policies, efficiency usually refers to cost-efficiency, that is, how much of the goal of the policy is achieved per unit of investment. In the case of renewable electricity policies, efficiency of the policy can be measured by either production of renewable electricity or installed capacity divided by the cost of the policy.

(2) Effectiveness refers to how much of the goal is achieved. For example, if there is a large dark warehouse that needs lighting, a small lamp will be ineffective to properly illuminate the building, regardless of whether the lamp is an energy-efficient CFL or an inefficient light bulb. When referring to policies, effectiveness refers to how much, generally a percentage, of the initial goal or objective is achieved by means of that policy, regardless of the cost.

An optimal policy will be both, efficient and effective. Unfortunately, in many cases there is a tradeoff, as effectiveness comes at a cost, and a balance needs to be achieved between efficiency and effectiveness.

Next, efficiency and effectiveness are considered for quotas and feed-in laws from a theoretical perspective. Figure 63 shows the marginal costs, prices and production levels of quota and a feed-in law at two different intervals of time under ideal market conditions. Table 48 reflects the economics for one or other type of policy assuming that innovation lowers renewable electricity costs over time.

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[19] A traditional 100W light bulb will produce 1200-1400 lumens, consuming 100W of power. A CFL producing the same amount of light will consume 20-23 W, almost five times less energy per unit of time.

Figure 63: Costs and benefits, quotas vs. fixed prices

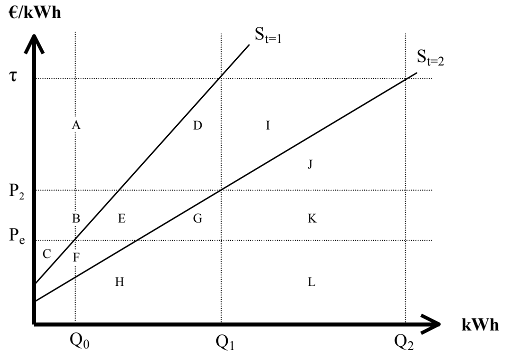


Figure 57 isolates the effects of innovation on quotas or feed-in tariffs. Assuming both policies are equivalent, at time t=1, a quantity Q_1 (the quota) is being produced at a price τ (the fixed tariff). P_e is the market price of electricity, and $S_{t=1}$ the supply curve of renewable electricity. At time t=2 innovation brings down generation costs, reflected in the new supply curve $S_{t=2}$. Reduction in capital costs shifts $S_{t=2}$ down, and reduction in operating costs reduces the supply curve slope. Producers under quota systems will generate the mandated quota Q_1 at price P_2 set by the market. Under feed-in tariffs, the intersection of the supply curve $S_{t=2}$ and the tariff τ will set renewable electricity production at Q_2.

It can be readily seen that under the simplest policy designs (a feed-in tariff with a fixed prices and a constant quota), once innovation is taken into account, feed-in laws will tend to overshoot the initial goal at a higher cost than initially expected, while quotas will tend stay on target at a lowering cost.

There are two components to the additional cost of fixed price systems over quota systems. First, under a feed-in-law, more renewable electricity capacity will be installed in period t=2 and hence more electricity produced. This accounts for the extra cost "J" and the extra subsidy rent "I" in the graph. "J+I" should not really be considered extra expenditures since a quota system designed to generate Q_2 renewable electricity instead of Q_1 would also incur in cost "J" and allow producers to capture rent "I." The second component "A+D" is due to the fact that under a fixed price, prices are fixed and producers capture the rents of technological innovation. Table 48 reflects more explicitly the differences between quotas and feed-in laws when accounting for innovation. Note that the difference in subsidy captured by producers can be seen as the windfall profit.

Table 48: Costs of fixed prices and quotas

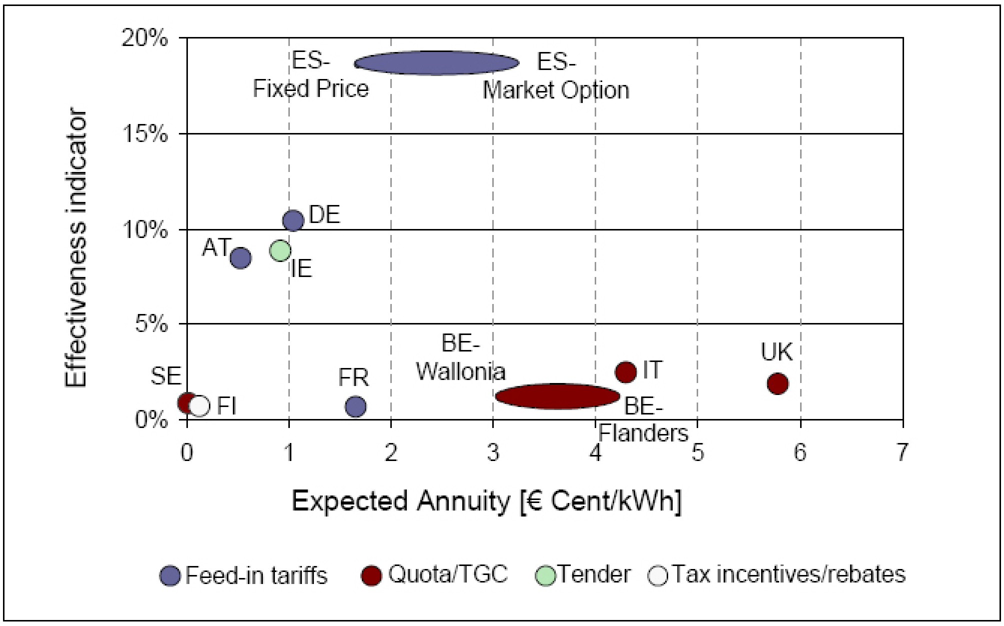
	Period 1	**Period 2**		
	Quota = Tariff	Quota	difference	Tariff
Revenue	A+B+C+D+E+F+G+H	B+C+E+F+G+H	I+J+K+L	A+B+C+D+E+F+G+H+I+J+K+L
Production Costs	D+E+F+G+H	G+H	J+K+L	G+H+J+K+L
Profit	A+B+C	B+C+E+F	A+D+I	A+B+C+D+E+F+I
Subsidy	A+B+D+E+G	B+E+G	A+D+I+J+K	A+B+D+E+G+I+J+K
Subsidy rent captured by firm	A+B	B+E	A+D+I	A+B+E+D+I

Both quotas and feed-in laws impose a cost on the system. This cost can be borne by the taxpayer, or more often, by the electric system, which under liberalized systems will ultimately reflect costs in prices paid by consumers. By imposing costs to the electricity consumers, governments are transferring the costs of their renewable electricity targets and policies to the electric sector. In doing so, the burden of reducing externalities passes from taxpayers to electricity consumers. Since renewable electricity policies have environmental motivations, this can be interpreted as a manifestation of the *Polluter Pays Principle* (Nielsen & Jeppesen 2003). The *Polluter Pays Principle* was established in Principle §16 of the *Rio* Declaration (UN 1992), agreed upon and signed by representatives of all states attending the United Nations Conference on Environment and Development (UNCED) held in Rio de Janeiro of Brazil in June 1992, also known as the Earth Summit. Renewable electricity goals, however, have non-environmental motivations as well, such as energy security and job creation. Therefore, promotion of renewable electricity could be considered a public good (Menges 2003). It could be argued that imposing the burden of renewable electricity policies to electricity consumers is only a partial manifestation of the *Polluter Pays* principle, or even more, a new "*Polluter Pays for all*" principle.

Due to theoretical arguments such as the one above, feed-in tariffs have been frequently criticized for high (perceived or real) overall costs (Menanteau 2003). Conversely, quota systems have been presumed to have higher efficiency than feed-in tariffs, by taking advantage of trading provisions and the associated efficiency brought by markets. In theory, under a tradable certificate system, producers will deploy renewable electricity technologies where it is cheaper to do, therefore realizing the comparative advantages of certain sites/technologies and reducing the overall costs.

However, as already mentioned in Chapter 8, real data shows that feed-in tariffs have proved to be more cost-efficient than quota systems. Figure 62 clearly illustrates costs of quota systems and costs of feed-in law systems for wind power in Europe.

Figure 64: Effectiveness and Cost for selected Renewable electricity policy schemes in the EU for wind power.



Source: COM(2005) 627 Final

There are various possible explanations for the observed inefficiency of quota systems observed in Figure 64. In general, quota systems have been ineffective for promoting renewable electricity deployment, as will be seen next. This means countries with quota systems have not achieved substantial deployment of renewable technologies, in turn creating a limited supply of renewable energy certificates.

Since efficiency is defined as the cost per unit produced, one explanation can be associated to fixed costs of the policy, such as administrative costs. The less renewable electricity is produced, the higher the costs per unit will be. Another cause can be the lack of market “thickness” and availability of certificates. Low availability can drive up the costs of compliance, and “thin” markets tend to be inefficient. In other cases, such as the

U.K., explained in Chapter 8, the causes of high prices for renewable certificates can be attributed to specific provisions of the policies, such as the revenue recycling provision.

Advocates of quota systems expect that, as quota systems grow, efficiencies will start to show and the cost of the policy will decrease.

Feed-in laws have the potential of being costly, and producing windfall profits for producers, as discussed in Chapter 4. Such high costs windfall profits have been observed in the past, in Denmark, Germany and Spain. Feed-in laws have subsequently been adjusted to provide for more flexibility and transfer the rents of innovation to consumers. Figure 64 also shows the effectiveness of promotion policies. But how is effectiveness measured? As already noted, a policy is effective if it achieves its goals. For example, an *additionality* criteria could be used, – the extent to which additional renewable electricity is installed (Menges 2003)

Some countries with feed-in-laws have surpassed their national targets (Lauber 2004). For example, FIT mechanisms have proven extremely successful in Germany (EEG), Spain (RD2818/1998), and Denmark, where the three countries surpassed their initial official targets for renewable energy. But other countries with feed-in laws, such as France, did not achieve their targets.

