Economic feasiblity study to provide Limburg of 100% green electricity

Is it economically possible to work towards a CO2 neutral Limburg?

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Preface

To conclude the education of Master of Management and obtain this degree, a master thesis is to be executed. My background as an electro-mechanical engineer directed the subject towards something with a technical link but an economic emphasis. As ‘renewable energy’ is a rather recent and more and more important topic, I chose this as a subject. Given the recent engagement of Limburg to become CO_2 neutral, I chose it as a framework on which to base this study. Due to the complex and broad nature of the topic, I limited the thesis not only to the northeastern part of Belgium, but also to the electricity generating sector.

The realization of this thesis was an interesting but not an easy job. Therefore I want to extend a word of thanks to everybody who contributed to this thesis.

First of all I want to thank my supervisor Prof. Dr. Theo Thewys and co-supervisor Dr. Ir. Steven Van Passel for their useful advice, professional opinions and feedback given throughout the year.

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Executive summary

The new European guideline ‘renewable energy 2020’ enforces Belgium to increase the share of their ‘renewables’ to 13% of its final energy usage. In this framework each member of the European Union has to describe its own strategy by June 2010. This strategy has to contain measures facilitating the path to this goal and making the achievement of the 13% renewables share possible. This plan has to make a distinction between renewable heat, electricity, biofuels for transports.

An eastern province of Belgium called Limburg goes even further than these guidelines with a commitment to try and become CO_2 neutral with the year 2020 as a deadline. This agreement is referred to as $TACO_2$[1]-plan. This is generally perceived as an ambitious plan and this thesis elaborates on this topic. As studying al the domains is too broad and complex for the time span of this thesis, the scope is limited to the electricity generating sector. This domain is after all responsible for a large share of the emissions.

To achieve this goal, drastic measures will be necessary. And as this goal is set on a rather short term given the topic new technologies (or emerging technologies) like carbon capture and storage are not taken into account as it is unlikely that they can contribute to the goal. The only way possible is to replace the existing carbon dioxide emitting electricity generating methods by renewables. Although they can also exhaust CO_2, it is only a fraction of the fossil fuel consuming technologies and is here considered to be CO_2 neutral.

In order to gain insights in what is possible, the electricity demand of Limburg is mapped. This is not done on the production side because this would neglect the net import of electricity that is present. Hence Limburg would not have its CO_2 neutrality in own hands as it is possible that it imports electricity produced with a coal fired power plant, which does produce CO_2, albeit abroad. For the sake of completeness, losses that are incurred are taken into account as these are inevitable. The current (2009) consumption of Limburg is about 7.3TWh, inclusive losses. The goal is set on 2020, so the electricity market is to be geared on the estimated demand in the future. A growth of 1.21% is estimated per year between 2010 and 2020, so a consumption of 8.25TWh is likely by 2020.

It is logic that if a wind turbine park is deployed, it should first replace the most polluting electricity generating source as this induces carbon abatement at the lowest cost. To be able to take this approach, the current shares of each method of electricity generation have to be explored along

[1] Total Action plan CO_2

with their CO_2 emissions. The Belgian electricity mix of 2007 is used and is assumed to be applicable to Limburg as well. This is merely and credible assumption, the real mix is really hard to determine as it is needed to track down were the electricity (current or amperes) is physically heading. The nuclear electricity generation has the largest share in the total production with about 54%. Gas fired power plants take about 31% for their account. Then the figures dive under the 2 digits with 7.5% for coal as fuel type. Renewable fuels are responsible for 2.6 percent of the total generation. Oil, waste, pump and other renewables make up for the remaining 5%.

The CO_2 emissions that come with this generation are the highest for coal fired power plants with about 950kg CO_2 per MWh produced. Oil and gas emit about 770 and 440 kilograms per MWh respectively. These are the fuel types that cause the most carbon emissions. The rest is thought of as CO_2 neutral. But a life cycle analysis approach provide figures from around 50kg for solar panels, 20kg for biomass, 15kg for wind turbines and even 11kg per MWh for nuclear power plants.

With these figures the total carbon dioxide emissions can be calculated (over 1.8 million ton) and the abatement potential can be estimated according to the potentials of renewable implementation.

Renewables are generally thought of as more expensive than the current fleet of generation methods. The thesis lists all the costs and does this with a certain upper and lower boundaries as the costs can change depending on all kind of factors. To make good decisions, the true cost should be reflected. This can only be done when external factors caused by electricity generation are taken into account. So, monetized values of externalities are taken into account to represent a full cost picture. Consequently, this is not a cost perceived by the electricity generating companies. Using these costs, two scenarios are built for later use. One that favors the renewables, called 'pro scenario', and one that favors the fossil consuming energy sources, called 'bau scenario'.

Not all energy sources are applicable everywhere. And given the short time span (from 2010 to 2020) it is assumed no 'yet to emerge'-technology can contribute to the $TACO_2$ plan. The presently used energy conversion technologies will have to be used to achieve this goal. The use of biomass, solar panels and wind turbines should be extended. Hydro energy can be improved, but there is little room to do so.

Up until now, still little is known about the potentials of renewable energy sources. "What is possible in Limburg regarding the installation of renewables?" is the question to be answered. But given the small area, little research has been conducted concerning this. Therefore potentials for renewables are listed on the broader level of Flanders and Belgium. This way the amount of data is sufficient and this increases the reliability. The potentials then are translated to Limburg by the use of suitable allocation keys. For photovoltaic energy for example, the built-over land is used as an allocation key as the majority of the solar panels are installed on roofs. The share of built-over land for Limburg compared to Flanders for example is used to allocate a Flanders potential to Limburg.

Because of different definitions of some potentials, a framework is explained in this thesis for future use. Because of the lack of cohesiveness concerning the potentials, 2 broad groups are used, i.e. a technical potential and a socio-economic potential. The only constrain of the former is the technology conversion rate and the space needed to implement the technologies. Constrains of the latter consist of economical feasibility, policy measures, society's tolerance and so on. For the technical potential, scientific literatures indicates a potential figure of just under 4TWh on the downside and over 10TWh on the upside after allocation to Limburg. The difference with the socio-economic potential is much lower with on the downside only 0.5TWh possible electricity generation from renewables and 3TWh on the upside.

The amount of electricity generation to be replaced by 2020 is 3.6TWh in order to replace the major CO_2 emitting energy sources. This seems a small amount given the 8.25TWh consumption. But as nuclear energy can be categorized under the non CO_2-emitting methods and obtain a 54% share in the electricity production, this figure is not far off. In both (high and low) technical potentials it would be possible to achieve CO_2 neutrality. This represents a 44% renewable share. For the upper limit of the technologic potential this would cause a total cost of the whole mix of 460 million euro in the pro scenario and 530 million in the bau scenario and an emissions reduction to just over 100,000 ton CO_2. The lower limit causes the cost to rise to 600 and 770 million respectively and a reduction of CO_2 emission to just over 140,000 ton.

For the socio-economic potentials carbon dioxide neutrality is possible in neither of the cases (upper nor lower limit). The high socio-economic potential comes close though with a percentage of almost 38%. The cost with the pro vision would 520 million euro, and almost 600 million in the bau scenario. The abatement would be about 1.5 million ton to 340,000 ton CO_2. For the lower limit in the socio-economic potential the renewable share could be almost 11 percent. This causes abatement to 1.4 million ton CO_2 and a cost of just over 500 million and 380 million for the pro and bau scenario respectively.

These figures can only be assessed appropriately when compared to a suitable benchmark. The 2020 situation with the current electricity mix is used as a benchmark. As already mentioned the emissions would be over 1.8 million ton. The costs to provide this electricity fleet would be 520 million in the pro scenario and 350 million in the bau scenario.

List of units

Units of Energy

1 J = 1 Joule = unit of energy

1 MJ = 1 megajoule = 1 million J

1 GJ = 1 gigajoule = 1 billion J

1 kWh = 1 kilowatt power during 1 hour

1 kWh = 3.6 miljoen J = 3.6 MJ

1 MWh = 1 megawatt hour = 1,000 kWh

1 GWh = 1 gigawatt hour = 1 million kWh

1 TWh = 1 terawatt hour = 1 billion kWh

Energy = The capacity of a physical system to perform work.

Work = Force over a distance of displacement

Units of Power

1 Wp = 1 Watt-peak

1 W = 1 Joule per second = 1 J/s

1 kWp = 1 kilowatt-peak = 1,000 Wp

1 MWp = 1 megawatt-peak = 1,000 kWp

1 GWp = 1 gigawatt-peak = 1 million kWp

Power = energy per unit of time

List of abbreviations

BAU – Business As usual

CCGT - Combined Cycle Gas Turbine

CSP – Concentrated Solar Power

CCS – Carbon Capture and Storage

CREG – Commission for the Regulation of Electricity and Gas

EU – European Union

EUR – Euro (as currency)

GDP – Gross Domestic Product

GHG – GreenHouse Gas

IPCC – Intergovernmental Panel on Climate Change

LCA – Life Cycle Analysis

LRM – Limburgse ReconversieMaatschappij

MAC – Marginal Abatement Costs

MDC – Marginal Damage Costs

MSW – Municipal Solid Waste (incineration)

NSE – Non sustainable energy

OECD – Organization for Economic Co-operation and Development

PPP – Purchasing Power Parity

PV - PhotoVoltaic

RES – Renewable Energy Source(s)

R&D – Research and Development

USBR – United States Bureau of Reclamation

USD – U.S. Dollar (currency)

VREG – Flemish Regulating agency for the Electricity and Gas market

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1 Problem Statement

To familiarize everybody with the subject a brief background on the matter is given in the first section. This also shows the context and the relevance of the subject. Hereafter the problem statement or central question and sub questions are formulated. For the sub questions an explanation is given of why it is necessary to take them into account.

1.1 Contextual background

When the IPCC[2] First Assessment Report was published in 1990 it was still not generally accepted whether people were to account for climate change(-issues). It might have been just a natural and cyclic phenomenon that occurred once in so many years. In the meantime, the fourth Assessment Report of the IPCC has shown with more certainty that people are to account for a huge amount of the emission of greenhouse gases[3] (GHG's). Now, climate change is a more accepted phenomenon and people become more and more aware of the problems it might cause/is causing if nothing is done to mitigate the exhaustion of GHG's.

Although, it aren't people in person who cause the highly elevated levels of GHG's, but it are their activities that influence this. CO_2 is exhausted when using your car (transport), turning on the light (electricity production) and while working (assuming industry). But even deforestation[4] is an important cause because it prevents CO_2 to be captured from the air, and in turn increases the pollution indirectly.

Since the awakening to climate change there have been several conventions between countries worldwide to do something to reduce the GHG's. This entails a reduction of air pollution, earth's temperature and so on. This should be done because these things cause major losses for society and not only on a human or bio diversified basis, but also on an economic one. After all, if a tsunami strikes or a hurricane touches down in a city, major costs are involved for the revival of those places.

The most known convention is the Kyoto protocol that came into force in February 2005. (Kyoto protocol 2009) states that "The Kyoto Protocol is a legally binding agreement under which industrialized countries will reduce their collective emissions of greenhouse gases by 5.2% compared to the year 1990 (but note that, compared to the emissions levels that would be

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[2] Intergovernmental Panel on Climate Change
[3] Mainly carbon dioxide (CO_2) but also methane (CH_4), nitrous oxide (N_2O), sulfur hexafluoride (SF_6), HFCs, and PFCs (Kyoto protocol 2009)
[4] Putting down trees, which convert carbon dioxide into oxygen

expected by 2010 without the Protocol, this target represents a 29% cut)." For Belgium this means a reduction to 92% of the emissions compared to the levels of 1995 (UNFCCC 2009).

In a meanwhile there are countries that ratified other conventions. The successor of the Kyoto protocol, 'the Copenhagen convention' seemed promising at first, but failed to make specific agreements on how to tackle the climate changes. The so called 20-20-20 agreement is another convention, in which the EU countries committed themselves to reduce its overall emissions with at least 20%[5] and increase the share of renewable energy to 20%[6] (ECE 2008).

New guidelines impose Belgium to increase their 'renewables' share to 13% of its total final energy usage. (European parliament and council 2009)

These initiatives are global and European. All this has to be translated towards more local actions and measures. For the province Limburg in Belgium this means a ratification of some international agreements. But Limburg went even further by engaging with LRM with the ambitious goal of making the province CO_2 neutral[7] by 2020, referred to as the $TACO_2$ plan. (Het Laatste Nieuws 2009) Limburg plans to do this in four different domains; renewable energy production, building, living and working energy efficient, sustainable material flows and traffic and transportation. (LRM 2009)

There is more than meets the eye on this matter. There are several domains, as just mentioned with the article (LRM 2009), to cut the CO_2 emissions. According to (International Energy Agency 2006) the power generation sector accounts for the largest CO_2 emission portion. Since we cannot cope without electricity the urge to find and use alternative electricity generation methods is big.

The big problem with this acting in the interest of the environment is not that people don't want to reduce the CO_2 emissions; it is simply because this abatement costs money. It seems to cost much more to implement green energy solutions than to keep using the conventional methods.

A distorted view can be created if not accounted for all costs. The CO_2 exhaustion is an important externality[8] that should be taken into account when comparing the costs of the conventional electricity generating with those of renewable electricity generation. But it is hard to quantify the costs of CO_2 abatement since these costs exist of subjective figures. What is the harm done to the

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[5] Below the 1990 levels
[6] In proportion of the whole energy production
[7] Neutral meaning an equilibrium between emission and sequestration (storage)
[8] Action by either a producer or a consumer which affects other producers or consumers, but is not accounted for in the market price (Pindyck 2008)

environment? Are there human health implications? How much does it costs for installations to reduce the CO_2 emission?

The fact that demographic, geographic, economic and technologic properties of a region can differ substantially doesn't facilitate the problem of comparing the costs and possibilities of alternative electricity generating methods. An African country might have enough space to implement renewable energy sources, but not the technology nor the financial resources. In a western, densely populated, country as Belgium this could be the other way around.

Since it is unrealistic and not feasible to elaborate on the economics of CO_2 neutrality in the broad sense, this thesis will only elaborate on providing Limburg with renewable electricity. This way, it could be used to analyze CO_2 neutrality as a whole.

1.2 Problem Statement

First of all a central question is stated that will be the core of this thesis. On this broad statement the needed sub questions will be derived according to emerging issues.

The objective of this thesis is to gain insight in the feasibility of providing Limburg with electricity generated with only renewable energy sources. This brings us to the central question:

"Is it feasible to make Limburg CO_2 neutral in the electricity generating sector?"

The emphasis of this research will rather be on the economical side (availability and cost) than on the technical side (technologies and efficiency).

The amount of electricity used and the composition of this consumed electricity is the basis of the problem. After all, the capacity of the energy sources has to be tailored to the consumption of electricity. When too little is generated, families and industries fall short of power. It won't be hard to imagine that this would disturb your life. Indeed, nowadays it's hard to imagine a life without electricity. More important, when industries fall short of power, huge economic losses accumulate with every minute or even seconds without power. But this is still nothing compared to life-threatening situations that occur when hospitals fall without electricity (That is of course why hospitals are provided with backup generators). This to illustrate that a sufficient (preferably an excess) capacity is very important. This excess capacity comes with a toll (very literally). Bigger infrastructure, more machines, labor,… are needed to provide this extra capacity, which raises the costs. It is preferred to produce enough extra to be safe, and not spend too much for this mostly unused capacity.

In the short run, electricity producing companies predict hourly demands of power. When these demands shift new peaks of demand can emerge, this should be well considered when you cannot control (increase or reduce power generation) your energy source very well. The capacity should be mainly adjusted to this peak (Truyens and Motmans 2009).

Since there aren't any good measures to date to capture and store CO_2 it is assumed for this thesis that to be CO_2 neutral, the whole production of electricity should be sustainable. This is considered to be one of the major mitigation options (Verbruggen, et al. 2009) as opposed to for example carbon capture and storage (CCS).

To see how much it will cost to provide all electricity with sustainable energy, the existing non sustainable energy sources should be replaced by renewable. Since there already is some energy production from renewable, not the whole production has to be replaced, this is only needed for which produce the GHG's. And if it would only be possible to provide a certain percentage with renewables[9], it is logical first to replace those with the highest emissions first. But the costs have to be considered as this might not be the most economic solution.