Likewise, some countries/states with quota systems have achieved their goals, while most have not. As noted in Chapter 6, in many cases the objectives were so unambitious to begin with that meeting the goals hardly represents any success (Glickel 2003). In addition, the percentage of a quota must not be interpreted as an ambitiousness level, because it has to be compared with the existing renewable capacity/generation in the electric mix (REN21 2005).

Effectiveness in Figure 64 is defined according to an estimate of achievable mid term potentials for each particular technology in each particular country. In particular, effectiveness is defined as the percentage of the remaining target achieved in a particular year, according to Equation 1, which is a simplified version of the original (Ragwitz et al 2006),

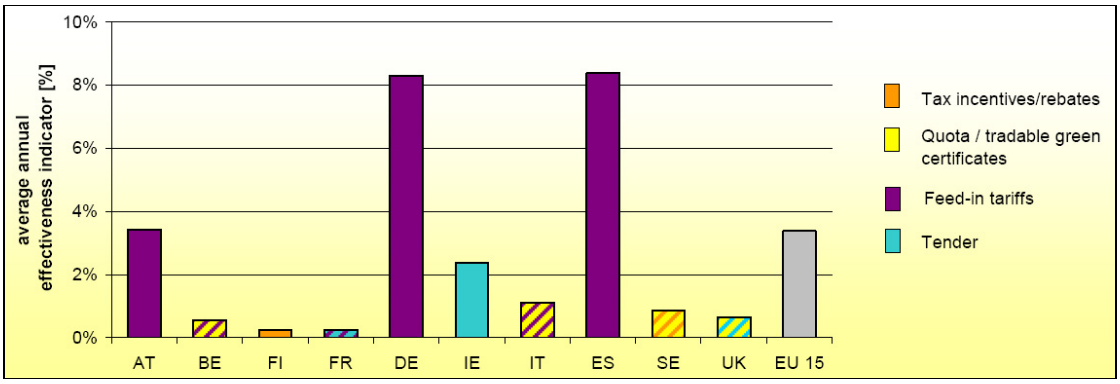
Equation 1: Effectiveness definition in Figure 64

$$E = \frac{CAP_n - CAP_{n-1}}{POT2020_n}$$

where CAP_n is the installed capacity in year n and POT2020 is an estimate of realizable mid term potential by year 2020.

The effectiveness shown in Figure 64 is for year 2004. It happens to be that 2004 was a particular good year for installation of wind power in Spain. Therefore Figure 64 could be misleading, showing Spain as having a disproportionately effective policy. However, averaging effectiveness indicators over several years can give a better picture. This is shown in Figure 65.

Figure 65: Averaged Effectiveness for select European countries



Source: Ragwitz et al 2006

It can be observed that the four countries that outstand in Figure 64, that is, Spain, Germany, Ireland and Austria, also outstand in Figure 65, therefore showing that, albeit Figure 64 might exaggerate the effectiveness of Spain's policies, it captures nevertheless the big picture adequately. And the big picture is that feed-in laws are more effective than quota systems.

14 – Innovation

Innovation is a critical element for renewable energy technologies and for renewable electricity polices.

Most policies for the promotion of renewable electricity work under the explicit or implicit assumption that renewable electricity cost will eventually be competitive on its own with fossil fuels and there will be no need for further specific support. This competitiveness will presumably be caused by increasing prices of fossil fuel electricity (due to scarcity and internalization of externalities, particularly climate change), and what is relevant to this section, due to innovation. As discussed in Chapter 5, direct public investment in R&D can foster innovation. However, in this section, I address a different question: how do quota systems and feed-in laws promote innovation? Before addressing this question, I will explore another concept implicitly present in most polices: learning curves.

11.1 – Learning Curves

The concept of learning curves in energy technologies (McDonald & Schrattenholzer 2001) is widely diffused among policy makers. Leaning curves are also referred as experience curves (van Arkel *et al* 2003). Leaning curves describe in an empirical way how costs decline with cumulative production. Learning curves do not offer an explanation of what drives the cost decline.

Under learning curves, the pace of reduction for each technology is described by the learning rate (LR), that is, the percentage at which the cost is reduced for each doubling of cumulative production. Learning curves are commonly described by Equation 2 or a similar variant.

Equation 2: Learning Curves

$$C_t = C \cdot \left(\frac{P_t}{P} \right)^{\alpha}$$

Where C_t is the cost at a given time t, P_t is the cumulative production at time t, C is the cost at a time when there was a cumulative production P, and α is a learning elasticity parameter. The progress ratio (PR) is defined as 1- the learning rate, PR=1-LR. In other words, if the learning rate is 20%, that is, each doubling of cumulative production reduces cost by 20%, then the progress ratio is 0.8, meaning that each doubling of cumulative production reduces the cost to an 80% of the former cost. The progress ration and the learning elasticity parameter are related by the following relation: $PR=2^{\alpha}$.

The learning curve is easily understood in a graphic manner, such as represented in Figure 66.

Figure 66: Theoretical learning curves

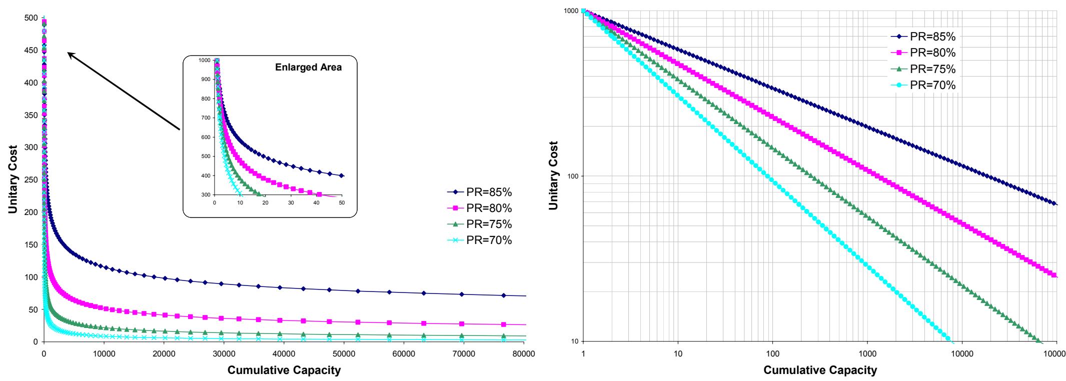


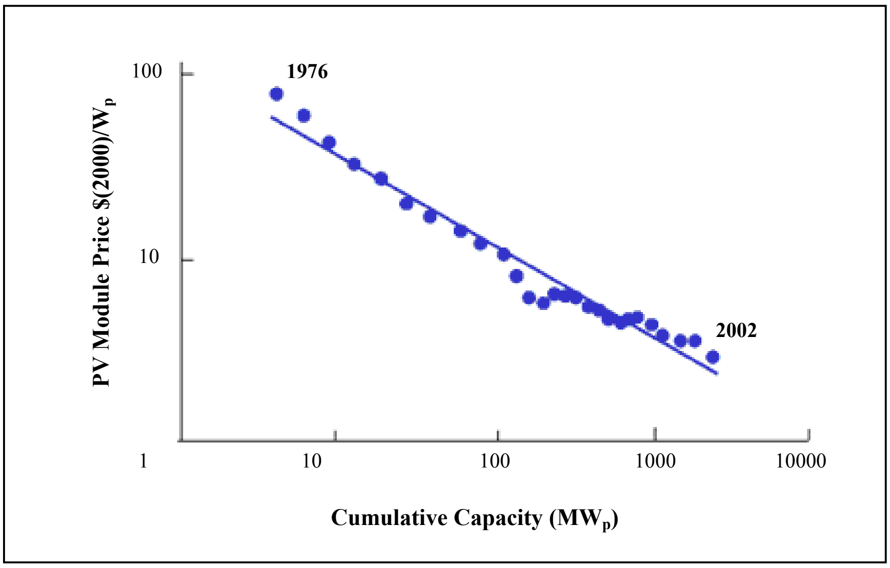
Figure 66 illustrates the concept of learning curves. The two figures are for the same points, but one in linear scale and the other in double logarithmic scale. The double logarithmic representation has the advantage that the Progress Ratio can be directly calculated from the slope. In Figure 66 four different progress ratios are shown (85%, 80%, 75% and 70%)

In the case of renewable electricity, cumulative production can be measured in either installed capacity or cumulative generation. However, installed capacity is the measure generally used.

Figure 66 shows a theoretical learning curve. The next figure, Figure 67, shows a real learning curve for the case of Solar PV.

The cost decreases in solar photovoltaic have been consistent with a learning rate f 20% (PR=0.8). However, it is interesting to see that cost reductions fluctuate, with periods of faster and slower learning rates. It is also interesting to see that cumulative capacity is measure as cumulative production of solar PV panels, regardless of whether they are used to power a 10kW solar plant or less than a watt for a solar calculator.

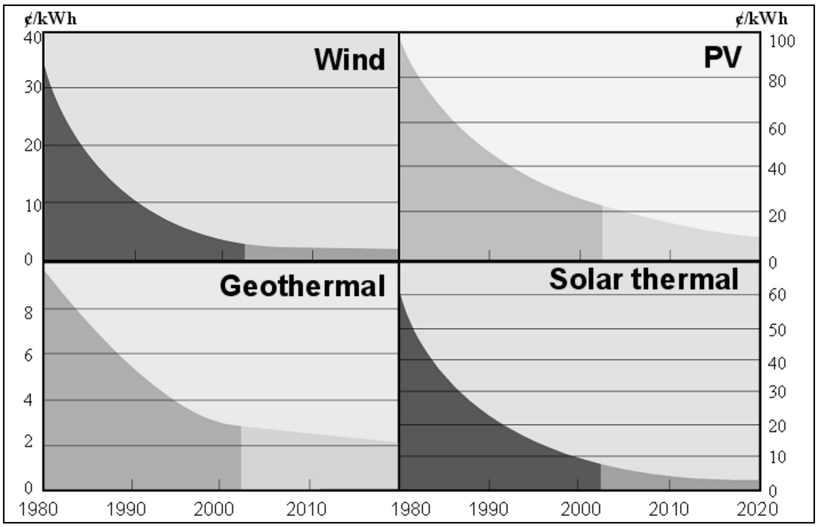
Figure 67: Solar PV Learning curve



Source: van Arkel et al 2003

As noted, learning curves can be graphically attractive, which can be one of the reasons why they result so enticing for policymakers (and to influence policymakers). The next figure, Figure 68, illustrates the sort of learning curve figures to which policymakers are exposed. These type of graphs reflect historical cost trends, not necessarily precise annual historic data, and generally consider sites with good quality resource availability. The forecasts offered by these kind of graphs tend to be simple extrapolations.

Figure 68: Declining costs for renewable electricity technologies in the USA



Source: Adapted from NREL Energy Analysis Office

Figure 68: This figure illustrates declining costs for renewable electricity technologies in the USA from the 1980's till projections in 2020. The vertical axis is ¢$/kWh, in constant year-2000 US$

In the case of Figure 68, the schematic learning curves are adapted from the United States National Renewable Energy Laboratory (NREL). I want to bring special attention to the almost 20-year projections. Based on learning curves, costs come down as a function of installed capacity. Nevertheless, the horizontal axis in Figure 68 is time, not installed capacity. These differences are easily overlooked by the policy maker, but in changing the horizontal axis from installed capacity to time assumptions need to be made about deployment rates. These assumptions (as well as the choosing of scale) can greatly affect the way one graph looks. Another problem with forecasts is that, while learning curves fit with many successful technologies, learning curves do not necessarily apply to technologies that did not succeed but reached an early end (such as Zeppelin freight transport). Therefore, a price reduction in the present is no guarantee of future price reductions (van der Zwaan & Rabl 2004)

As appealing as learning curves empirical theories might be, they do not discriminate on how deployment is achieved, or whether there are particular incentives for innovation. And learning curves theories have drawbacks, the main one that they are an empirical theory that fits well some tendencies but offers no explanation.

Despite these misgivings, learning curves remain an interesting and useful instrument in formulating policy. Many of the support schemes have as an ultimate goal (again, implicit or explicit) to achieve sufficient deployment of renewables to, according to learning curves, reduce costs. This is also known as “buying down the learning curve”.

Next, I analyze what incentives are there for innovation under feed-in laws and quotas.

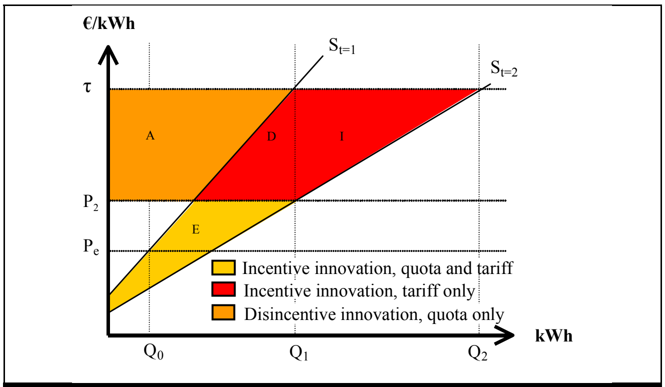
15.1 – Incentives for innovation: feed-in vs. quotas

It is generally believed that competition spurs innovation. When there are several competing firms, having a superior or more efficient technology can be the edge that makes one company more successful than another. Therefore, companies have an incentive to invest in technology, either to “out-innovate” the competitors or to avoid being “out-innovated” by them. Oppositely, it is also generally assumed that lack of competition and a guaranteed stream of revenue provides no incentive for innovation, since benefits are assured.

From these general assumptions, it is tempting to directly extrapolate to quota and feed-in law systems. It is generally believed that quota systems, because they are driven by competition, lower the prices and promote innovation more than feed-in laws, with their guaranteed prices. In theory, the theory goes, under a competitive environment renewable electricity generators will have an incentive to innovate so they can outperform their competitors and have greater profits.

However, on a closer look, it is easy to see that these assumptions do not hold and cannot be extrapolated from general competition to the case of renewable electricity. Figure 69 explores the economic incentives for the industry as a whole to innovate under quota or feed-in law systems. Figure 69 is adapted from Figure 63 from the previous section but highlighting the incentives to innovate.

Figure 69: Innovation incentives for quota and fixed price systems



	Quota	difference	Tariff
Incentive to innovate	E+F-A (may be <0!!)	A+D+I	D+E+F+I

Figure 69: This figure is adapted from Figure 63, but it specifically highlights the incentives and disincentives for quotas and feed-in tariffs to invest in innovation. Innovation will bring the supply curve from $S_{t=1}$ to a lower $S_{t=2}$. As discussed before, this leads to a quota system to generate Q_1 renewable electricity at price P_2 and a feed-in tariff system to generate Q_2 electricity at price τ. Under the new generation pattern, a quota system will capture additional rent E and F (green), but will loose rent A (in orange). If A>E+F then generators under a quota system have a net disincentive to invest in innovation. Under a feed-in tariff system, the additional captured rents are D+E+F+I (green+red areas).

Under a strict feed-in law system, producers have an incentive to invest in innovation, since they are poised to capture the rents from areas D+E+F+I in Figure 69. Therefore, their incentive to innovate is any quantity between 0 and D+E+F+I>0. In essence, the lower the costs of generation for renewable electricity generators, the larger the rents they can capture and therefore the larger their profits.

On the other hand, under a strict quota system, renewable electricity producers' incentive to invest is greatly reduced, and can be even negative! The incentive is the quantity E+F, which are the gains from cheaper production, minus A, which is a rent that producers captured under higher production costs and that is transferred to consumers as a result of a lower marginal cost curve.

With this simple analysis it is shown that, while a competitive system brings more efficiency in theory, it does not necessarily promote innovation in this particularly case.

But one might ask, what are the drivers for innovation in a feed-in law market? Do developers engage in innovation themselves? It turns out that developers and manufacturers of renewable electricity equipment tend to be different players. While developers may carry out innovation on financing architecture and project development mechanisms, technological innovation is primarily done by the equipment industry, such as wind turbine manufacturers. In the case of fixed price policies, developers are sheltered from competition, but their suppliers are not. Therefore, intense competition among manufacturers to sell their turbines, towers, and components to developers encourages price competition and innovation. The results are lower prices and more technological innovation, as has been observed in Denmark, Germany and Spain, home to world-leading wind manufacturing industries.

Quota systems, on the other hand, have not been observed to promote innovation, as measured by a local industry in countries with quota systems. High risks and low rewards are probably responsible. Low rewards to innovation have already been shown in Figure 69. High risks come from competition itself. In the absence of long-term contracts, renewable electricity developers not only have to face competition from other developers in the present, but also from future deployments, which in five or ten years will come on-line with more advanced technology and lower costs. Therefore the risks are higher under quota systems, which do not have income guaranteed for a large portion of the project lifetime as do feed-in-laws.

16 – Efficiency under uncertainty

Uncertainty has a cost. For that reason businesses and investors do not like it. Likewise, uncertainty imposes a toll on policies and a cost on society. It is often the case that policies are designed under certain assumptions *ex ante*, but reality actually differs from those assumptions. Differences can range from negligible to very substantial, and impose deadweight losses on society. In the case of renewable electricity policies, both, the marginal social benefit (MSB) and the social marginal cost (SMC) curves have large uncertainties, uncertainties on the facts and uncertainties in the money valuation. The economist Weitzman (Weitzman 1974) demonstrated that under uncertainty regarding SMC and SMB, quotas or fixed prices may be preferable policies to attain a social optimum, depending on the relative slopes of the SMC and SMB curves. Using Weitzman's results, I argue that fixed price policies are more efficient than quotas if uncertainty is considered. Figure 70 illustrates Weitzman's results applied to the renewable electricity case.

Figure 70: Losses due to uncertainty for quotas and fixed prices

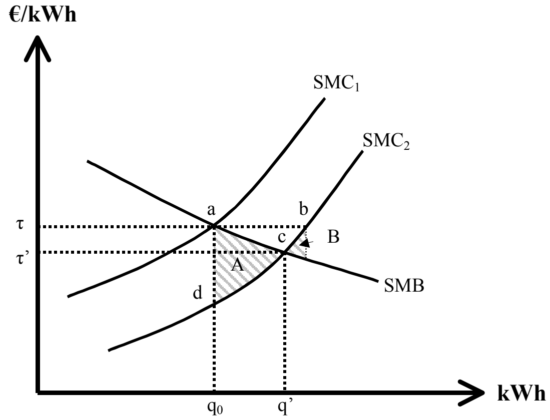


Figure 70: Weitzman's results applied to renewable electricity. Initially a policy is designed for estimated SMB and SMC_1. Both, a fixed price τ or a quota q_0 will attain optimal point a. However, SMC_1 was uncertain and real marginal costs turn out to be SMC_2. The new optimal point is c instead of a. To reach point c, fixed prices should have been τ' and the quota q'. What is the loss associated to each policy? The quota q_0 will reach point d instead of a, and will cause a deadweight loss shadowed in area A. The fixed price τ will reach point b instead of a, and will cause a deadweight loss shadowed in area B. These type of losses are known as deadweight losses. Clearly, the deadweight loss associated with fixed price policy is lower than the loss of a quota system under uncertainty. The same results can be obtained if the $SMC_2 > SMC_1$, or if SMB is shifted up or down.