To make an economic study of the implementation of renewable energy sources, the possibilities have to be listed. A literature study of which energy sources exist is necessary. Also the upcoming technologies in the future are important. A breakthrough in a technology might change the energy market dramatically. The available technologies are not the only important factor, the applicability of these technologies in the area are essential. After all, it is less efficient to install wind turbines in places where "wind time" is not sufficient or to install them in mountainous regions which would increase infrastructure costs. Based on this information, the renewable energy sources with a significant contribution to electricity generation will be used throughout the study.

A basic economical assumption is that, "other things being equal, the consumer always prefers more of any one product to less of that same product". (Chrystal 2004) So, if two energy sources have the same costs, that source with the highest capacity will be chosen. Or in other terms, a list will be obtained with a ranking of the energy sources, evidently the technology with the lowest costs/MWh[10] will be chosen. But to quantify those costs it is important to state which costs to include. Some of the cost being: capital costs, fuel costs, operation and maintenance, cost of externalities like CO_2 and employee effect, system integration costs and others still to be discussed. Then there is the issue of how to monetize costs like externalities. It is difficult to quantify the costs and benefits in terms of money because externalities include socio-economic valuations. When comparing costs, subsidies have to be considered. It might well be that there are lower costs due to subsidies somewhere along the supply chain, this way the cost would be underestimated. An estimation of the cost developments over a certain time span (2020) will be necessary as these will decline due to learning and scale economies.

This time span is used because of the commitments of Limburg to become CO_2 neutral as stated in section 1.1.

Based on the geographic properties of Limburg (the applicability, i.e. can the energy sources be implemented in Limburg) and the obtained cost ranking of the energy sources a certain energy mix can be chosen which provides the electricity for this region. This will most likely depend on some variables, the different variables will be determined in the thesis and some possible (e.g. optimistic and pessimistic) scenarios will be given.

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[9] Term to indicate 'renewable energy sources'

[10] MWh or Megawatt Hour is a unit of energy

Differences in the energy mix will result in total cost differences. A closer look at the advantages and disadvantages will give a clear view to the consequences of the chosen energy mix.

As this mix is supposed to (partially) replace the existing one, costs are also to be compared. Here some assumptions have to be made in order to calculate the costs. Some variables are hard to predict due to their volatile behavior. So again, some scenarios (which will have a link to the energy mix scenarios) will be necessary to get a better understanding of the situation. Of course it is one thing to solely look at the costs, it's is still quite another to do the morally 'good' thing and switch to renewables. This political issue lies beyond the scope of this thesis though.

From this the following sub questions are used to obtain an answer to the central question:

1. **How much CO_2 is produced trough energy consumption in Limburg?**
2. **Which energy sources exist to generate renewable electricity?**
3. **How much does this electricity cost?**
4. **Which energy mix is applicable in Limburg?**

What this all means in terms of obtaining CO_2 neutrality will combine the former questions to answer the central question.

1.3 Research method

The goal of this thesis is to analyze whether it is possible to supply Limburg only with green electricity and what the economic implication are of these possibilities. Besides this main goal, the thesis also intends to bring a transparent view of the problems studied here.

The first part gives a methodology framework which is the basis of this thesis. This framework is used to extend the problems to the case of Limburg.

So a literature study will first be executed to get familiar with the matter and to form a theoretic framework. Mainly International, Belgian and Flemish article, reports and case studies will be used for this literature study via the internet. This has the great advantage that there is up to date information available form over the world in just a blink. Especially for this thesis this is preferably because much of the needed recent information is not available on a national level. The great disadvantage is that the accuracy or reliability of this data can be low. This is why data is used related to renowned research or governmental institutions.

Besides a framework, data will be subtracted from this literature study as well. Given the short time span in which this research has to be executed for the Master of Management program, it is not feasible to make own cost calculations. So other studies will be used and compared to each other in order to acquire good data. A framework will be given with this data since it will be based upon many assumptions.

The obtained data will be translated to the situation in the province where the University of Hasselt is sited in, i.e. Limburg. The data from the literature is then applied to Limburg based on its characteristics.

Hereafter it is possible to state a good conclusion to the central question and make recommendations.

2 Methodology

This section is the theoretic guideline of the thesis. The methods used in the practical part of the thesis are discussed. First this is done in broad terms to get a good overview which will increase the understanding of why certain topics are handled. Then all the topics covered are studied in depth in order to know how these topics are used to obtain answer on the sub questions and the central question. This section then will serve as a framework for the more practical part ranging from section 2 to 7.

The mitigation option of replacing the current fleet of polluting electricity generation methods is used here to decrease the CO_2 emissions. Other options might have been installing advanced filters to capture carbon dioxide or CO_2, promoting rational energy usage etc, or combinations of this. But given the commitment of Limburg to strive for CO_2[11] neutrality, the latter two only will succeed to achieve this goal in extreme cases. On the one hand, if all CO_2 should be filtered, this would require filters that don not yet exist; on the other hand no energy should be used anymore to reach this target, which is totally unrealistic. Therefore replacing the existing CO_2 exhausting generation methods is the best shot in growing towards CO_2 neutrality.

The first necessity in gaining insights whether this is possible is to explore the current electricity sector in terms of usage (demand side) and of which production methods the generation constitutes (supply side). As there are already renewables deployed, not all electricity supply has to be replaced, only when replacement is beneficial for the CO_2 abatement. To be able to do this, it is also important to know which electricity generating methods are used to provide the supply and their share in the total supply. If only the coal fired power plants are to be replaced (in a simplified example), the total amount generated by this method has to be known. Accordingly decisions about implementation of other renewable energy sources (RES) can be made. As this study is geared to mitigate carbon dioxide, these emissions should be examined as well. Each generation method exhaust a different amount of CO_2. Even if all the polluting methods are replaced the remaining emissions have to be calculated as it is not a certainty that all exhaustions can be diminished[12]. It is generally assumed that renewables are more expensive than the conventional generating methods[13]. This has to be verified however with a view towards future prices as these will go down due to economies of scale to name only one possibility. And more important than

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[11] CO_2 refers to CO_2 equivalents and thus strictly also represent CH_4, N_2O and fluorides (Belgian national climate commission 2007)

[12] Even RES emit pollutants, albeit indirect, considering the life cycle analysis discussed later

[13] i.e. coal-, oil-, gas-, nuclear (fired) power plants. For which nuclear will prove to be a special case as it does have no or little carbon emissions.

which is cheaper is the question: “How much cheaper/ more expensive?”. In addition there are costs that are not taken into account, but have to be paid by someone in the end. These are referred to as external costs or externalities. In decision making processes, it is important to have full cost data at one’s disposal (Zimmerman 2009). For this reason an internalization of the externalities provides better insights in decision making. Additionally it cannot be taken for granted that it is possible to just replace the current deployed electricity generating methods. There are numerous constrains to overcome to make this change happen. The possibility to implement energy sources is called “potential”. There are many different potentials and no uniform method is used up to data to define these potentials. With an overview of which methods are applicable and what capacities are possible to install the last missing pieces of the puzzle are on hand.

Now it is possible to see how much potential there is to deploy renewables, how much this implementation would cost[14] and how much carbon dioxide emissions are then abated.

2.1 Electricity generation

In order to obtain CO_2 neutrality it is assumed that all the electricity production should come form renewables. This is not necessarily true though. If a small part still produces CO_2, it can still be neutral if the emissions that are exhausted are captured[15] so that the total balance of the emissions in the air is zero. The first reason for this assumption is that power generation is only one of the domains which exhaust GHG’s. If it is possible to replace the conventional fleet of electricity production with renewables this will leave more room for the other domains. It might be more difficult in the transport sector to abate emissions. Abating more CO_2 where it is easier gives more room for other domains to still have some emissions. The second reason is that with the implementation and electricity generation by renewables still CO_2 is produced. Albeit indirect, during the production of solar panels, transport of the wind turbine blades or somewhere else in the whole chain.

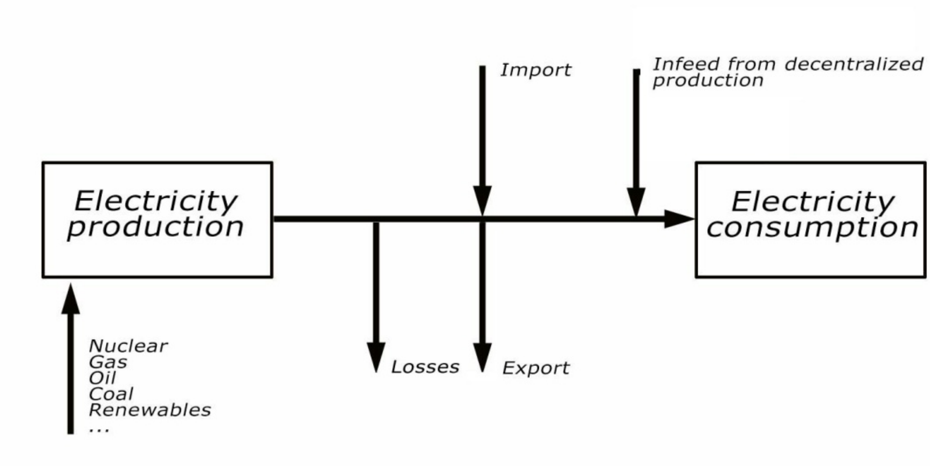
It is hard to indicate the exact electricity consumption of a specific region because of the complex network of the electricity grid. Current[16] is something that is thought of as something abstract. Although it is measurable, it is not possible to indicate a direction to current. It is possible to look at what is produced and build further upon this. But Figure 2-1 indicates that Belgium imports a part of the energy (FOD Economie 2009), so the consumption has to be the measure in order to provide or supply the entire current. It is useless if the production occurs with only renewables, but

[14] This will be an indication of the order of magnitude due to uncertainties
[15] This can be either a natural phenomenon, trees consuming CO_2 and producing O_2 under daylight. Or artificially when CO_2 is captured, transported and stored for example in the ocean or underground.
[16] Measure of the amount of electrical charge transferred per unit of time; A

then import from other countries that use fossil fuels to generate electricity. Some people would call it hypocrisy. Then the consuming part is still responsible for the emissions caused by the own electricity consumption. Even if this CO_2 is emitted in another area, in this case the area where the power plant is located.

The consumption is measured very accurately as people have to pay for their usage. These figures can be obtained through electricity regulating instances, electricity suppliers or electricity distributors. As already mentioned, area restriction concerning this matter is rather difficult. Suppliers can deliver to a broad area and if the electricity market is liberalized as is the case in Belgium, different suppliers can 'rule' over a certain area. This hampers with the data gathering as different instances have to be willing to cooperate by providing electricity consumption figures. Regulating instances also have the available data on hand, but not necessarily in the right format. The data are often consolidated for example and once this is the case, splitting up is difficult as electricity consumption drivers have to be found to allocate and split up the data correctly. The electricity distributing company can have a good clue of what is going on as they know what passes on their electricity grid. It is still hard to look solely at a particular region, as this depends on the position of grid connections. This is still a good measure as there is no need for exact data, but merely a good order of magnitude. After all estimates will have to be made and depend on many varying factors, because of this an exact figure will only have little added value. (Truyens and Motmans 2009)

Figure 2-1: Simplified chart of electricity distribution



Source: (Truyens and Motmans 2009), own processing

Figure 2-1 also shows that losses occur when distributing or transmitting the electricity. This is caused by transforming between voltages and voltages drops due to cable resistance and is an inevitable electric phenomenon. Although it is not actually consumed, it is driven by the amount of usage. The more usage takes place, the larger the losses will be. If only the actual usage would be generated, these losses would arise anyway, resulting in an undersupply and hence an instable electricity grid. To avoid this, the losses have to be added with the usage.

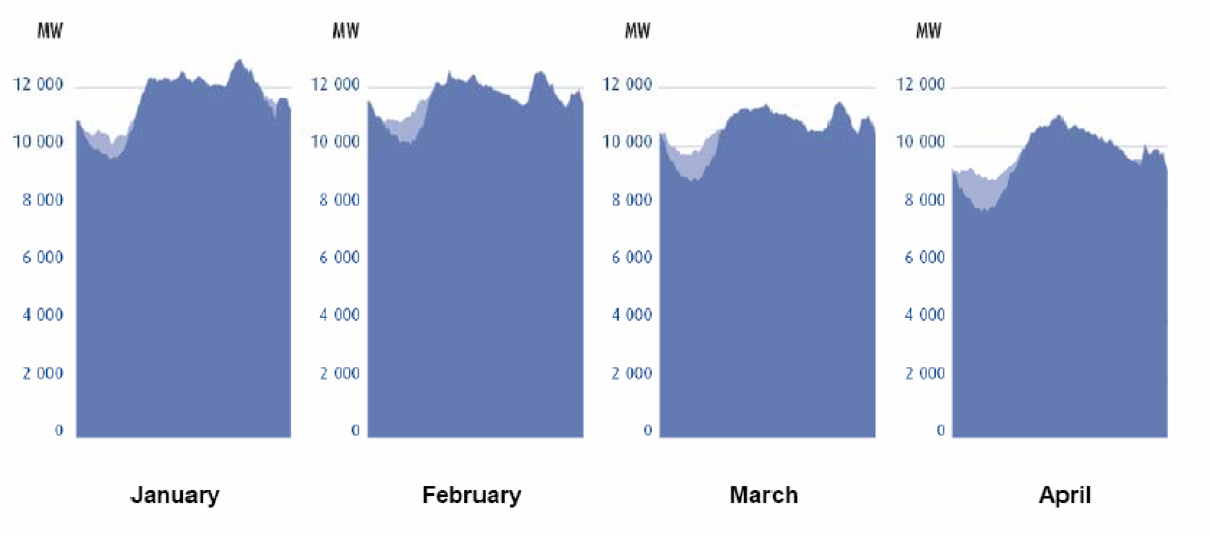
Electricity demand is not static and can vary yearly, daily and even every minute. It mainly evolves according to the need of the people[17]. Hence, estimates have to be made to know the consumption during the year of reference. In the case of this thesis, Limburg pursues CO_2 neutrality by 2020. If 2010 consumption is used, it is likely that the figures will be different. So an estimate will be made of the 2020 electricity usage. The electrical grid companies have to estimate these figures in order to adapt their system up front. Many studies also estimate growth percentages that can be applied to the data.

Unfortunately, this is still not the end of the consumption story. Most studies use figures that represent an average demand throughout the year.. Figure 2-2 shows that the electricity demand is rather volatile and varies from month to month, day to day and even hour to hour. The use of an average is thus a simplification of the real situation. Near the end of January a peak in the demand can be seen. To fully understand this peak demand it is important to have an insight in the correlation between MW and MWh. The following simplified example will clarify the issue.

[17] Demographic (number of inhabitants), economic (wealth), policy (rational energy usage) are factors influencing this need

Assume a power plant with a capacity of one MW. If it was commissioned 24/7 during one entire year, it would generate electricity nonstop for 8,760 hours. The total supply would be 8,760MWh (the capacity multiplied by the time in operation). So the demand in which it can foresee is 8,760MWh. A problem arises though when the demand peaks with a maximum higher than the capacity of one MWh. If someone would turn on a machine consuming 2MW for one hour, the demand for that hour would be 2MWh. The problem here is that on the supply side the capacity limits the production to only 1MWh (over a time span of one hour). A peak therefore would render the electricity grid instable. So to avoid this, the capacity on the supply side should be able to produce enough to cover these peaks.

Figure 2-2: Monthly electricity demand from January until April in Belgium



Source: (Commission Energy 2030 2007)

Every kind of energy production has its own characteristics. They have their own typical fuel costs, energy efficiency and so on. The same accounts for their CO_2 emissions. The production of a certain amount of MWh's causes the power plant to exhaust a certain amount of CO_2 emissions. To know what amount of MWh each type of energy source produces, the structure of electricity production for a certain area has to be known. With the structure, the composition or energy mix for the electricity production is meant. It can be thought of as that if one MWh is consumed, it was produced for example with a coal power plant for 20% and a nuclear power plant for 80% (fictitious example). Defining these numbers for a particular area is very difficult because, as is already mentioned, the current has no direction. It actually follows the easiest path. If electricity is produced in area A, and B and C lie equally far from area A with A in the middle, both B and C will be able to consume. Therefore the composition of electricity generation for a broad area is accurate enough as it is hard to pinpoint who actually uses energy from where. It is important to note that an energy mix can be very misleading, because it can be composed of the total energy demand. This is a huge difference with only the electricity demand. Oil for example is only little used for electricity consumption, but a lot more for transport for example. Nuclear power plants makes up for about $1/5^{th}$ of the total energy usage, but constitutes for more than half for the electricity supply. (FOD Economie, K.M.O., Middenstand en Energie 2008).