In Figure 70 the key assumption is that the SMB curve has a flatter slope than the SMC curve. Social benefits from renewable electricity are several. The most obvious is mitigation of greenhouse gas emissions (particularly CO_2) and climate change. Carbon dioxide's effects on Climate Change depend on its concentration in the atmosphere, not on CO_2 emissions. Therefore, CO_2 behaves like a stock pollutant, where damage is not a function of emissions at any particular moment, but of cumulative emissions over time. Yearly CO_2 emissions from fossil fuel are the primary source for increased CO2 concentration in the atmosphere. Of those emissions, roughly one-third correspond to electricity generation. It is estimated that current emissions contribute around 1.9 pmm per year to global CO2 concentration, of a total of 379ppm in 2005 (IPCC 2007a). Renewable electricity even if deployed to provide a significant part of electricity supply, would still have a low marginal impact on total carbon concentration in the atmosphere. If we consider the damage function of climate change to be proportional to CO_2 concentrations in the atmosphere, then the marginal benefits of emission abatement will be very flat. This is a property of all stock pollutants. The only exception occurs when there is a threshold concentration in the damage function, above which non-linear or catastrophic damage occurs. Since no thresholds are considered in climate scenarios for current atmospheric concentrations (379 ppm, up from pre-industrial concentrations of 280 ppm), it can be assumed that the SMB of renewable energies due to climate change is relatively flat, at least for the 21st century.

Other benefits from renewable electricity are energy security and creation of employment, but these are not as clear-cut to analyze from the Weitzman perspective. For instance, one might consider that energy security would contribute to a flat slope. The world's leading economies are largely dependent on energy imports. Energy security benefits will rise slowly, tending to level off gradually if massive amounts of renewable electricity are produced. Therefore, the marginal benefits, being the quantity derivative, would have a low and decreasing slope. This is illustrated in Figure 71.

Figure 71: Social benefit and marginal benefit for energy security

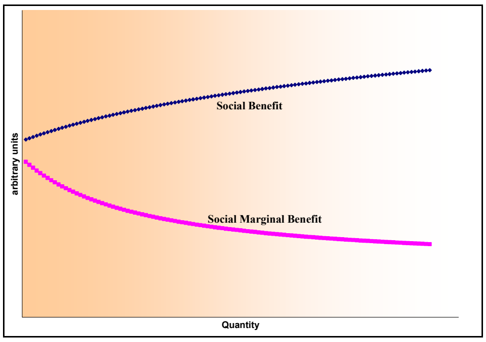


Figure 71 shows an imaginary curve for the social benefits of renewable electricity with regards to energy security, and its quantity derivative, that is, the social marginal benefits.

As for employment, it is unclear how it would contribute to the SMB slope, but it presumably would be a smaller contribution than climate change or energy security. As noted in Chapter 8, renewable electricity is more labor-intensive than conventional energy sources (Ecotec 2002, Goldemberg 2004, Kammen *et al* 2004, REN21 2005).

The case for steeper social marginal cost curves is more straightforward. In the exploitation of natural resources, and renewable energies are a natural resource, better and cheaper resources are generally tapped first, what is known as Ricardian ordering.

It has already been shown that deployment of renewable electricity has been more a question of adequate policies than resource potential. However, within countries with adequate supporting policies, such as Germany and Denmark, most of the best wind quality locations have been already used. As less windy locations are tapped, the marginal costs of production increase. If more expensive technologies, like solar PV or biomass are added to the mix, then the marginal cost increases even more than for wind power alone. It can be considered that largest part of the social marginal cost is actually the monetary cost. The approximation SMC=MC is appropriate for this exercise, as most renewable electricity externalities, such as the visual impact of wind turbines, are proportional to the installed capacity. Therefore, the marginal cost, which is a derivative quantity, can shift upwards or downwards according to those impacts, but its relative slope will stay unchanged.

With the above arguments, there is a case to consider that social marginal cost curves are steeper in general than the social marginal benefit curves of renewable electricity. Given that circumstance, and considering Weitzmann's arguments, as illustrated in Figure 70, it can be asserted that feed-in law systems are superior policy instruments in attaining a social optimum with regards to uncertainty regarding the marginal costs and benefits of renewable energy.

17 – Administrative issues and regulatory risk

When a policy is defined, an institutional setting needs to be arranged to implement and maintain the policy.

From and administrative point of view, feed-in tariffs are simple to implement, relatively quick to establish, and have low regulatory and administrative costs (WWF 2003, Menantenau et al. 2003, Madlener & Stagl 2005). A feed-in tariff needs basically two tasks: (1) definition of the policy, including premiums and tariffs, and (2) registering transactions; and (3) redistributing the costs of supporting renewables.

In the case of quota systems with REC markets, some tasks are necessary in order to ensure the proper functioning of REC markets. Such tasks can be carried out by independent agencies, the grid operators, or the respective ministries of economy or energy, depending on the national political traditions. Responsibilities include: (1) definition and implementation of operational rules, (2) issuance and redemption of certificates, (3) monitoring of certificates to ensure they correspond to generated renewable electricity and are not duplicated, (4) registering of RECs and REC transactions, (5) control of compliance with quotas and, (6) imposing sanctions.

Regulatory Risk

Policy consistency is a key requirement for policies to succeed. Policy changes create uncertainty and hinder deployment of renewables. Policy predictability (Madlener and Stagl 2005), on the other hand, provides the necessary stability for the renewables sector to develop and mature.

Regulatory risk is the risk associated to changes or discontinuity in policies. A typical example is the U.S. production tax credit, which has been in place intermittently, causing stop and go effects in the wind industry (Chapter 9, Figure 57). Another example is the Netherlands, described in Chapter 8, with many regulatory changes in recent years.

Both quotas and fixed prices are subject to regulatory risk, in the sense that they are subject to future changes in policy and political winds. However, the risks are of different type, and can be mitigated to different extents.

The main regulatory risk for feed-in laws is the discontinuity of the policy, or a lowering of the premium. To deal with that risk, most feed-in-laws have provisions that guarantee the subsidy to generators already producing under that scheme. This protects project developers. However, the manufacturing sector is not protected because future policy changes may reduce or stall new projects and hence demands on equipment. However, no policy is 100% guaranteed, and reversal attempts happen often, with changes of government or changes of the person heading the particular ministry or department in charge. For example, in Spain, in late 2006 a proposal was made to change the retribution system of wind power under feed-in laws, with a lower retribution level. In early 2007, a proposal was made that the changes be retroactive, causing outrage among renewable electricity producers and even some major utilities such as Iberdrola, which threatened to go to court over the retroactivity court. In the end it seems the Spanish government retracted from its intention but as May 1st, 2007, the new retribution system for wind power in Spain was still uncertain. This might have been the cause that in 2006 Spain went from #2 in new installed wind power worldwide to #4, behind Germany, the US, and India. The case of Spain also reflects the difficulty of reversing a policy once a stable renewables sector is established, with strong support from the business community, as well as the possible problems from a legal point of view of reversing a feed-in law with guaranteed compensation.

Quota systems also face the risk of policy discontinuity or change. But in the case of quotas a policy change can damage not only the new projects, but also the existing ones, particularly in the case of RPS. Renewable energy certificates (REC) have no guaranteed price. Price is based on demand, and demand is driven by the quota. If the quota is changed or removed, then RECs become worthless, leaving renewable electricity producers without a vital revenue stream. This problem is exacerbated by the lack of long-term contracts for REC (with some exceptions such as Texas, as noted before). There have been no documented cases yet of reversed RPS policies.

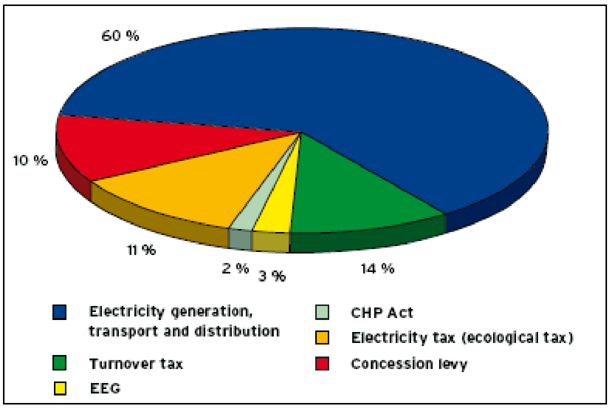
A different risk for quota systems is a lack of enforcement, which would be equivalent to a lowering of the quota and would also reduce REC prices.

18 – Funding

Funding to pay for the premium or the premium can originate from different sources. The most common are cross-subsidization by the electricity consumers, the Treasury, or a combination of both.

For example, in Germany and Spain, both with feed-in laws (EEG 2004 and RD 436/2004), the cost of renewable electricity premium is borne by the electricity consumers. It is like a hidden tax that increases final price to consumers. So far (2006), no strong public opposition has happened because levying electricity is a common practice, and similar fees are applied to subsidize national coal, energy efficiency, the nuclear industry or transition costs to liberalized markets. Figure 72 is a good illustration of this. In Figure 72 the different costs of average electricity at the household level are shown for Germany. The average household price in 2005 was 18.6 ¢€/kWh (Federal Ministry 2006a). Total costs of the feed-in-law in Germany were estimated at 200m€ for year 2000 (Menanteau et al 2003).

Figure 72: Composition of 2005 household electricity average price, Germany



Source: Federal Ministry 2006a

Alternatively, funding can be provided from the state budget or the Treasury. Direct public funding, however, can be politically, economically or legally unsustainable. If the premium is paid by the Treasury, as renewable electricity production grows, so does the cost of premiums to the taxpayer. The economic burden might be difficult to justify during budgetary negotiations. Denmark used to have a feed-in-law publicly funded. Political pressure due to the increasing burden on the Treasury caused Denmark to change its feed-in-law in 2001 (Lauber 2004b).

Mixed schemes that split the costs between consumers and the State are also possible in theory, cross-subsidizing near-commercial technologies such as wind power while maintaining public support for demonstration technologies, such as wave-power.

Quota systems with REC markets do not need a specific source of financing, since they are imposed on the system. As discussed before, the administrative system to maintain quotas does need financing.

19 – Technology and Geographical dispersion

In some cases it is the intent of the policy not only to deploy renewable electricity, but to deploy it with a certain geographical dispersion and across technologies. Feed-in laws and quotas have different tools to achieve this.

19.1 – Technology Diversity

Different renewable electricity technologies are at different stages of maturity, as described in Chapter 3. Therefore, in order to be commercially deployed, some technologies need more support than others. Additionally, countries have different endowments of different renewable energy sources. Therefore, a country with a large solar resource might be interested in promoting solar technologies while another with a long ocean coastline might want to promote wave energy.

Under feed-in laws, renewable electricity technologies can be differentiated through technology-dependent premiums or tariffs: each technology or group of technologies can be assigned a particular premium/tariff. This is the most common approach under feed-in laws. For differentiated levels of support for different technologies under feed-in laws, see for example Table 24 (tariffs in Germany) and Table 28 (premiums in Spain) in Chapter 8.

Under quota systems, discrimination amongst technologies is more complex. The approached followed in some US States with quota systems is to create groupings, or types of quotas. For example, the State of Pennsylvania has a quota system with two tiers, and a requirement of 8% from electricity from Tier I and 10% from Tier II by 2020 (DSIRE). However, a quota system cannot discriminate as effectively amongst technologies, because in order of taking advantage of the trading provisions and market efficiency, it needs a certain market thickness. In addition, establishing a quota for each renewable electricity technology is a cumbersome undertaking, difficult to implement and administer, and without the flexibility to adapt to technology developments.

19.2 – Geographical dispersion

It may be interesting for premiums to take into consideration geographical dispersion issues for several reasons. For example, it might be a policy or interest of the country to achieve a regional balance in the deployment of renewable electricity in order to accommodate regional interests. Likewise, a government might be interested in regional deployment of technologies to achieve some of their co-benefits, such as job-creation or grid robustness.

In addition, countries with more than one electricity system, such as Germany or the United States, can be interested in a fair distribution of the costs of promoting renewable electricity, regardless of which zone renewable technologies are deployed in. For example, this was one of the early problems found by the initial German feed-in law (StromE). The best wind resource is located in Germany's North, and most wind turbines were erected there. Consumers of the Northern region had to shoulder a larger share of the national policy's cost. As a result, the feed-in law was modified (EEG 2000) and "equalization" clauses were introduced. What equalization does, in short, is to pool the total cost of feed-in laws from all systems, and then distribute them according total electricity consumption in each system. For a specific example of equalization, see for example Article 14 of EEG 2004.

Under a quota system, geographical distribution can only be achieved through the scale of the trading market. In theory, there could be possible approaches for fostering geographical distribution. For example, a REC multiplying factor could be given according to the density of deployment of renewables in certain areas. However, such types of approaches would add another layer of complexity and administrative burden to the system, and have not been experimented.

20 – Experience Deployment rates and comparison summary

Early in the 00's decade some predicted rapid replacement of feed-in support schemes by quota systems and REC markets (Menanteau *et al* 2003).

Table 49 gives an idea of the pace of enactment of feed-in laws and quota systems until 2004. It can be observed that most European countries have feed-in laws, while most of the US states have quota systems. Many of the countries with early policies but little deployment had ineffective policies, either quotas or feed-in laws.

Table 49: Evolution of Feed-in Policies and Quota systems

Quota	year enacted	Feed-in
	1978	• USA
	1990	• Germany
	1991	• Switzerland
	1993	• Denmark • India
	1994	• Greece • Spain
• USA (Massachusetts)	1997	• Sri Lanka
• USA (Connecticut, Wisconsin)	1998	• Sweden
• USA (Maine, New Jersey, Texas) • Italy	1999	• Norway • Portugal • Slovenia
	2000	• Thailand
• USA (Arizona, Hawaii, Nevada) • Australia • Belgium (Flanders)	2001	• France • Latvia
• USA (California, New Mexico) • United Kingdom • Belgium (Wallonia)	2002	• Austria • Brazil • Czech Republic • Indonesia • Lithuania
• Minnesota (USA) • Japan • Sweden	2003	• Cyprus • Estonia • Hungary • Korea • Slovak Republic
• USA (Colorado, Maryland, New York, Pennsylvania, Rhode Island • India (Karnataka, Madhya Pradesh, Andhra Pradesh, Orissa) • Poland • Canada (Nova Scotia, Notario)	2004	• India (Andra Pradesh, Mahdya Pradesh) • Italy • Israel • Nicaragua

Source: Ren21 2005

Herman Scheer, a German politician and long-time renewables advocate noted that quotas do not work because renewable electricity is primarily a technology market and not an energy market (Scheer in Reiche (ed) 2005). Scheer is one of the fathers of the German feed-in law, and his views on quotas may be biased. Nevertheless, Part IV has shown that in regard to efficiency, effectiveness, innovation, administrative issues and access to funding, feed-in laws are superior instruments to quotas.

Table 50 shows the comparison of main aspects between quotas and feed-in laws.

Table 50: Feed-in laws and quotas comparison

	Feed-in-laws	**Quotas**
Effectiveness to promote new investment	Very effective in certain countries	So far not very effective
Cost-efficiency	In theory less efficient than quotas. In practice more cost efficient so far in successful countries.	Potentially very efficient (trade benefits)
certainty and reduced risk to investors	yes	no
control over achievement of targets	indirect	yes, but in practice targets not achieved
success stories	Germany, Spain, Denmark	Texas (partially, other factors such as PTC)
simplicity	yes, perceived	no
differentiation between technologies	yes	no, partially through bands
geographical dispersion	equalization, differentiated tariffs	
promotes innovation	yes	no, due to uncertainty
enforcement needed	only of grid access provisions	needs effective and credible enforcement system to work

PART V – POLICY PROPOSALS

Part V of this dissertation makes policy proposals based on the material exposed in Parts I, II, III, and IV. In particular, Part V includes an innovative proposal for harmonization of feed-in laws in the European Union (Chapter 17), and the creation of flexibility mechanisms for such a harmonized systems, including a profitability threshold, a premium revision mechanism and a target revision trigger (Chapter 18).

Part V also raises questions such as the ownership of rights derived from renewable electricity production, be it carbon credits, renewable certificates or some other tradable asset, as well as the need for special consideration for energy intensive industries and small-scale owners of renewable electricity generation. These issues are addressed in Chapter 19.

21 – Harmonization of feed-in laws in the European Union

21.1 – Introduction

Feed-in laws have proven to be both effective and cost-efficient, as demonstrated by the German and Spanish examples (Chapter 8) and as acknowledged by the European Commission in COM(2005) 627. Feed-in laws are compatible with liberalized electricity markets, and as established by a European Court of Justice ruling (PreussenElektra vs. Schleswag AG.), are compatible with EU state-aid and competition rules. Feed-in laws merit consideration for harmonization as the EU support mechanism for renewable electricity.

This chapter develops a suitable methodology for EU harmonization of feed-in laws based on a modular premium system. Harmonization is not of the premium itself, but of the *methodology* used to calculate the premium. This chapter defines what elements should be included into the premiums.

It has been generally assumed that harmonization of feed-in law support schemes is not feasible or, in European Commission's words, "difficult" (COM(2005) 627 Final, page

4). Some of the stated arguments against feed-in law harmonization are that it is difficult to establish an adequate value for an EU-wide tariff and the possibility of over-pricing, which creates windfall profits for producers and undue costs for consumers.

Such drawbacks to harmonization may be overcome if attention is given to harmonizing the methodology used to calculate the premium rather than to harmonizing the premium values. Hence the proposed flexibility mechanisms would also be harmonized. This approach has some advantages. Electricity markets have been liberalized in all Member States, following Directive 96/92/EC on common rules for the internal market in electricity. Nonetheless, electricity markets have different rules and characteristics, and show different wholesale and retail electricity prices across the EU. These differences make a straightforward EU-wide feed-in-tariff or fixed premium un-feasible. With the proposed approach of a harmonized methodology, premium values would initially differ from one Member State to another, according to their national circumstances. Nevertheless, since the same methodology would be used, if national electricity markets converged into the single European electricity market as planned, then, premiums and support for renewable electricity, by construction, would do likewise.

Harmonization would most likely take place under a new Directive on the promotion of renewable electricity, thereby updating Directive 2001/77/EC. This new/revised Directive could result from current discussions on the *Green paper for a European Strategy for Sustainable, Competitive and Secure Energy* (EU 2006), or from a separate process.

21.2 – Definition of the Model.

The approach for feed-in law harmonization proposed in this chapter consists of a feed-in law with a modular premium guaranteed for a period of 20 years.

This feed-in law would: (1) guarantee access to the grid and transmission for renewable electricity; (2) establish a premium; and (3) provide flexibility mechanisms (the later explained in Chapter 18). Premiums are chosen rather than tariffs because tariffs embody the price of electricity, while premiums let the market determine the price of electricity and then add the incentive. Therefore premiums have more flexibility and less potential for market distortion and over/under funding than tariffs, particularly if prices for conventional power change significantly.

In a harmonized feed-in law with a premium, renewable energy producers sell their electricity in the market. In addition to market prices for electricity (which are determined by the spot market or through bilateral or long-term contracts) renewable electricity producers receive a premium. The revenue for a renewable electricity producer in a particular country is calculated according to the following formula:

Equation 3: Revenue under a premium system

$$R_x = \int_t P_{x,t} \cdot kWh_t \cdot dt + \sigma \cdot kWh$$

where: R = revenue; P = market price; x = country; σ = premium; and kWh the power delivered to the grid.

The first component of Equation 3 reflects revenues from selling electricity in the market. Market price depends on the time of the day, with one kWh generated at peak hour being more valuable than one kWh generated in the middle of the night. Prices in real electricity markets are updated in quasi real time, with updates calculated every few minutes.

The second component of Equation 3 reflects revenue from the premium σ. Under the proposal for harmonization suggested in this chapter, σ is not a constant number, but is set separately for each country and technology. Although σ varies for each country and technology, and is adjusted over time, σ should remain constant for any particular installation in order reduce uncertainty on future revenue flows and to make financing accessible. Under the proposed scheme, when a renewable electricity plant is commissioned, the premiums it receives are fixed for the next 20 years. Because premiums can be revised over time, a second renewable electricity plant of the same technology commissioned on a different year might receive a different premium, also constant for the 20 years after its commissioning.

Under the proposed feed-in law the premium is calculated in a modular way that explicitly accounts for the different concepts being supported under this promotion scheme. The modular approach has the advantage that specific concepts can be added or removed from the premium over time, thus providing flexibility. Moreover, allocation of premium components to specific concepts provides transparency to the policy and allows for different funding provisions for each component.