2.2 Carbon dioxide emissions

To become CO_2 neutral, and to achieve this by implementing renewable energy sources, it is important to know how much renewables to install. The consumption figure here is not sufficient because, as already mentioned, the different energy sources produce different amounts of CO_2. And even not all methods produce emissions. So when talking about how much CO_2.to abate, first the total CO_2.emissions have to be known and secondly define which methods are responsible for what share of the emissions produced.

When thinking about the emission from a coal power plant people mostly think about a chimney with smoke pouring out. And this is indeed a part of the cause of the CO_2 emission due to electricity generation. But it goes much further than this. After all, to keep the coal example, the coal itself has to be mined, transported, etc which also consumes energy. The whole sequence of activities to obtain the fuel is referred to as the fuel cycle.

But there is more. When the coal is mined, it can be burned to heat water and drive a turbine which then generates electricity. This installation has to be built as well off course, itself again consuming energy and consequently producing emissions.

The total emissions can be split up into either direct or indirect emissions. The direct ones are those being produced while the power plant is in operation and is actually generating electricity. The indirect ones are those being produced along the whole chain from fuel mining, transport, building installations and eventually decommissioning. These two kinds combined give a so called life cycle analysis (LCA). The LCA thus takes the total lifetime emissions into account and represents a “cradle to grave” assessment of the technology. This logic can be applied to all the energy sources and they indeed should be investigated separately as they all have their own characteristics. This gives an idea of the real emissions LCA’s that should be used in the broad sense.

This also is valid for renewables, biomass has to be transported to the installation which then converts it into electricity[18], silicon has to be mined to be used in solar panels or turbine blades have to be produced for wind turbines. It all consumes energy and hence exhaust pollutants. When considering only the fuel cycle, renewables are CO_2 free[19]. But with the LCA they do have emissions, albeit not as high as those methods using fossil fuels.

Figures about the carbon emissions can be mined from scientific data. There are sound studies concerning this issue with comprehensive frameworks. Geographic differences do not really matter concerning this issue as a gas fired power plant in Asia with similar properties will have the same characteristics as one in Europe.

Figures can thus be obtained for the total LCA per fuel type. So transportation emissions of the fuel itself are included. When a global energy study is conducted, care has to be taken in referring to figures like these because of the danger of taking them into account more than once, and thereby distorting the view.

On the other hand, if CO_2 neutrality is about to be reached, these figures are overestimations. To see this, assume the case that transport is all done with bio diesel. So only CO_2 is produced which is captured while growing the seeds of which it is produced. This is neutral on its own and no CO_2 emissions have to be abated when transporting coal f.e. The same reasoning can be extended to other domains, rendering the whole chain, except the generation step, CO_2 neutral. So in the future, when global CO_2 neutrality is studied, only direct emissions should be taken into account. Because there is still a long way to go to achieve this, the LCA emissions are used.

How much to abate?

Whether it is necessary to abate all the emissions is a difficult topic with pro's and con's from many sides. How much of the emissions to abate is a hard question to answer. Certainly in the broad sense, when considering things like the amount of emissions allowed to be exhausted. People nowadays talk about ghg's as if it something completely bad. On the contrary, in fact people cannot live without it. Ghg's have been around for ages, and they're the reason temperature on earth is bearable and within the ranges for life to exist. Too much carbon dioxide equivalents however is not good as This causes a global warming above the average temperature. Economically speaking there is an optimal point of emission and emission abatement. This does

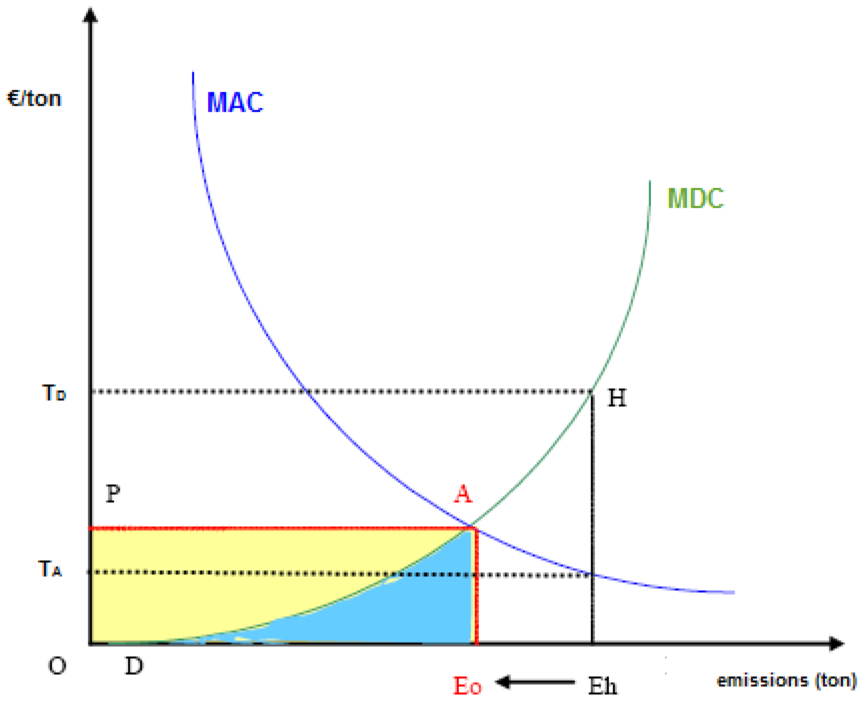
[18] This can also be heat, which is an energy source that lies beyond the scope of this thesis

[19] They either do not exhaust any CO_2 or the emissions exhausted are captured in a previous stage. Biomass for example exhausts carbon dioxides, but these were captures from air and soil earlier and the total balance therefore is neutral

assumes a perfect market, so perfect market information as well. This means that the prices of electricity with the externalities are exactly known. Or stated differently, the costs to society are known. Figure 2-3 shows the relationship between the costs per ton of emission with the total tons emitted. The marginal damage cost function (MDC) represents the costs that would occur with the corresponding amount of emissions. The marginal abatement cost function (MAC) represents the costs that would occur if the emissions are abated.

Measures to diminish the emissions have to be taken to decrease the environmental damage cost (MDC). In general, these measures are not without costs. And usually these costs increase the further one wants to reduce the environmental damage (MAC curve). E_h is the point of the present emissions. This corresponds with a cost per ton of T_D. As the cost to abate the emissions is much lower, $T_{A,}$ the invisible hand would kick into action (in a perfect market) and the point of equilibrium would emerge to the optimal point A corresponding with the emissions level of E_0. After all, it would be less costly to abate the emissions than to pay for the damage caused. The optimal point is where the both the MAC and MDC curves intersect. Or one would be indifferent to abate or to pay for the damage costs. The problem here is that it is hard to track emissions and the originator of the emissions does not bear for this cost due to an imperfect market. This can be thought of as a marginal damage cost of zero or just the x-axis. It is evident that if the originator does not have to take measures to abate, costs are avoided and he/she himself would be better off. But the welfare globally seen would be worse off. Welfare losses occur when not in the optimal point. Certain maximum exhaustion levels can be imposed by the government to force the originator to invest in abatement (the MAC 'arises'). And this is done for emission originators. A trade off will have to be made between bearing the costs of abatement and bearing the costs of damage.

Figure 2-3: illustration of the economic optimum for emission reduction

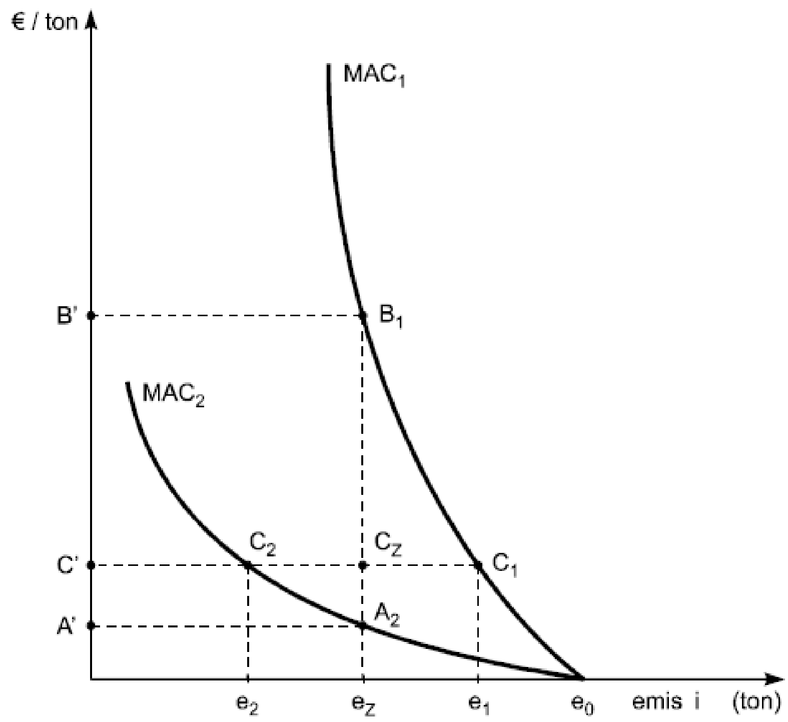


Source: (Torfs, et al. 2005)

This is a good mechanism to work towards the optimal point in our imperfect market. But not every industry or even plant has the same possibilities or capabilities to abate to the same level or the same amount. Hence the costs for the abatement will be different and they all have an own optimum point as their MAC curve is different. Figure 2-4 shows the different abatement cost curves for two plants, one with a low cost and one with a high cost to reduce emissions. If both plants emit an amount of e_0 nothing is done to reduce emissions. Now if a certain limit of emissions is imposed (suppose e_Z) to which they both have to abate. Plants 1 (with the steepest cost curve) would have to bear the cost of B' and plant 2 the costs of A' which is much lower. For both plants this is the optimal point (economically seen), but not optimal for the total welfare. Globally it is possible to abate a same level with lower costs if plant 2 abates more than plant 1, assume both at a rate of C' euro per ton. The marginal costs for both plants are now the same, but plant 2 will not have any intention to do so because the quantity to abate is much higher and therefore also are the total costs. The emission permits solve this problem as is done nowadays with the CO_2 emissions. The permits are issued and give a right to a certain emission amount and are freely tradable and prices are liable to supply and demand forces. In this case plant 2 owns emissions permits and because of that does not abate more than necessary. Plant 1 has a problem because it faces large costs to keep under the level its permit allows. Because of these large costs plant 1's permits are more valuable to itself than plant 2's permits are for plant 2. It will logically offer a price for the permit of plant 2 higher than the costs of abatement for plant 2, but lower than the costs of abatement for plant 1. This renders both plants better off. This mechanism continues until the costs both plants have to bear are equal.

This mechanism is now opposed to the intentions of total CO_2 neutrality, as it does not take into account total welfare. CO_2 neutrality would cause the MDC function in Figure 2-3 to be close to zero, hence nearby the y-axis. As this is not the optimal point a welfare loss occurs. But all this actually depends on the costs of electricity generation. If for example wind power generation is cheaper than coal fired generation, full costs considered, a total welfare gain would occur. Whatever the costs, this method does not take into account what would be best for total welfare. But as this is really hard to monetize, questions could be raised with the methods that use this principle.

Figure 2-4: Marginal abatement cost (MAC) curves for two different plants



Source: (Commission Energy 2030 2007)

In the framework of this thesis (Limburg wanting to abate practically all emissions) this will only work if the true costs of the MDC are known and if they are consistently higher than the marginal abatement costs. As the costs to abate will be higher than the damage cost this will cause the equilibrium not to be on the optimal point and thereby create welfare losses. This would not be if the emissions are only abated to a certain level where it is economically not worth pursuing further abatement. But CO_2 neutrality means abating (almost) all emissions. Consequently this can be situated close to the y-axis in Figure 2-3 where MAC exceeds MDC.

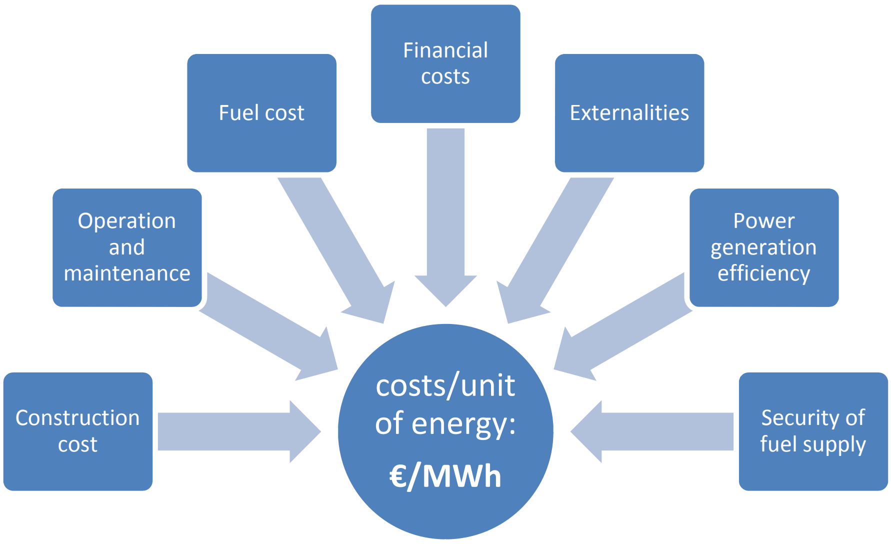
2.3 Costs of electricity production

2.3.1 Contributing factors

It is important to gain greater insights in the costs of electricity in order to make sound decisions about future development of the electricity supply and the electricity grid. The electricity generation costs are influenced by many factors. It is important to explore the variables that make up the cost to know which cost to take into account. If the knowhow is present it is possible to control these costs. It is advised to give an overview of the variables to see the composition of the costs in the right perspective. To reflect the true costs, it is important to take the external costs into account in order to obtain a reliable view of the competitiveness of the renewables with the conventional energy sources.

The variables that make up the total cost are combined in Figure 2-5. These can influence the outcomes of the cost figures. Each of them is explained in this section.

Figure 2-5: Variables making up the electricity generating cost



Own processing mainly based on (Ea Energy Analyses 2007)

The construction costs consist of the cost to build the infrastructure needed to convert the fuel[20] to electricity. It contains materials, labor, design, terrain and so on. It is possible that the power grid needs to be adapted or upgraded to make it suitable for a particular energy source. These costs should be taken into account as well, after all they would not occur when a certain method is or is not implemented.

The thesis assumes the year 2020 as target to try to achieve CO_2 neutrality. Consequently only existing technologies are considered as the time span is too short for new technologies to emerge and become fully operational. Research and development cost are not included because the data provided are those based on the existing technologies. And since R&D costs are sunk costs[21], they should not change the outcome of the costs per unit of energy.

The operation and maintenance costs are made up by the costs of keeping the conversion of energy running and the costs to maintain the output by for example renew obsolete equipment or replacing broken parts.

The fuel costs are for most renewables rather low or even non-existing. This in contrast to for example a coal-fired power plants where there is a cost to obtain coal. Since these can be very volatile, this is an important variable in the future success of renewables. If the conventional fuel prices go up drastically, it will become relatively cheaper to use renewables.

The implementation of renewable energy technologies costs money and this money has to come from someone or somewhere. If this money is obtained via a bank loan (debt) you have to pay a certain amount of interest. If it is obtained via equity, the equity providers want a return on their invested capital. After all there are other opportunities (opportunity cost[22]) in which they can invest in order to receive interest on this capital. It can also be a combination of debt and equity like capital. Then a weighted average cost of capital[23] is calculated for the rate of return. In each case, the capital provider wants a return on his invested capital, so if it is invested in an installation to generate electricity, there will be an interest (financial) cost that should be taken into account. In this case it is for a social cause, for this kind of investments a rather low percentage is mostly used of around 5%. (International Energy Agency 2006) (Ea Energy Analyses 2007)

Externalities should be taken into account to obtain a real cost of electricity generation. After all, these (externalities) are things that aren't accounted for in the cost. To show this with a simple example, assume a coal fired power plant that emits carbon dioxide in the west of Europe. If the

[20] The fuel depends on the energy source. (E.g. coal, uranium, organic waste, wind,…)
[21] Sunk costs are costs that already have been incurred and cannot be recovered (Smith and Smith 2004)
[22] Opportunity cost is a measure of costs expressed as alternatives given up (Chrystal 2004)
[23] An average of the return percentages taking into account the share of each method, debt or private, in the total capital.

wind comes from this side, it will end up in the east and the emissions will cause harm here. The people or society in the east will have to bear the costs, but cannot trace the originator of the emissions. So it is hard to take this into account. Additionally these things are not easy to monetize. How much ton CO_2 is exhausted by for example a gas-fired power plant? What are the effects of this CO_2? What are the environmental and health consequences of this CO_2? What is the value of this caused damage? There are no clear cut answers to these questions, but they need to be addressed in order to obtain good estimates. A more extensive view is given in next section

With the conventional power generating methods there is a high capacity credit. This means that people will not fall short of power due to a lack of fuel[24]. But with solar energy for example, this is not the case. To generate power, there has to be light and to be more productive an amount of sun-hours are needed. For a wind turbine to be efficient there has to be wind with a minimum speed. These are things that are not controllable, there either is wind and/or sun or there isn't and it is impossible to decide when this 'fuel' is available. Because there is no easy and good manner to store energy[25], an overcapacity is needed to set off a low electricity generation. The latter can be caused for example by photovoltaic cells with some clouds covering the sun at an inconvenient moment. On the other hand there is security of fuel supply. This then means that there is high price volatility. A high fuel price will slow down the economic activity and results in a welfare loss that cannot be recovered. Although this is mentioned separately it can be viewed as an externality as well.

To be able to compare the costs of different energy sources, they have to be put on the same denominator. Everything is expressed in terms of power generation-consumption (MWh) since this unit is a convenient measure. Since this is the denominator it surely influences the ratio costs over energy generation. A method with the same costs but a higher efficiency or just a higher capacity (assuming same operational hours) will have a relative cost advantage over the less efficient electricity generation method.

The above mentioned topics are on their own elaborate things to investigate. Data has to be gathered concerning the installation costs, the labor hours, the cost of capital, the fuel costs (which can be volatile), power generation, operating capacity, maintenance costs and so on. This has to be done for each of the different power generating sources. In addition, all this data should be cross referenced to several other sources to see whether the obtained data is reliable. That is why existing scientific studies will be used to come up with cost data. On the downside they have made

[24] Assuming that the fuel price is not a barrier to the availability of the fuel.
[25] Currently pump installations are used to pump up water into a basin. This stores the energy which it can be regained when this water in turned drives a turbine when it descents. Another upcoming storage method can be hydrogen, but this methods still has some issues to date. (APS 2007)

their own assumptions concerning the just mentioned topics, but on the upside they have more power to investigate it thoroughly. To have a reliable view, different studies will be compared to see where any irregularities occur and why they occur.

2.3.2 Costs vs. prices

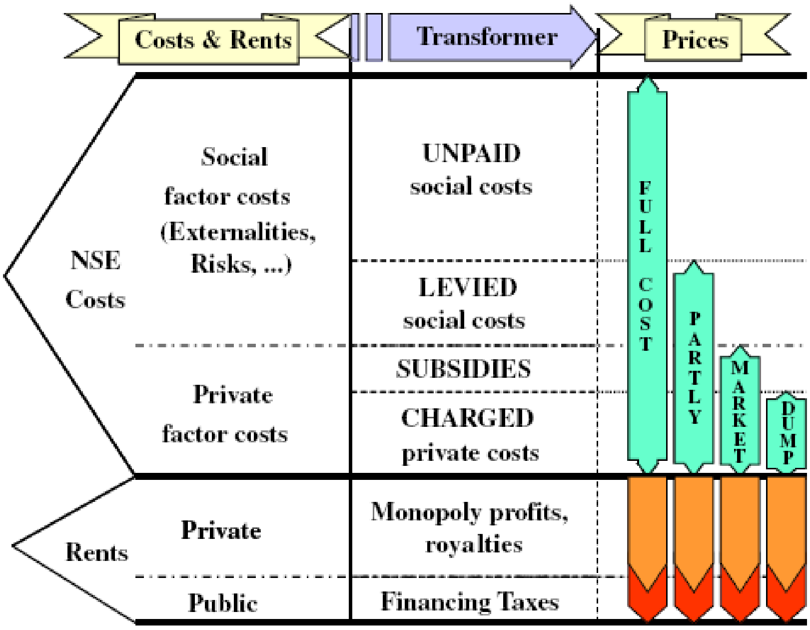
When discussing costs, prices are usually not far behind. Although prices do not belong to the core of the thesis, it might come in handy to improve insights in why certain decisions are made concerning what to take into account for the cost.

Price setting in the electricity market nowadays is much like any other price setting and is dependent on the market forces of supply and demand. This was not always the case. Before the first of July 2003, people could not choose between suppliers and since no one could go without electricity (and also gas in this case) suppliers had a strong monopoly position. The liberalization of the energy market should[26] be beneficial for the customers as competition drives down prices. Confusion here has to be avoided as prices are not the same as costs.

People understand quite well what is covered by the term “costs”. But in an economic context the term can lead to ambiguity and is not always so clear-cut. In the economics profession, costs refer to the use and consumption of real resources or production factors (material, land, buildings, labor time, etc). Costs are often thought of as incurred only at the production phase; this is not always the case. One thing is sure, costs are not perceived by the market, in contrast to prices. Prices are in fact transferred or transformed costs. These deviations can be large. Figure 2-6 shows the difference between costs and prices. Or better said; it shows the different factors that constitute the costs and the prices.

[26] Should is deliberately used as (Magnette 2010) states that this did not work out the way as planned

Figure 2-6: Non-sustainable energy (NSE) supply costs transformed into energy prices



Source: (Verbruggen, et al. 2009)

The real costs can be classified as either private or social. The former are costs paid by private entities[27] as opposed to the social costs, which are paid by third parties (often referred to as society in general). Social costs are mostly the use of natural resources, knowledge freely available, and so on, mostly denoted as externalities or external costs. The rents are raised on top of the real costs.

The costs can then be transferred into prices. The private costs are a sort of base for the price. A price based solely on this is a market price. They can be altered by policies, like a subsidy. This is not a real good reflection of the actual costs. A better one would be if the social costs are fully levied or transferred to the price. Then a full price is obtained which reflects the real cost or full costs. This should be without subsidies and rents as these distort the view of the real cost. As this is not attainable due to the difficulties in monetizing these social costs, at least a partly levied social cost is preferable. Figure 2-6 on one hand helps understanding that the correspondence between costs and prices is not univocal; it can lead to ambiguity. For example, financing taxes added to a good or service do not reflect direct economic costs, these are merely called transfers in the accounting world. But they are expenses for the private customers and hence will see it as a cost.

[27] Companies, individuals, households, etc)

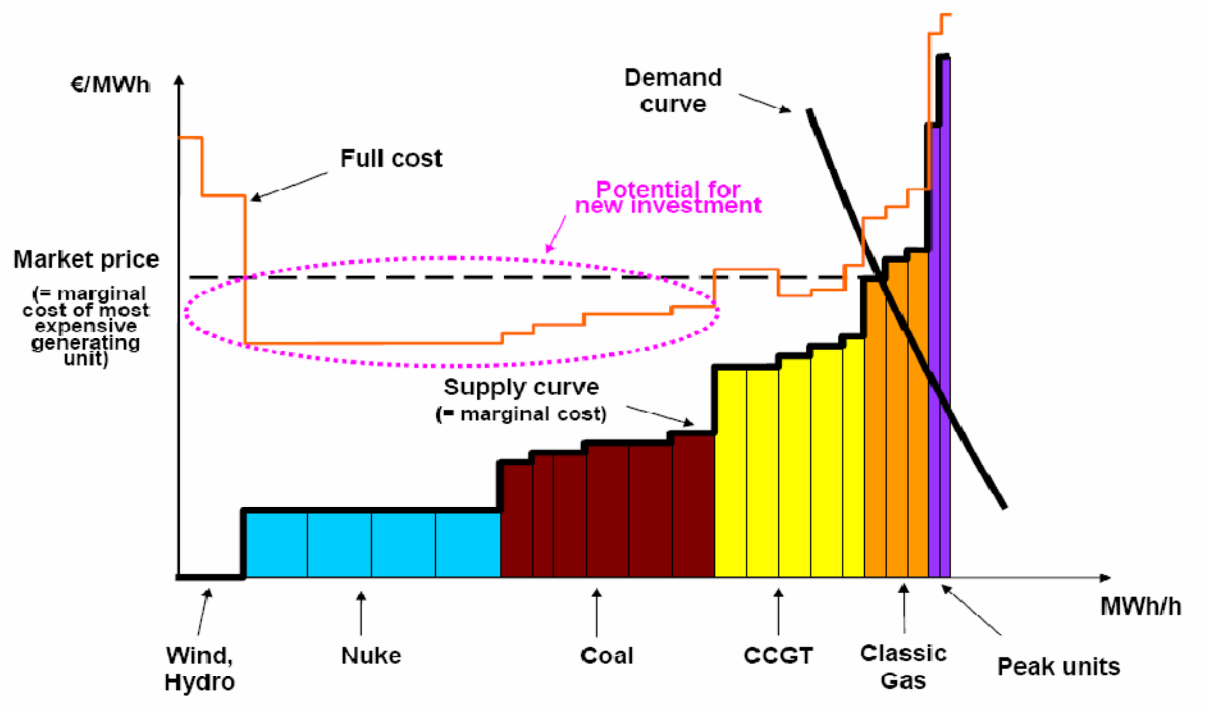
This framework based on (Verbruggen, et al. 2009) not only provides an insight in the relationship between costs and prices but also gives a view on the cost structure used in this thesis. The costs used in section 5.1 are only the private costs. Subsidies are not taken into account as these say nothing about the costs. By considering the major social costs used in the current scientific literature an effort is made in obtaining the full costs. The figure discussed is for non sustainable energy sources in particular. Renewable energy sources will have a larger private cost part and a smaller social cost part. This can be confirmed with the data on hand and used in this thesis, being the larger costs of generating electricity but the smaller externality costs for renewables.

2.3.3 Price setting

The correlation between cost and price does not tell us anything about the real price determination of electricity, but does give us a better understanding of this topic. The actual price setting is done by supply and demand and is explained next. Figure 2-7 shows the supply curve, determined by the suppliers and supply methods, and demand curve, determined by the consumers of electricity. One of the basics of economics dictates that an equilibrium of price (€/MWh) and quantity (MWh/h) will be formed at the intersection of the supply curve and the demand curve albeit only in a perfect market (Chrystal 2004). This equilibrium can also be seen in this figure. The supply curve is equivalent to the marginal costs[28]. The intersection of the two curves gives the market price and is equal to the marginal costs of the most expensive unit of electricity generation at the moment. The full cost is also displayed in the figure. Hence it can be deducted that the price of renewables (wind, hydro), is more expensive than the market price. The nuclear and coal plants generate electricity under the market price and give rise to an investment potential due to a surplus of financial inflows. As with many things it are the peak units that are the most expensive. This is due to the flexibility that has to be built into this. The figure only contains the price for the commodity itself, extra costs will be charged for the transmission, distribution and administrative costs. This is the same for the costs of electricity generating sources used in this study. There is no real use for this subject in this study and is merely mentioned for the sake of completeness for the price of electricity generation.

[28] The increase in total costs resulting from raising the rate of production by one unit (Chrystal 2004)

Figure 2-7: Determination of the electricity market price in a competitive market



Source: (Commission Energy 2030 2007). CCGT: Combined Cycle Gas Turbine; Nuke: Nuclear power

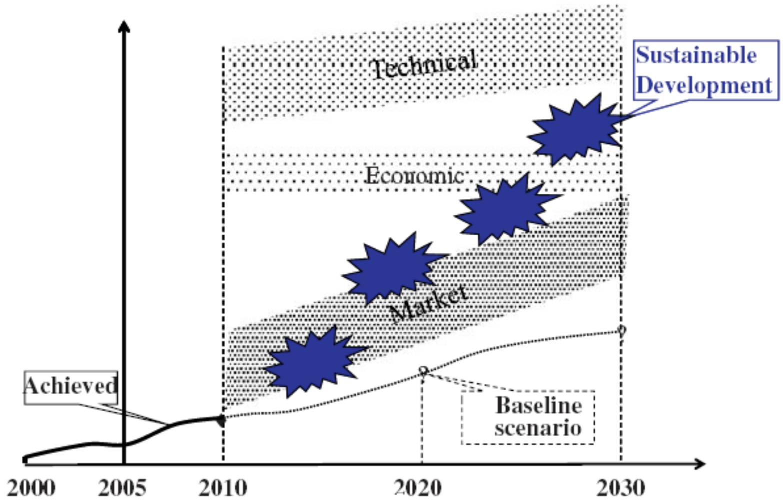
2.4 Potentials of renewable energy

It is one thing to look solely at the costs of generating electricity, but the energy extractions are not always feasible due to constrains or barriers. After all, there are more than a dozen barriers which can be of all sorts to or to not take into account (Neyens, et al. 2004). There is a lot of blurriness about which potentials there are and which of them should be taken into account, as was evident during the study.

First of all, it is important to have an overview of the applicability of the energy sources in the area. Given a short time span the use and expansion of the existing energy generation sources will be the main source of electricity generation. Consequently a look at the present applied technologies proves to be very helpful.

'Potential' is described in most dictionaries as capability or possibility; something that has the capability of development into actuality. This implies a gap between the actual (present) state and the potential (future) state. In the linguistic sense of the word this is no rocket science. In the context of renewables though, a lot of confusion exists when it comes to specific potentials. The gaps that cause the difference between the present and the future are caused by a wide range of factors and are referred to as barriers in the comprehensive framework of (Verbruggen, et al. 2009). All the barriers can be grouped in different levels of potentials as can be deducted from Figure 2-8. The barriers preventing the achievement of the different potentials will not be explored into depth in this thesis. It is mentioned though as a suggested guideline for future potential studies. The same article also provides a good assessment of the different used potentials in the energy context.

Figure 2-8: Renewable energy supplies potential



Source: (Verbruggen, et al. 2009)

The baseline scenario is the development of the renewables share when no extra effort is made to increase the penetration level of the sustainable energy sources. It is mainly referred to as a business as usual (BAU) case.

The market potential is the amount of renewables expected to occur under forecast market conditions that are shaped by private economic agents and are regulated by public authorities. These forecasts are thus based on prices experienced by the market (not the costs of the energy!) and hence are influenced by policy measures like subsidies and taxes.

The economic potential output is projected when all costs (social and private) related to the output are included. This means internalizing the externalities (social costs) and the use of a social discount rate to balance the interest of consecutive human generations. This is thus an ideal situation and can be strived for by increasing the urge for real costs reflection and a sharper focus on long term interest. Barriers to obtain this potential can be lack of competition or inadequate information availability.

The sustainable potential can be realized if the 4 sustainable dimensions are taken into account in an integrated manner. I.e. the exploitation of resources, the direction of investments, the orientation of technological development and institutional change are all aligned to obtain a greater sustainability. This is mentioned for the sake of completeness and will not be entered at length.

The technical potential is obtainable by full implementation of the state of the art technologies. No reference is made to costs or policies, only at the technical transformation rates[29] of the available fuel given a certain technology.

A last potential used in the literature is the physical potential which is often used to indicate the large availability of fuel to convert into energy, but isn't a real useful number as it merely distorts an already cluttered view of potentials as it assumes that all energy[30] available can be converted into electricity with no losses nor barriers at all.

The reality is that, given this is a very recent framework, no or only little studies have based their potentials using this guideline. Almost all studies use some sort of variant of potential. This makes it almost impossible to compare the different potentials meaningfully. Two broad distinctions can be made however. Although this increases the possible range (hence uncertainty), it will simplify the matter and help with a better understanding. On the one hand a technical potential can be used, where the limits are solely based on conversion rate of the technology considered and the regional constrains, i.e. the space to set up the installations. On the other hand a socio-economic potential is used which combines the market, economic and sustainable development potential from Figure 2-8. This is done because the main differences in potential definition are in these areas. In the end it comes down to the same. The variables making up the socio-economic potential vary from social acceptability, policy measures, and economic implications to the growth potential of a electricity generation method. It is just a matter of cataloguing the subjects under the right potential.