The following concepts are included in the proposed harmonized premium: (1) investment costs; (2) grid services; (3) a political incentive. Additionally, a non-harmonized component is allowed to account for national priorities. This modularity is reflected in Equation 4:

Equation 4: Harmonized Premium

$$\sigma = \overbrace{\underbrace{\sigma_{RoI}}_{Investment} + \underbrace{\sigma_{Grid}}_{Grid\_Services} + \underbrace{\sigma_{EU}}_{EU\_Political\_Incentive}}^{Harmonized} + \underbrace{\sigma_{Nat}}_{National}$$

Next the three suggested harmonized components of σ (σ_{RoI}, σ_{Grid}, σ_{EU}) and σ_{Nat} are described.

21.3 – σ_{RoI}: Investment

The objective of σ_{RoI} is to provide a reasonable expectation of cost recovery for investment on renewable electricity plants. Following a system similar to Spain's (described in Chapter 8), each renewable electricity source/technology has a defined premium value. This value would be calculated considering a variety of factors including the technology costs, the expected revenues from electricity sales, and the cost of financing.

The component σ_{RoI} needs to be revised periodically to account for technological innovation, changing prices of electricity, changing financing conditions and fulfillment of national/EU goals. Those revisions must be based on transparent, pre-established, technical criteria, in order to minimize uncertainty and reduce political interference and lobbying. In Chapter 18, options are described for the revision of σ_{RoI}.

21.4 – σ_{Grid}: Grid Services

The objective of σ_{Grid} is to compensate renewable electricity producers whenever they provide grid services which are not explicitly reflected in electricity prices. Examples of such services include grid stability, distributed generation, resilience, or sustaining tension gaps. Some of these services are reflected in electricity pricing schemes in some Member States, but there is no homogeneous approach. This heterogeneity is because liberalization (the process by which electricity systems were divided into generation, transmission and distribution segments) was designed according to the particular technical characteristics of each system, generally based on large centralized fossil, nuclear and/or hydroelectric plants. In most cases, the technical provisions of current pricing systems amount to market barriers to renewable electricity deployment.

The component σ_{Grid} is country and technology dependent. Ideally σ_{Grid} would not be limited to renewable electricity producers, but include all power plants. In the long-term and under ideal conditions, σ_{Grid} would be phased out because compensation for grid services would be fully integrated into the pricing system in a non-discriminatory way, eliminating current bias benefiting large centralized fossil fuel, nuclear and hydro power plants.

21.5 – σ_{EU}: Political incentive

The political incentive premium, σ_{EU}, signals the degree of political willingness from the European Union to promote renewable energy sources. Under the proposed scheme, this component is linked to the EU stated targets on renewable electricity and is the same across Member States for all renewable electricity generators of the same kind. σ_{EU} can be the same across technologies, or, if alternative technologies are deemed a priority at the EU level, then σ_{EU} can vary accordingly. This premium is the component that gives "teeth" to EU targets, by linking them to a financial instrument.

21.6 – σ_{Nat}: National Premium

The objective of the component σ_{NAT} is to allow national priorities, which might include regional policies, to be reflected in the support scheme. In some cases, EU Member States might want to promote some renewable energy technologies beyond the official targets agreed at European level. In other cases, the use of renewable energy technologies is part of an integrated solution to a particular environmental or social problem. To allow for these special cases the national premium σ_{NAT}, compatible with the Directive, is proposed. Under the proposed scheme, σ_{NAT} is optional, unlike the harmonized σ_{RoI}, σ_{EU}, and σ_{Grid}. The national premium σ_{NAT} is highly configurable, and when used, changes from country to country according to national circumstances. Possible items included under σ_{NAT}, include social benefits, environmental benefits, regional distribution and other benefits, as shown in Equation 5.

Equation 5: Components of σ_{NAT}

$$\sigma_{NAT} = \underbrace{\sigma_{NAT-soc}}_{social\_benefits} + \underbrace{\sigma_{NAT-env}}_{environmental\_benefits} + \underbrace{\sigma_{NAT-reg}}_{regional\_distribution} + \underbrace{\sigma_{NAT-ext}}_{other\_externalities}$$

Examples of integrated solutions to a social/environmental problem in which renewable electricity can play a key role are manure treatment in areas with high concentrations of livestock, or forest fire prevention.

A different application for σ_{NAT} can be regional distribution. It might be in a Member State's interest to achieve broader distribution of renewable electricity plants even if that means exploiting sub-optimal (resource wise) locations, in order to share the co-benefits (and impacts) of the plants, such as creation of local employment and infrastructure or visual impacts from wind turbines. If a Member State wants to provide incentives for regional distribution, it can use σ_{NAT} to complement σ_{RoI}.

A further application of σ_{NAT} is that it can be used as the basis for a transition mechanism from previous support schemes to the harmonized feed-in law.

21.7 – Funding

A critical question for any policy is how that policy is funded. A feed-in law as proposed here does not involve a direct subsidy from the state. In a fully liberalized electric system, remuneration for renewable electricity with the proposed feed-in law premium, would work in the following way: (1) all electricity producers (including renewable electricity producers) make their bid in the daily or intra-day electricity market; (2) electricity producers bidding under the clearing price, have their electricity programmed for delivery; (3) the TSO or an independent body pays electricity producers for their sold electricity at the clearing price; (4) in addition to the clearing price, renewable electricity producers get paid by the TSO or the independent body the premium established for each one of them; (5) the TSO or the independent body sells electricity to distribution companies, using total costs (prices + premium + transport) to calculate its selling price for a particular period; (7) distribution companies sell electricity to final consumers, competing among themselves, at a price determined by the market and their commercial strategies.

The cost of the proposed premium system is imposed on the electric system, eventually being passed onto the final electricity consumers. Initially, as Member States transpose the new harmonized feed-in premium into their legislations, premiums are paid at the national level by national consumers. In countries with more than one electric system, an equalization provision, such as the one in Germany, can be necessary to evenly spread the cost of the policy. If and when a single EU electricity market is established, some components of the premium σ, particularly σ_{EU}, can be shifted from the national consumer to the European electricity consumer.

The funding of σ_{NAT} can be different. Because of its special nature, designed to accommodate Member State priorities and needs, σ_{NAT} can either be funded through the same mechanism as the harmonized premium or by other entities. For example, the

National Parks System could finance σ_{NAT} in the case of a biomass plant clearing public forests for forest fire prevention.

22 – Flexibility mechanisms

One of the keys for a successful feed-in law is that it needs flexibility to allow adjustment for technology innovation, changes in the economics of the energy sector, and fulfillment of established targets, while providing a fair distribution of costs and a stable investment framework.

Three flexibility mechanisms are proposed next, which can be applied to the harmonized feed-in law proposed in the previous chapter or to any feed-in law in general:

(1) a profitability threshold to avoid windfall profits;
(2) a semi-linear step function to revise premiums; and
(3) a target revision trigger.

These mechanisms should be based on objective, pre-set criteria, to prevent interference from lobbying and short-term political interests, as well as to minimize regulatory uncertainty. The proposed mechanisms also ensure that the benefits of technology innovation are passed down to final electricity consumers, while maintaining incentives for innovation.

22.1 – Profitability threshold

To protect against windfall profits while ensuring an adequate incentive, the use of a profitability threshold is proposed. Windfall profits for renewable electricity producers are one of the main risks of feed-in laws. Windfall profits can occur when premiums are set too high or rendered too high by innovation, and/or by increases in the price of electricity. This has been the case for example in Spain in 2004 and 2005.

The proposed profitability threshold specifies the overall remuneration for renewable electricity that would make a technology competitive at the time of deployment without the need of any support scheme. If the price of electricity increased enough to make total revenue per kWh (price plus premium) higher than the profitability threshold, then the premium would be reduced until total revenue equals the profitability threshold. In the harmonization scheme proposed in Chapter 21, the profitability threshold would affect σ_{RoI}, and $\sigma_{EU,}$ but not σ_{Grid}, which is a compensation for grid services. In other words, if the price of electricity alone was enough to reach the threshold, the renewable electricity producer would not receive σ_{RoI} or σ_{EU}, but would still receive σ_{Grid} on top of the electricity price.

The profitability threshold must be defined at the same time as the premium, and be locked for each installation for the 20-year duration of the support scheme. In that way, if future technological innovation reduces the profitability threshold, current investors are still guaranteed recovery of their actual costs.

Strategic behavior could occur as a result of the profitability threshold, and should be avoided. Producers of non-dispatchable renewable electricity (wind, solar) are unlikely to display a strategic behavior pattern because their incentive is to produce as much electricity as possible when the resource is available.

Producers of dispatchable renewable electricity such as hydro and biomass, however, may engage in strategic behavior in order to maximize profits. In particular, if electricity prices are high, those producers could collude with conventional peak power plants under some benefit-sharing scheme and sell at times of the day when electricity is cheap, allowing peak power plants to reap the benefits of peak time electricity prices. To reduce perverse effects and strategic behavior, an average electricity price (instead of hourly prices) should be used when calculating the profitability threshold for dispatchable technologies. This way, dispatchable electricity sources have the incentive to sell at peak hours, thus increasing the electric system's efficiency.

22.2 – Premium revision and technology innovation

There are different ways to revise premiums to account for technological innovation. One is fixed degression rates, such as those used in the German EGG. Fixed degression rates foster early deployment.

In order to allow adjustment for technological innovation, revisions for premiums can be structured using a semi-linear step function. This proposed function is illustrated in Figure 73.