Another problem is that for small regions data are hard to find, if there is any data at all. There will be data available for larger areas however, but not immediately useful or applicable for the smaller area. It is important though to have figures of the smaller area at disposal as to conduct the study on a smaller scale. Not that it is impossible to generate electricity outside the area of concern (in this case Limburg), but the land for example in an adjacent area (assume Antwerp) will preferably be used for the Antwerp energy supply. After all if Antwerp puts effort in a move towards renewable energy generation, it will need the land itself to create space to deploy electricity generating sources. This is not representative for the real life situation. Although this is a possible

[29] The efficiency by which electricity can be generated given a particular fuel type.
[30] A broad term here used to indicate the fuel available for the renewable energy sources

approach, it leads to short term thinking, and it will inevitably cause other problems in the long run. The region of concern for the electricity supply and thus the corresponding area subject of renewable implementation is shaped by the organization of the electricity grid and will not necessarily follow the regular borders. To still get the data only relating to Limburg, the information for the broader region is allocated to Limburg and the shape of the organization of the electricity grid is neglected. This method calls for suitable allocation keys[31]. Each electricity generation method has its own characteristics as already mentioned. This is also regarding the typical space where it can be deployed or where it gets its fuel. For each of the techniques a measurable and suitable key should be used. It has to be measurable because if you can have a perfect allocation key, but it is hard or too costly to measure, it is not wise to use it. By suitable is meant that when allocated, the figures may not be distorted too much and have to represent the reality as good as possible. In this case the results cannot be evaluated. To get a correct view, all characteristics of each generation method should to be compared with the availability of these characteristics in Limburg. This was not feasible in the scope of this thesis. So a key will be assigned to each method to allocate the potentials.

Since policy measures are to overcome, the major limiting factor not yet taken into account will be the space available. For Limburg this is much less than for Flanders or Belgium of course, hence a certain percentage will be estimated which represents the share of Limburg in the total potential (Belgium of Flanders) picture. This share will be estimated for each electricity generating method still up and running to be implemented in Limburg on a short term base. Other allocation keys can be number of inhabitants, or GDP of the region. Because this does not represent the real limitation being space, they are considered to be inadequate.

This raises questions of what to do with energy sources like offshore wind. On the one hand it would be unfair if only adjacent regions could benefit from this just because of their ‘lucky’ location. It is perfectly possible that Limburg[32] invests in offshore wind turbines and thereby is responsible for that part of renewable electricity generation. Although closer regions will actually consume this energy, it will give rise to a lower conventional energy usage in total which is the effect originated by Limburg. This contradicts an earlier statement where was said that Antwerp, neighboring Limburg, would use its own land to generate for itself. But in the sense that oversea areas belong to Belgium in general, it would be unfair that only the direct adjacent areas could benefit from this. The contra side is already mentioned. It is physically not so realistic to get power from offshore wind turbines in which Limburg invested to Limburg itself. For this thesis it is

[31] Measures by which larger lump sums can be assigned to smaller parts without losing too much accuracy
[32] Being approximately 170km apart from offshore area (Google Earth 2009)

assumed however that Limburg can benefit from the electricity generation from offshore wind potential.

2.5 Transition of energy system

A great problem, encountered in the domain of renewable energy generation is the suitability of a specific region for the implementation of renewables, as just mentioned with the off shore wind energy. Another one is the unpredictability of the renewables using direct solar energy and wind energy. The former problem limits a region to make extended efforts to implement or further reduce its dirty energy production. The latter problem is omnipresent when narrow regions are considered. If only Limburg is taken for example to consider wind energy, probably its greatest disadvantage is the discontinuity of the electricity production. If the wind lies down, the turbines are not generating power anymore. Then the electricity has to come from somewhere else. If it is assumed (for simplicity) that the only available renewable in Limburg is wind turbines, the electricity has to come from outside Limburg. But as Flanders, or even Belgium for that sake, is fairly small, there is much chance that the wind energy over whole Belgium is undersupplied. A possible solution for this important issue (and risk of falling short of electricity) is removing the boundaries even more than is already done with the foundation of the EU and the introduction of the euro stretching it to the electricity sector. After all, on the long term, renewable energy is best thought of as something global. An increase in throughput from electricity on a larger scale can be helpful to solve this problem. The risk of falling short of electricity then can be reduced as the possibility that wind energy is not available in an area compared to Limburg is much smaller than the possibility that wind energy is not available over whole Europe.

This has an additional advantage of using cost advantages over larger regions. It can be much compared to the discussion of the two power plants with different marginal cost function described in section 2.2, but then with regions. Assume that country A can deploy electricity generation technologies at lower costs than country B. Country A will only install enough to foresee its own needs as will country B. But when work together and country B convinces country A to deploy more , B can buy the surplus from A at a higher price than the generation cost for A but lower than the costs for B. This can be linked to the comparative cost advantage paradigm[33], but in fact this is not

[33] The ability of one nation, region or individual to produce a commodity at a lower opportunity costs in terms of other products forgone than another nation, region or individual (Chrystal 2004).

totally true as the service produced is the same. So the only matter is to do this at the lowest (marginal) cost[34].

This might all sound good, but there is one important drawback. Electricity transport should be limited due to increasing losses proportional with the length of distribution. To date there is still not an efficient way to store electricity. Although hydrogen is a possible storage method, some disadvantages prelude their commercial use. In the storage domain the pumped hydro method is superior to batteries, compressed air and still other storage possibilities (APS 2007). After all, a decent storage method could also tackle a great part of the problem of peak demand and electricity supply.

This section can be briefly summarized as cooperation between countries to reduce risk of electricity shortages.

2.6 Analysis of the data

To provide a conclusion for this thesis and hence to answer the central question it is necessary to combine the matter discussed so far to see what is possible in the electricity market by 2020 and at what cost. As most of the previous data are well informed estimates, they are liable to uncertainty. This is reflected in the ranges of data that are often used to show possible outcomes according to different assumption made by the studies. Using only a uniform framework for the conclusion would bias the results as the ranges are not taken into account. Therefore, different scenarios, which are based on different costs, are built to provide a clear view of the possible outcomes by 2020. This provides a sort of future exploring method or a what-if analysis[35]. The scenarios show pathways towards the future, they show the interrelation between the considered factors. They picture an uncertain future by depicting different possible future visions (Vmm 2009).

As there is a lot of uncertainty involved (barrier removal, policy measures, growth rates, fuel prices, and so on) scenarios can be created that provide extreme cases. It can be seen as an upper and lower limit or an optimistic and a pessimistic view. The truth will lie somewhere in the middle. The exact number will be liable to how the factors that make up this potential evolve. (e.g. the policy implemented, technology growth rate, human behavior towards RES, etc.)

A benchmark should be formed to create insights when calculating the future possibilities. Without a benchmark the figures cannot be compared and have less meaning. A logic benchmark is a

[34] The cost increase with one additional unit of output, in this case MWh. So for example the cost increase when an additional unit of wind turbines is installed.
[35] What if the prices of fossil fuel generation go up drastically? This question can be reflected by using the upper boundaries of the price ranges provided in the cost section.

scenario without any evolvement regarding the electricity mix and with a view of nowadays prices. But still some factors should evolve, as is the case with electricity demand. So a benchmark should be created with a future view, with current variables like prices and energy mix.

The method that is used here to abate the CO_2 emissions is making sure that the energy sources do not produce any, or only little. To achieve this, existing energy generation methods have to be replaced by sustainable ones. And one wants to do this at a cost as low as possible off course.

This can be done by implementing the cheapest sustainable energy sources first. Secondly the second cheapest can be installed and so on. To realize a fast abatement progress, first the most polluting energy sources are to be replaced, then the second most polluting and so on. This way, the most CO_2 can be abated in the cheapest way at first, but it becomes more expensive in the end to abate the same amount.

This method unfortunately does not represent the reality as it assumes equal costs of each energy generating method for the whole implementation potential. In real life, the costs of, for example one MWh generated by an onshore wind turbine, will be low at first as people will seek the cheapest ground to build the turbine, use the areas with most wind hours etc. In the end, to use all the space, the ground will be more expensive than the first piece, the areas with high wind availability or wind speed will be gone and the turbine will not work as efficient, etc. This results in a higher cost per MWh than the first installed turbines. Too counterbalance this assumption the cost data used will be manipulated a bit by discharging the upper and lower boundaries of the data. It would be not realistic for example to use only the lowest possible cost data for the implementation in all regions as is just explained.

Many studies calculate the costs to abate tons of carbon dioxide. Each method then has its own price and potential carbon reduction. It is relatively easy to see what methods are worth implementing and how much they can reduce the emissions. This however implies that, when renewables are deployed, they replace the existing generation methods proportional to the share they represent in the energy mix. If it were based upon the method used in this thesis, the method is subject to the implementation order. The first ones would replace the most polluting methods and hence it is relatively cheaper to abate CO_2 than when it is used to replace a method that only emits half of the CO_2 of the most polluting one. This method thus can only be used if a weighted average CO_2 emission per KWh is used. Each KWh of renewable energy generation then abates the average CO_2 per KWh instead of the CO_2 emission of the method it replaces.

3 Electricity market in Limburg

In this chapter the current and projected situation (for 2020) of electricity consumption for Limburg is given taking into account the losses, the growth and the peak demand. Then the composition of energy sources to produce this electricity is examined.

3.1 Electricity consumption

To avoid import and export issues, which distort the generation level needed, the actual consumption is mapped first. To obtain the needed electricity generation backward integration is used from consumption onwards. Everybody has to pay an electricity bill, so there is a measure of electricity consumption. For Limburg there are two companies for bringing the electricity to the customer. For distribution (for electricity converted to under 150KV[36]) this is Infrax and for transmission this is Elia (greater than 150KV). The private persons and small industries are served by Infrax, the big industries are served by Elia. For the former there was electricity consumption in 2009 of 4,740,294,989kWh or about 4.75TWh. 4,545GWh was delivered form the generation side and 195GWh was produced through decentralized production (e.g. solar panels, biomass, wind turbines,…) (Truyens and Motmans 2009). This figure also contains the consumption of the town of Laakdal (Antwerp) which is not a part of Limburg. This does not cause a problem since the number is only a small deviation. After all it is sufficient to have a good estimate of the order of magnitude of the consumption as this is something fluctuating and mostly growing each year and has to be estimated for the year of 2020.

The consumption of the larger industries in Limburg in 2008 was 2,660GWh and during 2009 totaled 2,230GWh (Rasker 2010). Here the impact of the economic crisis on the large industrial consumption is very significant. Although the crisis started in 2008, it was only in the end that it really struck Flanders. But it maintained influencing the large industries throughout 2009. It is also noticeable that the amount of electric consumption of the large companies is a significant large part of the total sum.

Adding the consumption via the distribution and transmission grid gives a total consumption in Limburg during 2009 of 6,970GWh (4,740GWh + 2,230GWh).

[36] Kilo Volts, electrical potential energy per unit charge

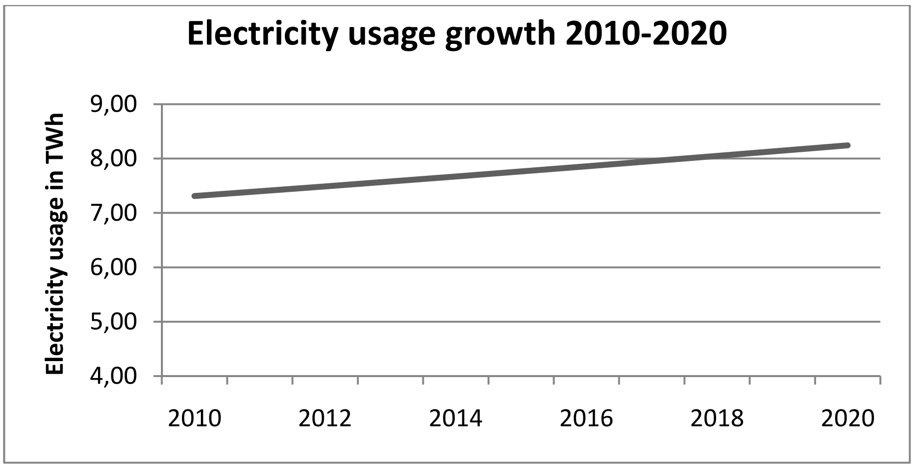
3.1.1 Electricity losses

During the transformation of electricity into different grids and transportation from production to consumption losses occur. As the figure that is obtained is measured by delivery (consumption), losses are not taken into account. It is necessary however to take these losses into account as it can be seen as an electricity consumption of the installations[37]. Without generating extra to cover for these losses, there would be an undersupply of electricity. Own calculations from (FOD Economie, K.M.O., Middenstand en Energie 2008) indicate a loss of about 4.9% on the electricity consumption. Considering the total consumption in Limburg, the loss is around 342GWh giving a total of 7.31TWh.

3.1.2 Electricity demand growth

The electricity consumption is not a static figure though. It varies with the needs of the people. Since the goal is to become CO_2 neutral in 2020, the installations should be dimensioned to this consumption figure. They actually should be dimensioned to foresee in the growth for the time new installations are deployed. (Commission Energy 2030 2007) estimated a growth rate of 1.21% a year between 2010 and 2020. Since this figure is also given in the growth rates in (Groep Gemix 2009) it is used to estimate the electricity demand in Limburg for the year 2020. The year corresponding to the figure yet calculated is 2009, but given the economic crisis during that period the demand for electricity did not increase during this period. From 2010 on an increase in demand is expected. So an increase over 10 year gives a total consumption of 8.25TWh (i.e. 7.31 times 1.0121^10) of which the evolution is shown by Figure 3-1.

Figure 3-1: Electricity usage growth for Limburg



Own processing based on the growth rate mentioned in this section

[37] I.e. transformers and cables

3.1.3 Electricity peak demand

As the demand for electricity is volatile and cyclical there is an additional problem as indicated in section 2.1 There already is a problem concerning this issue in Belgium. The installed capacity is not sufficient to cover the peak in the demand. The installed capacity in Belgium in 2008 was 13,149MW (CREG 2007) and the peak demand in 2006 was 13,702MW (Commission Energy 2030 2007). Although the years indicated do not correspond, it is obvious that not enough electricity could be delivered since the demand in 2008 would be even higher than the figure of 2006. This is solved by a net import of electricity via France, Luxembourg and The Netherlands[38].

Both (Commission Energy 2030 2007) and (Groep Gemix 2009) give the same ratio for the peak demand over the total demand over the year. The peak demand (in MW) is about 0.016% of the total demand (in MWh). It looks peculiar as the peak is only a small part of the total demand, but remember that total demand is over one year, the peak is on a particular moment. A peak demand during the whole year would result in a much higher total demand. In addition, this is only a tool to estimate the peak demand, the percentage on its own has no real meaning.

The total peak demand and so the needed installed capacity for Limburg is 1320MW (8,250,000MWh times 0.016% equals 1320MW). This assumes however the same mix, as this capacity and output are related through the capacity factors of the used power plants.

This peak will not be used in the thesis, but indicates that the results and conclusion have to be looked at from the right perspective. The basis for the further reasoning will be the global consumption of 8.25TWh in 2020.

3.2 Energy mix for electricity production

Every kind of energy production has its own characteristics. They have their own typical fuel costs, energy efficiency and so on. The same accounts for their CO_2 emissions. The production of a certain amount of MWh's causes the power plant to exhaust a certain amount of CO_2 emissions. To know what amount of MWh each type of power plant or energy source produces and consequently the corresponding total emissions, the structure of the production of electricity for Belgium has to be known.

The (IEA 2009) and (FOD Economie, K.M.O., Middenstand en Energie 2008) both indicate a contribution of 54.3% for nuclear power plants to the electricity production. There is a political issue on this matter though. It is stated that the nuclear power plants should be shut down

[38] There is no direct grid connection with Germany or the United Kingdom (Commission Energy 2030 2007)

gradually beginning from 2015. Since this is rather a political issue, this lies beyond the scope of the thesis. So the assumption is made that in 2020, the current capacity of the nuclear power plants is still at our disposal. This is also assumed because the easiest way to replace these renewables will be with a conventional electricity generation method and will generate more carbon dioxide. So to reduce the CO_2 emissions, it is assumed that the methods that do not produce, or emit only little CO_2 are maintained.

(FOD Economie, K.M.O., Middenstand en Energie 2008) states that the part of gas as a fuel type to generate electricity is 30.7%. Given the upward trend over the years from 1996 to 2007 of this fuel type (Eurostat 2008) the current share is likely to be larger. But since there are no reliable figures on hand and it is still possible that the gas power plants achieve a maximum capacity de mix of 2007 is used. The latter two sources also indicate a coal share in this production of about 7.5% and an oil share of 0.9%. The remaining part is divided as follows: renewable fuels (e.g. biomass) 2.6% recuperation (waste) 1.5%, pumps[39] 1.5% and other renewables[40] 1%.

Using this number the electricity generated per fuel type (energy source) can be calculated.

Table 3-1: Electricity generation mix for Belgium in percentages and gigawatt hours

Electricity consumption 2020 (in GWh)		
Energy source	**mix 2007**	
	%	GWh
nuclear	*54.30%*	4479.75
gas	*30.70%*	2532.75
coal	*7.50%*	618.75
oil	*0.90%*	74.25
renewable fuels (biomass)	*2.60%*	214.5
waste	*1.50%*	123.75
pump	*1.50%*	123.75
other renewables[40]	*1.00%*	82.5
	100.00%	8250

Percentages mentioned are explained in this section. The generation is calculated by multiplying the percentages with the total electricity demand

(VREG 2009) provides figures of the subsidies granted for the generation of renewable electricity. For each 1000kWh generated they grant one certificate indicating you originated this amount of electricity. These certificates are freely tradable and currently the electricity grid companies have to buy these certificates at a fixed price. Via this route it is possible to calculate the amount of green

[39] These are used to store electricity by pumping water to a basin when demand is low and convert this potential energy by lead down the water to drive a turbine when demand is high
[40] E.g. solar-, wind-, geothermal-, water energy

electricity generated in Flanders as this is often not specified in general mixes due to the small quantity. In 2008 the generation through biomass was over 1.5TWh or almost 81% of the total renewable electricity. This is followed by onshore wind energy with almost 18% or 333GWh. Solar energy and hydro energy respectively are responsible for 1.2% and 0.19% (22.4 and 3.6GWh). Compared to the solar energy generated in Limburg there is a rather big difference. Taking into account only the small installations (less than 100kW) Limburg is responsible for 7.9GWh. This is over 34% of the solar energy generation over whole Flanders. This does assume that the certificates that can be granted are all issued. This is not necessarily the case as it is demand driven.

4 CO_2 emissions

To become CO_2 neutral, and to achieve this by implementing renewable energy sources, it is important to know how much emissions to abate and hence how much renewables to install. The consumption figure here is not sufficient because, as already mentioned, the different energy sources produce different amounts of CO_2. And even not all methods produce emissions. So when talking about how much CO_2.to abate, first the total CO_2.emissions has to be known and second which methods this produce.

First the CO_2 emissions for the different methods of producing electricity will be examined. According to these figures and the estimated consumption given the energy mix in section 2.1 and 3.2 the total emission[41] of CO_2 for Limburg can be calculated.

4.1 CO_2 emissions by energy source

There are a lot of contributing factors influencing the emission rates. For fossil fuels for example fuel characteristics, caloric value[42] and conversion efficiency are among these factors (L. a. Spadaro 2000). Because of the lack of information relating to the specific characteristics of the power generation in Belgium, it is not logic to try and make a complete qualitative approach in assessing these data sources. However, there is a distinction made to some extent. To get a clear view on the LCA issue, the direct and indirect emissions are separated and can be found in annex 10.1.2. It can be easily deducted from the tables in this annex. that only the fossil fuel consuming technologies emit CO_2 directly. And although de indirect emissions are small compared to the direct ones, there are still significant and should not be neglected. This way it is clear how much is emitted during the generation phase only. Hence this data can be used for when conducting a study on a large scale including other sectors without the problem of taking the emissions into account more than once. Another important difference in the reports examined is that some work with only CO_2, while others made calculation for CO_2 equivalents[43]. A quantitative approach is used however where data from 17 different sources is examined to get a reliable insight in the carbon dioxide emissions. The methodology is explained in annex 10.1.1.

[41] Caused by only electricity
[42] A measure for the amount of energy a fuel contains. This varies from fuel type to fuel type and even can vary for the same fuel types due to a quality difference.
[43] Including CO_2, CH_4, N_2O all converted to an equivalent impact to CO_2

(Smeets 2009) talks about abating the CO_2 equivalents and since the other emissions than CO_2 also have an impact on the environment the figures of the equivalents should be used for further calculations.

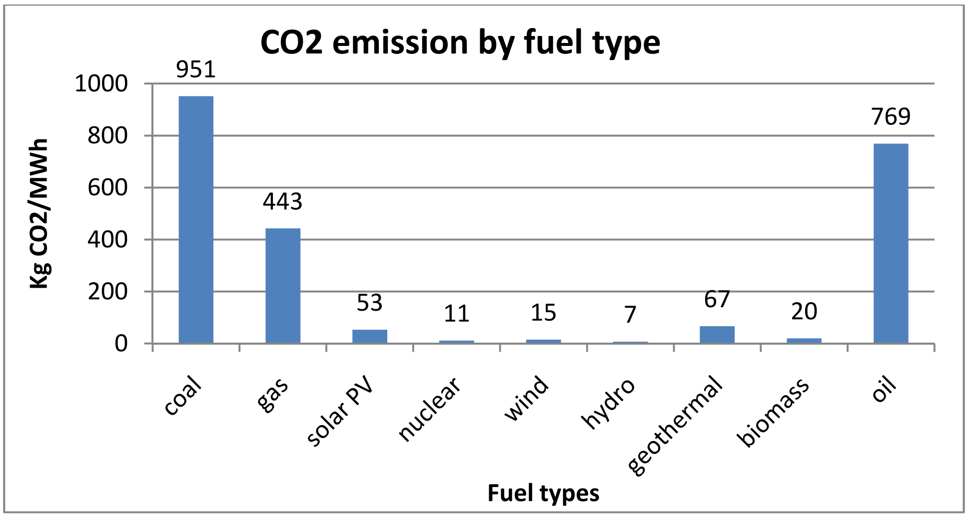
Table 4-1: Total life cycle analysis emissions

Total LCA emissions (direct + indirect)						
		1	*3*	*2*	*4*	*5*
Fuel type	**coal**	815	990	974	755	1094
	gas	363	653	469	389	642
	solar PV	51	84	39	30	18
	nuclear	20	-	9	15	10
	wind	7	124	14	19	0
	hydro	-	18	-	23	15
	geothermal	-	23	-	-	-
	biomass	-	-	-	46	-
	oil	925	733	-	546	881

Figures in *kg CO2/MWh.* Extensive table can be found in annex 10.1. Source: 1: (Krewitt, et al. 1997) – 2: (Criepi 1995) – 3: (Meier 2002) - 4: (Spadaro, Langlois en Hamilton 2000) - 5: (Dones, Heck and Hirschberg 2003)

Table 4-1 shows the carbon dioxide emissions for several fuel types when used for electricity generation. The data from (Krewitt, et al. 1997) and (Criepi 1995) only consider the CO_2 emissions. The other data take into account CO_2 equivalents. It's conspicuous that although the assumptions made (CO_2 vs. CO_2 equivalents) the average figures of each assumption are quite similar. Because of this, the average figures are used. Many studies make a nuance by including carbon capture and storage (CCS), these figures are left out deliberately given the time frame used. Studies like (Commission Energy 2030 2007) and (Groep Gemix 2009) indicate that the likeliness that this technology becomes operational before 2030 is low. Figure 4-1 gives a summary of the average figures calculated in the annex for the considered electricity generating technologies.

Figure 4-1: LCA CO_2 emissions by fuel type



Figures are averages emissions of the table in annex 10.1

4.2 CO_2 emissions in Limburg

Sections 3.1, 3.2 and 4.1 elaborated respectively on the electricity consumption, how this electricity was produced and how much CO_2 these production methods exhaust. To know specific figures for Limburg, these sections can be combined as is done in Table 4-2.

By multiplying the electricity production of each energy method with the corresponding CO_2 emissions per unit of electricity generated, the total CO_2 emissions for Limburg caused by the electricity generating sector are obtained.

Table 4-2: CO_2 emissions from electricity generation

Carbon dioxide emissions in Limburg				
	Mix 2007		CO2 emissions/source	Total CO2 emissions
Energy source	*%*	*GWh*	*in ton CO2/GWh*	*in ton CO2*
nuclear	54.30%	4479.75	11	49,277.25
gas	30.70%	2532.75	443	1,122,008.25
coal	7.50%	618.75	951	588,431.25
oil	0.90%	74.25	769	57,098.25
renewable fuels (biomass)	2.60%	214.5	20	4290
waste	1.50%	123.75	0	0
pump	1.50%	123.75	7	866.25
other renewables	1.00%	82.5	20[44]	1650
total	100.00%	8250	221.05	1,823,621.25

The left part is taken from Table 3-1. The right table is calculated as indicated in this section

Although the majority of the electricity generation is done with nuclear power plants, this energy source is not the largest contributor to the emissions. In operations it does not produce CO_2 emissions in contrast to the gas-, coal- and oil fired power plants. It is obvious that the greater part of the carbon dioxide emission is caused by the fossil fuels. Electricity production by means of waste usage as a fuel is a complex topic. There are emissions caused while burning this waste, and yet the table states that there are none. On the on hand this is caused by the nature of this fuel, it is waste that is produced anyway, so the particles contained by the waste are released into the environment anyway. So actually it is just an alternative way to release the pollutants. On top of that it is really hard to determine the composition of the pollutants, different kinds of waste cause different amounts of pollutants.

[44] This emission of the 'other renewables' is calculated according to the relative share of the renewables in (FOD Economie, K.M.O., Middenstand en Energie 2008). I.e. hydro: 34.8%, wind: 43.5%, solar: 21.7%.

5 The cost of electricity generation

As this thesis does not only study the possibilities to implement renewable energy sources, but also the cost that they are bringing along, it is important to gain greater insights in this topic. This chapter elaborates on these costs by exploring the different variables in the scientific literature. Then the costs themselves will be listed and ranked according to their competitiveness along with an explanation why differences occur.

It is important to explore the variables that make up the cost to know which cost to take into account; this is already discussed in section 2.3.1.

Not only will the costs of the sustainable energy sources be explored, but also those of the conventional energy sources to gain a better view on the price[45] ranges and the competitiveness of the renewables. When elaborating on the costs, obtaining the true costs will be the pursuit. For this reason the external costs will be examined too.

It was not feasible to gather the cost information separately and make own calculations as it is very time consuming to gather the needed data. Although there is a consistent cost structure for the different energy sources, data needed are scattered along many instances and organizations. Hence, the cost data are mined from professional literature.

The different costs will later be the foundation of the scenario's used in this thesis.

5.1 The cost of the different energy sources

Many studies give price ranges instead of a single price because of the uncertainty of some parameters. The values of these parameters influence the cost per MWh produced. Because different scenarios are plausible the 'price range'-method is maintained in the form of an optimistic and pessimistic method later on.

The common discount rates used is 5 percent and in some cases can be 10 percent. 5% is a low rate, but conventional for socio-economic project as these. This discount rate is also inflation adjusted. A higher discount rate would be a disadvantage for capital intensive project like those of renewable energy sources. The higher the cost of capital (discount rate), the higher the price for a MWh of electricity production.

[45] Price is used, from an economic point of view incorrect, interchangeably. Although costs and prices are linked, this is not so clear cut (Verbruggen, et al. 2009). When price is meant in an economically correct way, this is stated explicitly.

Externalities are not taken into account at first. They would shift the costs benefits of the “dirty” energy sources and make them relatively less advantageous or even more expensive compared to the renewables. Externalities are not necessarily negative. Job creation might be a positive externality that accompanies an energy source. (Ea Energy analyses 2007)

The geographic location is also a very important parameter. In mountainous areas there will be higher infrastructure costs, in windy areas wind turbines will have an advantage, in areas containing coal-mines prices won’t be so volatile, and so on. These are all things that affect the price of electricity generation.

Larger installations often come with greater efficiencies. When a 1MW power plant is installed the cost per MWh produced can be higher than for a 10MW power plant due to a lower efficiency. To avoid a cluttered view caused by too many variables or possibilities, averages of these figures are taken into consideration.

The scenario used to gain insight in the future can be different as well. These contain estimations about fuel prices, impact of policy measures, the time frame energy sources are used, the technologic development and much more. Different scenarios use different estimates and so provide different outcomes.

Differences might occur due to[46]:

- Currency used
- Base year
- Discount rate (financial assumption, source of capital)
- Externalities included
- Local purchasing power
- Capacity (factor)
- Heat sales
- Region (geography) availability of fuel, possibility to built
- Scale economies
- Installed capacities
- Learning rate
- Fuel prices
- Policies
- Time frame
- Technologic development

Ranges in the scientific literature are caused by different possible values of some of these factors.

[46] List not exclusive

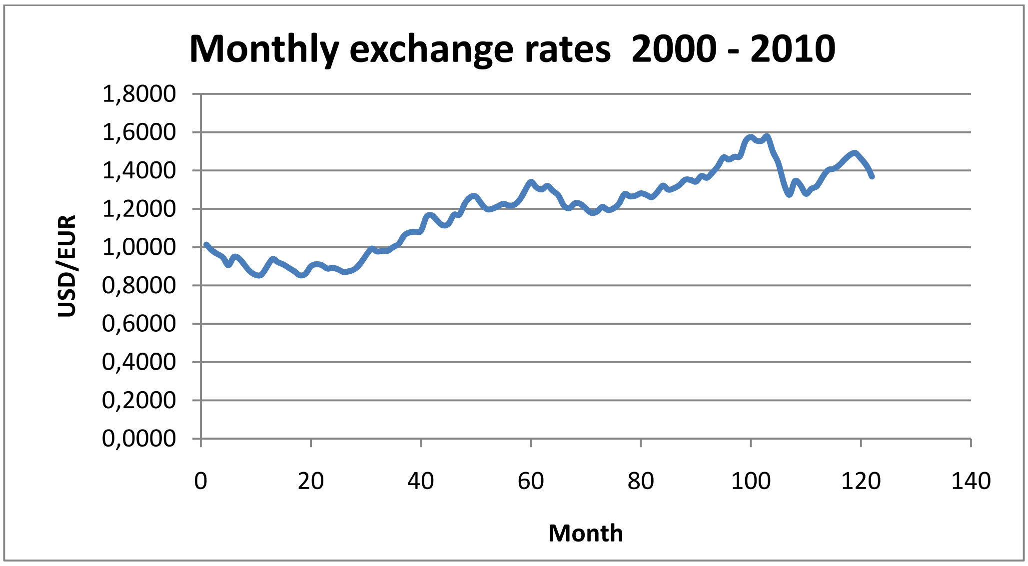
Now the costs of different energy sources and different studies are compared and ranked to obtain a good overview of the competitiveness of the electricity generating methods. The great problem with the different studies is that they all have to make assumptions as just mentioned. Some of them based on other studies, some of them based on own data or metadata[47]. Not even all studies provide all their suppositions in their article or report. That makes it especially difficult to develop a good framework to control the data on hand. In addition, if the rules are too strict applied, not much data is left which renders the output uncontrollable. The specific characteristics for the Belgian situation have to be made transparent in order to evaluate the cost models used the studies, hence the output of those models. Typical Belgian factors should be used for capacity factor, outages, heat sales, fuel prices, labor wages, insurance, regulations and technical efficiency[48] to name only a part of the lot. Because of these difficulties in assessing the numbers, a quantitative approach will be used to obtain a range of figures as is done with the CO_2 production. With the upside of this method being that a larger amount of data is available to compare and see it in the right perspective. On the downside is that the used data does not all match the Belgian characteristics. The calculated data used in both methods can be uncontrollably (with the time limit of the thesis) biased if looked at separately, but with the former method it can be compared to similar studies. This does not mean the data is just used randomly without a critic view. All the data used is of concern to at least the OECD[49] countries or Europe and only data of governmental or renowned organizations are used. Data about for example California (California energy commission 2007) will not be taken into account due to the differences of which regulation and climate are examples. The large coastline and sunny climate would understate the cost of generating electricity via solar panels and wind turbines based only on the capacity factor to name just one possibility. So a first selection procedure was to determine broad similarities with Belgium (and consequently Limburg). These studies were all listed along with the prices or price ranges found in the studies.

As not all studies used the same currency nor the same base year[50] in which they expressed their costs, these differences have to be cancelled out. The dollar and the euro are the two currencies used in the different studies. Since the local currency is euro, everything should be converted to the euro. But what exchange rate to use?