Figure 73: Adjustment of premium for technology innovation

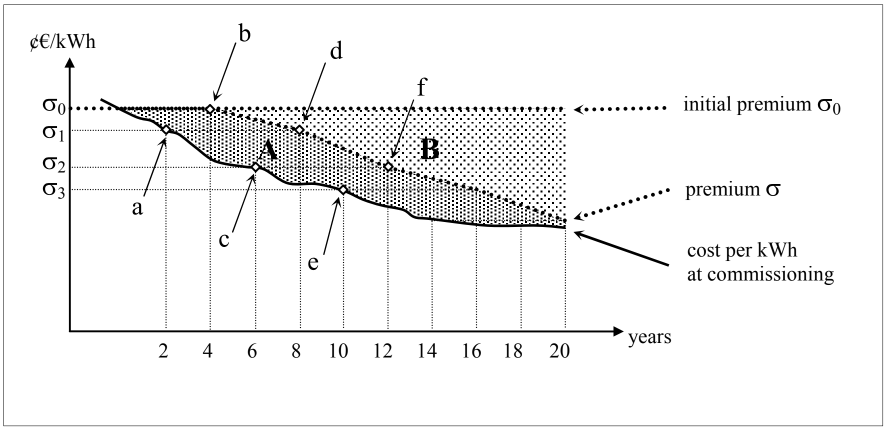


Figure 73: Premium, σ is adjusted in 4-year periods to reflect the decreasing costs due to technology innovation. For the first four years since the policy is enacted, σ remains constant at σ_0. After two years the cost per kWh of newly commissioned plants is assessed, (point "a") determining a new value, σ_1, for σ. On year 4 (point "b") σ begins being linearly adjusted from σ_0 to σ_1 over the next 4-year period (line "b-d"). On year 6 (point "c") the cost per kWh of newly commissioned plants is assessed again, determining a new value, σ_2, for σ. On year 8 (point "d") σ begins being linearly adjusted from σ_1 to σ_2 over the next 4-year period (line "d-f"). The process is repeated at points "e" and "f" and thereafter, in four-year periods.

The two years between assessment and actual adjustment reduce uncertainty for investors, who know what rates two expect at least two-years in advance, and strategic behavior. The linear adjustment, which can be calculated monthly or quarterly, guarantees a smooth adjustment, reduces uncertainty and prevents stop-and-go effects at the end/beginning of newly adjusted values for the premium σ. The four-year period is suggested because it adjusts well to business cycles.

The semi-linear step function has the advantage of adjusting premium σ according to real technology innovation patterns. The rents from technology innovation can be described as the sum of shaded areas A and B in Figure 73. Through the adjustment of σ the innovation rents in shaded area B are passed to consumers. However, the four-year adjustment period plus the two year gap between assessment and adjustment allow renewable electricity producers to capture part of innovation rents, reflected in shaded area A. Allowing producers to keep part of the innovation rents is important because it provides and incentive to invest in innovation and seek maximum efficiency in their equipment, thus creating a competitive market among renewable technology manufacturers, which further fosters innovation.

Assessment of the cost curve should be done at the sector level based on industry data, preferably using international figures. Using sector data rewards the most efficient producers and promotes competition among manufacturers of renewable electricity technology and components. Using international figures prevents national players from attempting to influence the assessment of technology costs.

22.3 – Target revision trigger

Support systems for renewable electricity are eventually limited by cost and, ideally, by fulfillment of the goals that motivated them in the first place. As noted in Chapter 6, most existing renewable electricity policies limit support by stating upper limits of installed capacity after which the policy is no longer in effect. Linking support schemes to the achievement of established targets is one way of delimiting the total cost of a policy. However, this approach can be counterproductive if targets are unambitious or there is unexpected technology innovation. In the case of unambitious targets, the linkage renders support schemes ineffective. In the case of unexpected technology innovation, the linkage imposes limits below the support levels initially envisaged by the policy. These negative effects are compounded by the usual years-long time lags in policy making.

Setting an early trigger for revision of targets can be a particularly useful approach. With the early trigger, when a technology is nearing its goal (e.g. 50%), a revision of established goals would be mandated. This would set in motion the policy-making process and allow enough time for policy-makers to decide whether it is necessary/convenient to expand the target, or whether the support is no longer necessary.

An early trigger as proposed would have, for example, prevented what happened in the Netherlands, where the existing feed-in law (MEP see Chapter 8) expired due to achievement of targets and no provisions were taken on time to continue support (due to political issues extraneous to the renewables arena).

23 – Other Considerations

23.1 – Ownership of rights derived from renewable electricity

Under any policy for the promotion of renewable electricity, it is important to clarify the issue of ownership of tradable assets that are derived directly or indirectly from generation of renewable electricity. These assets include but are not limited to: green electricity certificates; carbon allowances under the ETS and other carbon markets; and NO_x, SO_x and other pollutant credits.

Lack of clarity on the issue brings uncertainty, additional costs and risk of litigation. For example, in the United States, litigation has been reported on the ownership of RECs under PURPA contracts and net-metering schemes (Holt & Bird 2005).

Under the scheme proposed in Chapter 21, ownership would fall on the TSO or entity in charge of pooling the premiums and equalizing costs. It is also proposed that any revenue derived from the sale, transfer or in any other way from such tradable assets must be used first to offset the costs of the premiums, and second to offset the costs of grid upgrading required to accommodate renewable electricity. Any additional revenue can be used for grid improvement or environmental measures relating to the grid system.

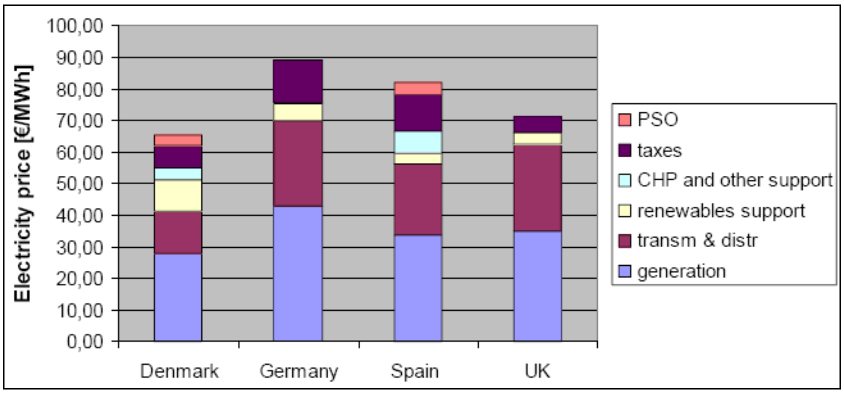
It is further proposed that if a renewable electricity operator forfeited the premiums for renewable electricity, it would retain ownership of any tradable assets related to generation of renewable electricity, while still enjoying the grid-access provisions of the harmonized feed-in law.

23.2 – Exceptions for non-commercial producers and energy-intensive industries

Small non-commercial producers, such as a home owner with a photovoltaic roof, generally do not have the capacity to operate in the electricity market. Requiring individuals to participate in the electricity market is a barrier to the deployment of renewable electricity. Therefore a simplified system is needed for small non-commercial producers. Simplified systems can be either a noncommercial feed-in tariff or an aggregation system in which commercial players are allowed to aggregate small non-commercial installations and act as brokers of renewable electricity in the market. Non-commercial producers also need specific taxation and accounting provisions. In order to allow for individuals and small non-commercial players to invest in renewables, it is important to eliminate any requirement to acquire commercial licenses or to follow business accounting practices. Taxation on possible benefits from renewable energy, if not exempt, should be included in personal income taxes, just as property or stock.

Special consideration may be needed for energy-intensive industries regarding their obligation to fund the premium. These industries include sectors such as steel or aluminum smelters and railway transport. Leprich 2005 provides definitions of energy intensive industries and effects of the German EGG on industry competitiveness. Because electricity is a significant cost for electricity-intensive industries, those industries' competitiveness is particularly vulnerable to changes in price of electricity, especially if they are competing in the global markets. Lost competitiveness can lead to relocation or closure of production facilities. Penalizing electricity-intensive industries would be self-defeating policy, because social and economic cohesion is one of the reasons for promoting renewable electricity, as stated by the European Commission in its White Paper ''Energy for the future'' (COM(97)599) and reaffirmed in Directive 77/2001/EC. Figure 74 shows the impact of renewables support policies in the final price of industrial electricity for Denmark, Germany, Spain and the U.K. in 2004.

Figure 74: Composition of average industry electricity prices in Denmark, Germany, Spain and the UK in 2004



PSO= Public Service Obligation, CHP= Combined Heat and Power

Source: (Com(2005)627)

Nonetheless, recent studies and models (Martin, 2004; Bode, 2006; Ragwitz et al., 2006) show that renewable electricity can actually reduce the overall costs of electricity, particularly by shaving off extreme price peaks during peak demand and by affecting the merit-order in a cost-reducing way. This is possible because even though the marginal cost of renewables increases, their net effect in the electric market is to decrease total costs, as was illustrated in Figure 3. Therefore, any special provision for energy-intensive industries would have to be based on actual electricity price increases, if any, once the savings to the electricity system due to renewable electricity generation have also been factored in.

CONCLUSIONS

In this dissertation we have seen what renewable electricity technologies are available, what are they attributes on how renewable fits in the liberalized electricity system; the support schemes, policies, measures and financing strategies for the promotion of renewable electricity; country case studies; a comparison of quotas and feed-in laws with respect to several aspects, including effectiveness, efficiency, innovation, uncertainty, administrative issues, technology discrimination and geographical dispersion; and policy proposals for the harmonization of feed-in laws in the European Union and flexibility mechanisms for feed-in laws.

The two main contributions of this dissertation are:

- a comparison between feed-in laws and quotas, and the finding that feed-in laws are a superior policy instrument for the promotion of renewable electricity sources
- the proposal of a methodological approach that can be used for the harmonization of feed-in laws in the European Union.

The next pages summarize these conclusions, and outline some related future lines of work that could be of interest.

Feed-in laws and quotas

As just mentioned above, the main conclusion regarding support schemes for the promotion of renewable electricity is that feed-in laws are a superior policy instrument than quotas.

As shown in Chapter 13, feed-in laws are more effective and have been proven more efficient than quotas. These findings are mainly empiric. In essence, feed-in laws are more effective because the countries that have experienced the greater deployment rates of renewables, Germany, Spain and Denmark, they all have feed-in laws, while countries with quota systems have had slower or no deployment. The success of those policies can be attributed to good returns on investment, but also to a stable revenue and policy framework that reduces risk for investors and therefore facilitates access to lower-cost capital.