---

[47] Data about data (Witten and Eibe 2000)
[48] Factors are explained in the next section
[49] Organization for Economic Co-operation and Development
[50] 1€ in 2000 is worth more than 1€ in 2010

Figure 5-1: Spot[51] exhange rates dollar-euro



Source: (De Nederlandse bank 2010)

Figure 5-1 shows the volatile character of the spot exchange rates. Significant variations even occur on a daily basis. It is evident that the result of the conversion would depend on the date used, so this cannot be used as a good measure to convert the currencies. An additional problem is that prices of goods and services are usually lower in poorer economies. A euro exchanged and spent in Thailand for example will buy much more than a euro spent in Belgium. Therefore the purchasing power parity is used to convert the currencies. The purchasing power parity theory specifies a precise relationship between relative inflation rates (price differences between the countries) and their exchange rates. It is based on the law of one price, the idea that in an efficient market identical goods must have only one price (Madura and Fox 2007). The PPP conversion factors are based on a given basket of goods and represent the conversion factors applied to equalize price levels across countries.

Table 5-1: Purchasing power parity rates between the USA and Belgium

PPP rates										
Year	***2000***	***2001***	***2002***	***2003***	***2004***	***2005***	***2006***	***2007***	***2008***	***2009***
United states	1	1	1	1	1	1	1	1	1	1
Belgium	0.8910	0.8856	0.8652	0.8790	0.8964	0.8996	0.9046	0.9097	0.9122	0.9120

Source: (Organisation for economic co-operation and development 2009)

[51] Foreign exchange market where transactions take place immediately (meaning within two days). (Madura and Fox 2007)

Table 5-1 shows the PPP rates for the Unites States and Belgium. The PPP rates are generally measured against the U.S. dollar, that is why the numbers for the United States denote 1. The united states is used on one hand because of the currencies is in dollars in several studies, and Belgium on the other hand as the energy sources are to be implemented there. As a result, the prices were converted into euro using this PPP.

In this thesis, the base year for the prices used is 2009. Consequently all input data in other price levels must be in- or deflated to this 2009 price level. Because of the explicit nature of the costs (mainly power plant related), not the global inflation rates are used, but indices for power plants in particular are used to inflate or deflate prices (Table 5-2).

Table 5-2: Power plant index by USBR

Power plant index											
Year	1977	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
USBR index	100	232	237	241	247	253	267	279	290	302	318

Source: (U.S. Bureau of Reclamation 2009)

The global inflation rate consists of a given basked of goods and services. To simplify, assume two goods with an equal share. Now, if one becomes more and the other less expensive with the same magnitude, there is no inflation. To avoid other goods or services over- or underestimating the price of 'power plants', only the index for these power plants is used. Using the USBR index approaches the reality more than the global inflation rate in this case. As a result, all prices were brought to the same level by using the USBR index.

Now all prices are listed in the same currency (Euro, €), in the same base year (2009) and are better comparable to each other. Still, many differences can be noticed among the studies. As is mentioned, it is not feasible to cancel out all differences according to the Belgian characteristics. Additionally, several factors used in the reports are estimates as they try to predict the costs. since the assumptions cause an uncertainty there is opted to use price ranges for the several electricity generating methods. The ranges can be considered as an optimistic and a pessimistic view. To get this optimistic and pessimistic view of the costs, it is good to have several data sources. After all the law of large numbers states: the larger the sample number, the larger the reliability. Or stated precise: under general conditions the sample average will be close to the population mean with very high probability when sample size is large. (Stock and Watson 2007) Of course there is a possibility that a study is biased towards a certain technology. Given that several other data sources are used, it is assumed that the biases should largely cancel each other out. Using the statistical interquartile ranges (the first interquartile and third interquartile[52], or the equivalent expressions, the 25 and 75 percentile respectively), the optimistic and pessimistic view of the prices are calculated. So what this means is that in the lower part of the data (really low prices) and upper part (really high prices) each time 25% of the data is left out. The first reason for this is that a large bias of a certain study could influence the average, so the median would be a better solution. But additionally, not just one figure is wanted, but rather a range. This is where the quartiles come in. So the outliers are hereby also ignored. Even if it is assumed that all studies did a very good job and avoided biases, it still is possible to generate extreme values by parameter estimates used. The low prices of for example wind energy will be calculated in very windy areas like Denmark, the low prices for solar energy in regions closer to the equator. Electricity generated by coal fired plants can vary in price due to price of coal, or national restrictions in the emissions exhausted etc. A second reason is to avoid these unrealistic price variances. Other reasons are already mentioned in section 2.6 The original data can be found in annex 10.2.1, as is the case for the recalculated table, which can be found in annex 10.2. Section 10.2.3 reports the statistics of the latter table and the first and third quartile form the ranges used in the thesis.

If all these things are applied to the data a table like Table 5-3 can be rendered.

Table 5-3: Ranking of the energy sources by electricity generation costs.

Electricity generating costs (excluding externalities)			
		optimistic	*pessimistic*
energy source	*wind onshore*	48	90
	wind offshore	59	120
	PV	217	365
	Solar thermal	91	205
	biomass	42	106
	MSW[53]	-11	0
	small hydro	46	73
	coal	22	46
	nuclear	23	43
	geothermal	42	106
	gas	37	54

Figures in €/MWh; real 2009 prices. MSW: Municipal Solid Waste (incineration). PV: PhotoVoltaic.

[52] A percentile is the value of a variable) below which a certain percent of observations fall. E.g. a 25th percentile gives a value where 25% of the value of the other observations is below, and 75% of the remaining observations values lies above. The first quartile is the equivalent of 25th percentile and the third quartile is equivalent with the 75th percentile. The median expressed in these terms would be the 50th percentile or the second quartile (Vanroelen G. 2005)

[53] This figure is based on only one study, normally it would be left out, but as it is a part of the electricity mix and it is only minor, it is kept for the sake of completeness.

The prices in Table 5-3 are based on the available technology today (2010 as a guideline). Due to learning curves and economies of scale these prices will drop further. As this is an assessment with a future view, even though in the short term (by 2020), the prices have a small opportunity to drop. This means working with prices for the near future, with obtaining the prices for 2015 as a goal.

The cheaper forms of electricity generation are, as was expectable, the conventional power plans as coal and nuclear. Economically it is logic to use these energy sources. However, these costs do not yet represent the true cost because externalities are not taken into account in this table.

The cheapest form of energy generation according to this table is MSW with even a negative figure. This favorable situation exists because instead of a cost, the fuel (waste in this case) provides revenues because people want to get rid of it.

PV power generation is the most expensive; this is rather surprising since the Belgian government encourages people to install this power generation method on domestic and industrial scale. On the other hand, it is more convenient than installing a wind turbine. PV can be installed on every roof, and there are strict rules and more paperwork is needed to try and install a wind turbine.

5.2 Internalizing the externalities

To look at the prices from the right perspective, the externalities should be taken into account. After all these externalities represent a cost that is not considered when making decisions, but in the end have to be paid by someone or something[54]. There are a lot of externalities that can be taken into account, and this is not only in a negative way (as is often thought). It is possible that an externality can reduce the costs, as is the case for example with a technology that creates extra jobs. If building and maintaining wind turbines would create more jobs than is the case with the present electricity generation sector, society as a whole would be better off with this job creation. But this benefit is not taken into account when calculating the costs. Externalities can be very diverse and elaborate because in order to be able to take them into account, all the different factors have to be monetized. If not expressed in dollars or euros, it is not possible to add it with the other costs and have a clear view. With the present market in CO_2 it is fairly easy to calculate how much a ton of CO_2 emissions cost. However, due to air pollution, buildings corrode, agriculture yields reduce and it also has an impact on human health. How to account for health impacts? How do you set a price on mortality? Some experts argue on one hand that the lives of elderly are

[54] Might be an ecosystem as well for example by a loss of biodiversity

almost as valuable as younger people[55]; on the other hand others argue that the life years lost should be the measure for valuing a life[56], meaning that a younger people's life is more valuable than an elderly life.

Because of the complexity of this topic, many studies take a different angle or take different externalities into account. (Torfs, et al. 2005) calculated the external costs on the basis of life cycle analysis (LCA) of the fuel and the infrastructure, the emissions in the production phase, profession risks not yet taken into account, and noise and other discomforts. (Ea Energy Analyses 2007) on the other hand elaborate on CO_2 emissions and other pollutants as the former study did, but also took into account system integration costs and fuel security. First the mutual externalities are investigated. Both studies just mentioned are based upon the (ExternE 1995) project initiated by the European commission concerning the mutual externalities. But both changed the methodologies corresponding to the new insight and knowledge since then. The Mira (Torfs, et al. 2005) study gives price ranges similar to the ExternE report. Recabs (Ea Energy Analyses 2007) on the other hand indicates lower externality costs for the whole range of technologies, which indicate a systematic difference, hence another methodology. As these are both renowned organizations the Recabs data will be used as a pessimistic cost[57] and the Mira as an optimistic cost. This is an analogous reasoning as is used by (EEA 2008). The following

Table 5-4 lists the findings of these studies concerning only damage by greenhouse gasses and classical pollutants. The ghg's are those mainly responsible for global warming, where carbon dioxide (CO_2) and methane (CH_4) are the most important[58]. The classical pollutants regard SO_x, NO_x, particles and radioactive emissions.

[55] i.e. 'value of statistical life' approach
[56] i.e. 'years of life lost' approach
[57] Optimistic and pessimistic here are used indicating the nature towards renewables. A high external cost favors renewables as they have a smaller share in this external cost. Hence this cost is optimistic towards renewables
[58] Even water vapor (H_2O) is a greenhouse gas

Table 5-4: Cost of CO_2 emission and other classical pollutants for electricity

Electricity generating externality costs			
		Pessimistic - Low	*Optimistic - High*
energy source	*wind onshore*	0	1.5
	wind offshore	0	2
	PV	0	6
	Solar thermal	-	-
	biomass	2	10
	MSW[59]	18.71	18.71
	small hydro	0	3
	coal	16.7	40
	nuclear	4	5
	geothermal	-	-
	gas	7.38	15

Figures in €/MWh, real 2009 prices. Represents only the external costs of ghg's and other pollutants. Source: optimistic/low case: (Ea Energy Analyses 2007), pessimistic/high case: (ExternE 1995), (Torfs, et al. 2005)

The Recabs study neglects the external costs for renewables, this can be seen by the zeros in the pessimistic column of Table 5-4. This might seem unreasonable but after all these costs are minor compared to the costs caused by the conventional energy sources. And if in the long run the emissions in general are brought to a minimum, these costs will be insignificant at all. With waste incineration there is a considerable externality due to the release of emissions 'stored' in our waste. This waste is stored anyway (e.g. garbage dump, scrapheap) and thus it can be discussed whether or not this should be taken into account. After all, the only difference is that instead of a slow release of these emissions, they are more rapidly exhausted during the burning process. The vast majority of the externalities are caused, as could be expected, by the fossil fuel consuming power generation methods. And apparently, these costs can be quite significant, even compared to the order of magnitude of the corresponding electricity generating costs[60].

Differences in externalities can be caused by the externalities taken into account. If for example the impact in human health is left out, it is logical that the externalities will be lower. The

[59] Again the figure for MSW is only based on one study and is used for the sake of completeness at it will not have a major impact on the results
[60] Excluding externalities

monetization of the external costs certainly have a great influence. If the cost of one kilogram CO_2 is lower for example, the cost impact of global warming will be lower[61].

When examining the data it is clear that only a part of the externalities cause the largest part of the costs. Among the externalities in the studies are impacts on human health, building material, crops, global warming, amenity losses, impacts on ecosystems and so on. The provokers of the largest fraction of the costs are SO_2 and NO_x through mortality (public health) and CO_2 equivalents by means of global warming.

In general Belgium has slightly higher externalities than the average country because of its location. Emissions exhausted cause more damage when emitted nearby densely populated areas. As Belgium itself has a large amount of inhabitants considering its size and the surrounding countries have crowded nearby cities, the emissions originated from Belgium are likely to cause more health damage than sited in less densely packed surroundings as Norway for example.

These are not the only externalities though. Renewables have important advantages and disadvantages. One of each causes an externality. Among the advantages for the renewables is that implementing these green energy sources avoids the problem of volatile prices. If Belgium were to generate all electricity needed with resources from the Belgian continent, it would reduce the dependency on other countries regarding the fuel supply. This is referred to as fuel security. A number of studies show that, according to Recabs, raising oil prices slow down economic growth by increasing inflation and unemployment. The same correlation applies to the volatility of natural gas price. This thus relates to a macro-economic consequence initiated by energy price shocks. This disregards the fuel of renewables since it is freely available (wind, sun) or recyclable (waste used for electricity generation). But on the down side (disadvantages for the renewables) is that the availability of wind-, solar- or water energy is not that predictable. This imposes a cost referred to as ‘balancing’ and ‘capacity credit’. Balancing costs arise when there are deviations from the planned production[62] and they arise because investment in reserves for the handling of outages of power plants or transmission facilities is needed. This cost can be seen as the ability of adapting the electricity supply instantly[63]. This is needed when the planned supply deviates significant from the consumption of electricity. Gas turbines can start or come to a stop rather fast unlike a nuclear power plant (EIA 2009). Another possibility is a reserve capacity that is needed in case of outages of various kinds.

[61] This has of course nothing to do with global warming itself
[62] Production is planned according to expected usage
[63] Instantly representing minutes to hours in this context

The difference with capacity credit can be looked at as the different time span. And it is a matter of timing. (UKERC 2006) uses the term capacity credit to ensure system reliability "This relates to the capacity that must be built or retained on the system with intermittent generation to ensure that a defined measure of reliability of supply during peak demand is maintained". This external cost relates to the subject mentioned in section 2.3.1. Plants which are able to adjust their production according to the system demand have a high value, whereas discontinuous technologies such as wind power would usually have a lower value.

Recabs puts the balancing and capacity credit costs under the "system integration" denominator. They also add the infrastructure costs, meaning the costs for expanding and adjusting the electrical grid in order to cope with the energy source, to the total figure of system integration. But as already mentioned this figure is already taken into account for the 'basic' electricity generation cost. If this adaptation is not carried out, there will be now power available as it cannot be distributed, transmitted or converted. Table 5-5 lists the total costs of fuel security, capacity credit and balancing. The costs regarding only the latter two are listed in annex 10.3.

Table 5-5: Cost of CO_2 emission, other classical pollutants, fuel security and system integration for electricity generation

Electricity generating externality costs			
		Low	*High*
energy source	*wind onshore*	9	10,5
	wind offshore	9	11
	PV	-6	0
	Solar thermal	-	-
	biomass	2	10
	MSW[64]	18.71	18.71
	small hydro	9	12
	coal	19	42.3
	nuclear	9.7	10.7
	geothermal	-	-
	gas	14.38	22

Figures in €/MWh, real 2009 prices. Represents all the externalities taken into account in this thesis. Source: Table 5-4 and (Ea Energy Analyses 2007)

[64] See 59 on page 55

6 Renewable energy potential

It is one thing to look solely at the costs of generating electricity, but the energy extractions are not always feasible due to constrains or barriers. The main purpose of this section is basically to examine how much Limburg accommodates to implement renewable electricity generating sources. But this is a rather narrow domain to gather data given the only constrain wanted is space. After all there are more than a dozen barriers which can be of all sorts to or to not take into account (Neyens, et al. 2004). There is a lot of blurriness about which potentials there are, this is already covered in the methodology section. Here the applicability of the energy sources in Limburg will be looked at. Not all energy sources are employable no matter where. Then this chapter gives a closer look at the potentials to implement renewable energy sources in Limburg after determining the allocation keys that will be used to derive potentials for Limburg from Flanders or Belgium.

6.1 Applicability of energy sources in Limburg

Because one of the barriers is the availability of the fuel, and so the applicability of the energy conversion technology it is important to look whether it makes sense at all to deploy certain electricity generation methods. This can be studied in depth and depending on the purpose, have an economical context, where a break even analysis can be useful[65]. Or assuming a pure energetic background, where an energy payback ratio[66] can be helpful. Since progressing towards CO_2 neutrality is a rather difficult path, a maximum deployment of all available technologies will be necessary. But on the contra side is the short time frame in which this is intended to be realized. Therefore only the present implemented energy technologies in Limburg and Flanders[67] are taken into account. However it might be that within 10 year a new technology is deployed and operational; it is unlikely that it will have a significant contribution to the electricity generation. So the technologies taken into account in the rest of this thesis depend on the applicability of the different energy sources. The methods that are already deployed on a relatively large scale will be used further in this thesis.