The fact that feed-in laws have proven to be more efficient in the European Union was somehow unexpected, as in theory quotas take advantage of the market mechanisms to achieve greater efficiency. This finding will definitely have an impact in the negotiations of the next EU Directive on renewable electricity, by the end of 2007. However, the causes for higher costs of quotas could well be that there is not really any successful quota system in place. If quota mechanisms survive long enough, they might still prove to be more efficient than feed-in tariffs.

Scheer (Reiche 2005) argues that feed-in laws work better than quotas because renewable electricity is a technology-driven market. This is why he argues that. In Chapter 14 it was shown theoretically that feed-in laws provide more incentives for investment in innovation than quotas.

In addition to being more effective, efficient and having more incentives for innovation, feed-in laws have less administrative burden, are easier to implement and simpler than quotas, and allow for discrimination among technologies and geographical dispersion.

All this advantages have not gone unnoticed. EU 2004 accession countries overwhelmingly chose feed-in tariffs, and even some US states are showing some interest.

Despite all the arguments above, the results that feed-in laws are superior instruments to quotas should be taken with caution. After all, not all feed-in laws are effective or efficient. For example, France, with a nominal feed-in law, has almost no deployment of renewables. Just having a feed-in law is not enough to guarantee success. The conclusions above have mainly been drawn from the successful feed-in law cases. But, as noted in Part II, a series of enabling measures and other policies are necessary besides the marked-based policies to ensure success. Among those measures, stability and providing a stable investment framework are paramount. Regulations are also required with clear definitions and standards and grid access provisions, including a defied burden sharing scheme on grid extensions and upgrades.

Harmonization of feed-in laws

The policy landscape regarding renewable electricity in the European Union has been marked by bitter debates between the camps of quota supporters and feed-in law supporters. While the results of this dissertation will probably be considered as in the “feed-in law supporters” camp, regardless of its assessment of quotas, this dissertation concludes that feed-in laws are an effective and cost-efficient way to increase the generation of renewable electricity and achieve renewable electricity targets. Feed-in laws are compatible with EU state-aid, competition rules, and compatible with liberalized electricity markets. Therefore harmonization of feed-in laws would provide the necessary long-term market stability and flexibility, and promote technology innovation. While harmonization as proposed would presumably not bring efficiency gains in countries such as Spain or Germany, which already count with effective feed-in laws, it would bring policy stability, it would rule out possible state-aid challenges in the future, and for countries with less effective (or ineffective) support schemes, it would boost deployment of renewable electricity.

In the long term, renewable electricity should be a mature industry with no need for specific support above that provided for conventional energy sources. This fact is captured in the proposed premium for feed-in law harmonization, which incorporates its own obsolescence by being phased out as specific technologies reach maturity and renewable electricity goals are attained. When a renewable technology becomes competitive, σ_{RoI} will be capped first by the profitability threshold and then by the revision according to industry costs. σ_{EU} is limited by achievement of established goals. This goals are established as part of a political deliberation process. If no further support is deemed necessary for a particular technology after achieving established goals, σ_{EU} can be discontinued for that particular technology. σ_{Grid}, as discussed, should not be considered a support mechanism, but rather a remuneration for a service provided to the grid.

For the proposed scheme for harmonization, it must be highlighted that, despite some elaboration in calculating initial premiums, in practice, the final result is simple and straightforward for policy-makers, developers, and system operators: a guaranteed premium for 20 years, with low transaction costs and easy enforcement which developers can use to finance their projects.

Food for thought and future lines of work

As a concluding section, I want to muse over a few matters that were not included in this dissertation, but that it would be interesting to study or monitor in future research. These issues include developing countries, policy-learning and innovation as a common good, future renewable energy policy developments in the EU and the USA, the role of carbon markets for renewables, and the future of renewables itself.

Developing countries

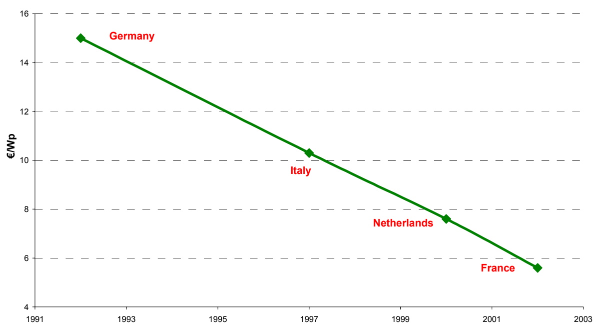
Electricity generation in non-OECD countries is expected to surpass electricity generation in OECD countries by 2015 (DOE/EIA 2007). Many developing countries, such as China and India are rapidly expanding their electricity systems. Most developing countries do not have liberalized electricity markets. Furthermore, most developing countries have chronic shortages of electricity and do not count with the overcapacity of electricity generation that developed countries had at the time of liberalization. In light of those factors, the policies as described in this dissertation are not readily adaptable to most developing country electric systems. Transferring the policy learnings from developed countries to developing countries while adapting to their circumstances is a very challenging and, if successful, rewarding exercise.

Additionally, the policies here considered are for grid connected applications of renewable electricity. Off-grid applications have completely different dynamics and technological features, and a significantly different approach is needed. It is expected that off-grid applications will play a major role in electrifying remote or sparsely populated areas in developing countries.

Policy-learning and innovation as a common good

As it has been discussed, one of the implicit or explicit rationales for renewable electricity support is buying down the learning curve, thus “learning by doing”. However, this raises an interesting question. Since renewables is a technology-driven market, and once innovation is made it can be transferred, is it a preferable approach "learning by doing" or "learning from your neighbor"? This question is best illustrated by Figure 75, which reflects the cost of PV installations at the time the first cumulative MW of PV was installed.

Figure 75: Cost of PV installations



	Germany	Italy	Netherlands	France
System price (€/Wp)	>15	10.3	7.6	5.6
Year 1st MWp	1992	1997	2000	2002

data source: Schaeffer *et al* 2004,

Figure 75 reflects the cost of installation for photovoltaics on the year that the first cumulative MWp of photovoltaics was installed in that particular country.

It can be seen in Figure 75 that France paid nearly one third than Germany for the same installed capacity 10 years later. Knowledge can be either a public or a private good. Knowledge is non-rival, meaning that one player benefiting from innovation does not preclude another from benefiting from the same innovation, the way a person using a bicycle precludes anyone else using the same bicycle at the same time. The trick to determine to what extent knowledge is a public good is whether it is or it is not excludable, meaning that one player (the owner) can prevent another player from using it. There is evidence pointing in both directions.

It would be interesting to analyze in detail and to develop methodologies to determine what countries benefited most, those that were early adopters of support policies (successful and failed) or those that waited and learned the lessons from their neighbors. In other words, what was the best policy approach from a country-perspective, to be an early adopter or a late-comer? The renewables-related developments in countries such as

France (late comer) and the U.K. (early adopter of failed policy) will be good case studies to answer that question.

Future developments in the EU and the USA

As noted before, the EU is due to review its approach to renewable electricity by the end of 2007. It will be very interesting to witness and hopefully participate in the discussions, and see what the outcome is for the policy landscape.

The policy landscape in the US will also be interesting to monitor. For most of the decade the federal government has not been supportive of renewables and states have taken the lead. However, a new administration is taking over in 2009, and the pressure is mounting from business and the public to take action.

Additionally, the recent interest for feed-in laws in the US, and the policy fragmentation in the country, where every state designs its own support scheme, is likely to produce some interesting quota-feed-in hybrids.

Carbon markets.

One of the most remarkable outcomes of the international negotiations on climate change under the UNFCCC and the Kyoto Protocol has been the establishment of carbon emissions markets. These markets are still at their early stages, are inefficient, ineffective and their continuity is not assured. Nevertheless, they have spurred a gold-rush style race to secure carbon credits and investment options among traders, brokers, and energy intensive companies. The EU Emissions Trading Scheme (EU ETS) is moving real money.

At present carbon emissions are not the main driver for renewables. But it is uncertain what future role will carbon markets play in promoting renewables. A great deal will depend on carbon prices, the availability of less costly options to mitigate emissions, and the rules on additionality and on whether and when investment in renewables qualifies for greenhouse gas emissions mitigation.

In any case, these effects will probably be very complex, not readily observable until a post Kyoto regime is agreed, and worthy of more than one dissertation on their own.

Future of renewables.

As noted in the introduction, the role of new renewables, albeit increasing at a 30% a year rate, is minuscule when compared to the world's energy system or global electricity generation. It is important to always keep this reality in mind when talking about renewables.

It is uncertain what future developments will be. If current growth rates are sustained, renewable electricity could play a much more significant role in a decade or two, and even dominate electricity systems by 2050. Conversely, growth of renewables deployment could falter or not keep up with growing energy demand, and renewable electricity could find itself relegated to a niche role with a reduced share of global generation. The wide range of future possibilities is what prompts analysts to use scenarios.

The factors that today seems that are going to have the most impact on shaping the future global electricity mix are climate change, energy security and cost and supply. Energy security and supply are drivers for more coal in power generation. Climate change is a driver towards de-carbonification of electricity supply (thus less coal).

While renewables might experience extremely fast growth rates in a carbon-constrained world, if climate change turns out to be less of a problem than currently thought, if countries fail to tackle greenhouse gas emissions or decide to ignore climate change mitigation, or if clean fossil fuel technologies are developed, the future of electricity supply looks dominated by fossil fuels. There could also be a nuclear revival if the issues concerning proliferation, wasted disposal, safety, high costs and security are solved.

Technology transitions can happen very fast, as any traveler who has lately been able to have a mobile phone conversation while in a remote African or South East Asian location can testify. In the case of electricity it takes longer, because investments made today in power plants will affect power generation over the next half century. But one thing is clear. If the use of renewable electricity is to expand and become mainstream, on of the required ingredients are good, effective and efficient support policies.

May 2007

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