The present technologies refer to those used circa 2010. The already implemented energy sources are there because of their competitively nature, energy policy, or perhaps just status. Anyway, the larger scale indicate a beginning potential of that energy source. The main renewables energy

[65] Using prices based on the real costs this includes social cost.
[66] A ratio comparing the energy input (over total lifecycle) compares with the energy output.
[67] Flanders is considered as well due to the similarities in topo- and geography and the fact that electricity is, if generated outside Limburg, it can also be available for the latter.

technologies will be briefly discussed according to their presence indicated in (Aspiravi 2009), (MIRA 2007), and (N. Devriendt 2005).

Water power is extracted via small hydro installations in Limburg (Bocholt and Peer) and over whole Flanders. But due to the small altitude differences, the currents are not strong enough to implement this on a larger scale. Hydro power will therefore only be looked at via small hydro installations.

The energy production form biomass is used in Genk and Mol. This is certainly applicable in most regions given the nature of the technology[68]. In every region there is material which can be used to fuel this technology.

Wind turbines are installed in Lommel, Hasselt and Lanaken. In the near future more turbines will be installed in Gingelom. By 2010, there should be an amount of 34GW installed in Limburg. This is the fastest rising renewable with a relatively low cost and thus definitely should be taken into account. Additionally a wind turbine gearbox manufacturer is located in Limburg, so it would be interesting to involve them with the expansion in this domain as this is economically beneficial as well.

Solar energy is used throughout the province and whole Flanders due to the subsidies that are given for the installation. The sun is, like wind, available all over the world. Limburg is no exception to this. Although Belgium is not the sunniest place on earth, it is certainly worthwhile to take this technology into account is it has several advantages. It is easy to implement without much amenity losses like noise and cast shadow that come with wind turbines.

Table 6-1 provides an overview of the number of installations for which subsidies are given in the Dutch speaking part of Belgium. As there are subsidies given, this indicates their potential. This table reflects the main of the above mentioned technologies.

[68] Using organic waste, crops, etc.

Table 6-1: Number of installations and corresponding power generation in Flanders for which subsidies are allowed

	Number of installations in Flanders which are subsidiesed	Installed capacity in Flanders for which subsidies are given (kWe)
biogas - miscellaneous	43	68,951
biogas -sewer purification	15	4,276
biogas - duming gas	13	18,993
recycled biomass	13	233,300
household biomass	9	42,440
agricultural biomass	27	232,016
hydro power	15	1,000
onshore wind energy	58	213,067
solar energy	46,336	236,186
TOTAL	**46,529**	**1,050,228**

Source: (VREG 2009)

The large number of PV installations is due to the many small scale household installations, which are heavily subsidies. This subsidy will be steadily declining as from 2010.

As biogas is derived from biomass not all studies made a distinction and so is assumed in this thesis although it is in fact a different technology for electricity generation. Besides that the costs of each technology are pretty similar as is indicated in (Ea Energy Analyses 2007), (European Renewable Energy Council and Greenpeace International 2007), and (Commission of the european communities 2008).

A technology not yet mentioned is geothermal energy extraction. This is currently not used on a large scale in the province, but as it uses the earth's heat, it can be applied everywhere, so also in Limburg. However, it is less used as an electricity generation method and mainly as a heat producing one. Although this heat can reduce the electricity usage a little[69], this will not be significant enough to take this into account.

Solar thermal power is not included because the weather conditions (sun-hours) are not sufficient to let the installation operate efficiently. This technology works efficiently in an environment with a solar energy of at least 2,000kWh/m². This corresponds with areas with a latitude of about 40°. (Greenpeace and ESTIA 2003) Belgium only has a solar radiation of 1,000kWh/m² (ODE organisatie voor duurzame energie 1999) and a latitude of 51°. In these latter mentioned areas

[69] An example is that a heat pump can be used for pre heating air in winter and cooling air in summer. During summer, this implies less electricity usage due to superfluous air conditioning usage.

this technology is more suited to 'preheat' water to reduce the heating needed in a boiler rather than electricity generation. So this technology will be dropped.

Offshore wind installations, hence potential may not seem useful in Limburg since there is no adjacent sea or ocean. It is physically not efficiently feasible to transport the electricity to Limburg. The energy flow that the electrons bring along would be consumed by nearby areas. On the other hand there are several examples about similar cases where this can be applied though. It is possible to buy air abroad to abate pollution. The nuclear power plants produce over 54% of the electricity supply, but are only located in 2 areas in Belgium[70]. So the electricity has to travel some way in order to provide the electricity. Certificates issued when renewable electricity is generated is freely tradable, this implies that the holder of such a certificate does not need to have generated the electricity himself (herself). So if sea area is divided among the different regions in Belgium and those regions can invest in offshore wind energy each has its own extra wind potential. If the Limburg example as region is taken, it is physically not possible to actually consume the electricity from the wind turbines invested in. What happens is that the renewable electricity is consumed by regions near the wind turbines. This of course implies they do not consume the electricity from the conventional supply, so less conventional electricity is used. But Limburg is still consuming the same electricity and does not directly abate carbon dioxide. But in fact, Limburg causes the electricity usage from conventional methods to decline as it has invested in the wind turbines that provide power to the surround areas. So although the sea area is not typical for Limburg, it can be argued that it can contribute for Limburg as well. It can also be thought of differently. Assume that each province is responsible for its own renewable energy generation. West Flanders that neighbors the sea area can fully use the sea banks to deploy wind turbines. If it does so it can probably foresee in its own needs with alone offshore wind energy. It can invest in one big project which would put downward pressure on the costs, and by doing this it would leave the other potential in West Flanders unused. Some of these unused potential would be very interesting for renewable electricity generation if offshore wind was not available to this extend. Other provinces will have to use more expensive methods whilst available potential is unused in another area. The reasoning is parallel to the abatement costs curve story discussed in section 2.2. Limburg then would want to pay more to West Flanders than it costs the latter province to generate electricity. West Flanders would be better off as it earns a premium. Additionally Limburg would be better off as it can use electricity at a lower cost than the electricity generated in Limburg due to less ideal spaces and the upward pressure this causes on the costs. This does not mean that the same reasoning can be applied for other areas that are 'owned' by a region. But as this sea area is

[70] Nuclear power plants in Belgium are located in Doel and Tihange

owned on a national and not on a regional level, this is not of concern here. It can be seen however that with collaboration the total cost would be lower. To provide a perspective the two options are considered. Offshore wind is taken into account and is contrasted by another vision where it is not taken into account. The latter can be viewed in annex 10.9.

In Limburg in particular there is a potential to obtain methane from certain places in the coal mines which are not longer in use. This, on its own, is of course not a renewable energy source. But the method can theoretically be combined with the injection/storage of CO_2. The carbon dioxide then would drives out and replaces the methane. So taking this into account, it is not yet really renewable, but the technology as a whole is CO_2 neutral. The amounts of methane that can be mined are estimated on 7 to 31 billion cubic meters (m^3). (LRM 2009) This gas then can be used either for heat or electricity generation. If we assume that all methane is used for electricity generation the total output can be calculated as follows. 1 cubic meter has a caloric value of about 34,000kJ (IEA 2009) and can be converted with a conservative efficiency of about 40% (Commission of the european communities 2008). This give a real output, considering the efficiency, of 13,600kJ. (IEA 2009) also provides that one TJ equals 0,2778GWh, or restated in the corresponding units, one kJ gives 0,2778Wh. Given the total estimated volume of methane, the possible electricity generation is between 26,4TWh and 117TWh[71]. So far there is nothing renewable or carbon neutral about the technology. But, this also contains a abatement potential of 27.5 to 122 million ton CO_2[72].

So all the major (most known) renewables will be taken into account; e.g. wind-, water-, biomass-, solar energy.

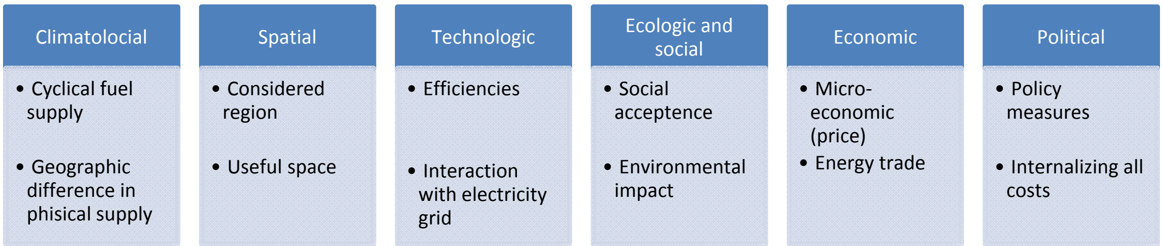
6.2 Energy potentials for Limburg

Many studies provide different future scenario's of what is possible in the electricity market. "How much can renewable energy sources contribute to electricity supply?" are questions that are addressed. The problem here is, as already mentioned in the previous section, that there are many different possible barriers to consider when assessing a penetration level[73] of renewables.

Possible barriers can be: climatologically, spatial, technologic, ecologic and social, economic or political as shown below in Figure 6-1: Possible barriers to higher potentials. This indicates the wide variety of factors that might be taken into account when conducting a study.

[71] This is calculated by multiplying the 0,2778Wh generation potentials from one cubic meter of methane by the total amounts of methane, i.e. 7 to 31 billion m^3.
[72] Calculations are mentioned in annex 10.8
[73] The extent to which renewable energy sources can contribute to total electricity supply

Figure 6-1: Possible barriers to higher potentials



Source: (Verbruggen, et al. 2009), (Neyens, et al. 2004)

The framework of (Verbruggen, et al. 2009) does provide a consistent view of potentials, but this is merely a suggestion of where to base the potentials upon in the future. Most studies are blurred by different factors in the calculation due to own definitions and assumptions as there is no real benchmark. Not to wonder that there is a wide range in the figures by which many studies conclude.

The potentials in this thesis are not based on this framework due to a lack of consistency. Instead an overview will be given of the potentials based on technologic barrier, and secondly the potentials considering other barriers[74] will be grouped together under the socio-economic denominator. The reason is that a technologic potential can be obtained by adjusting the other barriers, but the technological barrier itself is unlikely to change drastically in the short run. The second group can be managed on the short run by changing policies, gaining greater insights in the internalization of the costs, etc. The latter can thus be altered by making the right decisions. And in fact it is supposed that the right decisions will upgrade the potential to what is technologically possible.

For each energy source the highest and lowest values from the scientific literature are mentioned. This way, an extra dimension can be given to the data as opposed to just using one figure. A complete list of the literature taken into account can be found in annex 10.4.

As the region considered in this thesis is very narrow given the subject, only little literature explores data concerning only Limburg. So first data is sought that is applicable to an as narrow as possible area. Afterwards an allocation is made to Limburg itself. A summarizing table is given at the end of this section to give a better overview.

[74] Ecological, social, economic, political

6.2.1 Technical potential

The technical potentials take into account what is possible with the available technology and the space available to deploy. It neglects other restrictions like the costs, regulations, policies and so on.

Onshore wind energy

The potentials here are estimated to 9 to 25GWh/km² by (Huart and Marchal 2006). The available area in Limburg is 431km² (Cabooter, Dewilde and Langie 2005) of which 74km² is effectively useful. The other part can be liable to other, mainly social, constraints. Although this is a technological view, not the whole 431km² are considered but rather a surface of about 100km² to account for surfaces which still can be used for other purposes. This results in a total technical potential of 0.9 to 2.5 TWh for Limburg.

Offshore wind energy

The available sea area is assumed to also be available for every part in Belgium when it comes to social beneficial implementations like this. Hence it is considered that Limburg can use part of what is supplied through this channel. As it is a rather discussable topic (section 6.1), an alternative view without offshore is given in annex 10.9. (Brussels instituut voor milieubeheer 2009) uses figures larger than those of the onshore wind energy, being 17 to 39 GWh/km². This is due to a larger load factor as there are more full load hours off shore. (Van Hulle, et al. 2004) lists the available sandbanks situated within the Belgian continental shelf which totals to about 700km². So technically a potential of 11.9 to 27.3TWh for Belgium is available. The study (Ruyck 2006) conducted in function of (Commission Energy 2030 2007) even estimates a technical potential of 44TWh.

Photovoltaic energy

(Ruyck 2006) considers 100km² available useful space very feasible on roofs, highways etc. (ODE Vlaanderen 1997) estimated a 77km² of available surface to implement solar panels in Flanders. With the 100GWh/km² that (Brussels instituut voor milieubeheer 2009) maintains, this corresponds to 7.7 TWh for Flanders using the 77km² availability. Using the 100km² for Belgium this means an electricity generation of 10TWh for Belgium. These numbers are still conservative estimates compared to the 26.4TWh for Belgium that can be found in (CREG 2007).

Biomass energy

In most areas biomass availability should only be viewed from a waste point. This means only using the biologic waste for the generation of electricity. There is however the possibility of growing crops specifically for later energy generation, but it has some disadvantages. The first is its low efficiency compared to wind and solar energy. If the space was used to deploy solar panels or wind turbines, much more energy could be obtained. (Huart and Marchal 2006), and (ODE Vlaanderen 1997). The second reason is that if the nutrition in the soil is used (absorbed by the crops) there is less available for the food supply, which will harm it in an indirect way. And a third is that agricultural soil is scarce in Flanders compared to the usage. It makes no sense to shift the importation problem from electricity to food and wood for example. (Ampere 2000) estimated a theoretical amount of 18 to 31 TWh for Belgium. This is the same order of magnitude that the (ODE Vlaanderen 1997) provides, being 5.5 to 13TWh for Flanders. But for the northern part of Limburg the former story does not entirely hold. The soil there is contaminated with heavy metals. Growing food crops would bring these heavy metals in the nutritional 'world' and this could harm animals and humans. By growing crops for the purpose of energy production, they also extract these heavy metals from the soils. With good energy generation techniques, these heavy metals can be filtered so they are not emitted in the air and hence, an indirect soil sanitation is achieved. This process is called fytoremediation. (Thewys, et al. 2005) Taking this into account, there is a larger potential for this area and a higher figure can be used for Limburg. As this is hard to estimate, the figures on hand are used, but in reality there is a good chance of a higher potential for Limburg.

Hydro energy

This is a rather modest way of producing electricity for Belgium. (Brussels instituut voor milieubeheer 2009) uses 400 to 700GWh (0.4 tot 0.7TWh) as technical potentials. However (CREG 2007) considers 750 GWh as a minimum production in 2030, based on existing technologies. A technical potential has to be higher than that, so a technical potential of 1TWh for Flanders can be assumed as upper boundary.

Technical potential however are only to be achieved in the long run. After all the barriers preventing to achieve these potential will have a certain inertia and cannot be removed immediately. So the next section sketches the ranges of possible scenario's established by scientific literature.

6.2.2 Socio-economic potential

Because market and economic potential are not the same, this section is grouped under the name of socio-economic potential. And actually consist of the market, economic and sustainable potential. This is due the incoherent definitions used for the numerous potentials in many studies. The main difference is that a market potential focuses on prices while an economic potential uses costs. But there is a lack of clarifying frameworks for this. They all have named different potentials, but many of them take into account different barriers to that inhibit achieving higher potentials. The following they do have in common though. There is a clear difference between these potentials and technical potentials, which is just discussed. So the potentials here are based on the market or economy. In this context this means that there are barriers that prevent the technical potential to be reached. And by using policy measures these can be influenced. It can be seen as a sort of soft measure as it can be altered in the short run. The technical side then can be viewed as a hard measure and is harder to come by.

For each energy conversion technique the highest and the lowest estimates of different studies will be mentioned. But here the assumption is made that business as usual scenario's (BAU) established in different studies are not taken into account. The commitment of Limburg explained in section 1.1 renders bau scenario's history since effort will be made to increase the renewable shares.

Onshore wind energy

For the possible deployment of wind turbines in Belgium the low estimates are found in (MIRA 2007) with 1.2TWh. (Edora 2010) estimates an electricity generation from on land wind energy of 7.7TWh for Belgium on the high end. Other scientific studies estimated figures within these ranges. For Flanders figures indicate to 1.2TWh on the downside and 2.5TWh on the upside according to (Ode Vlaanderen 2007).

Offshore wind energy

Although the land area is much larger than sea area, fewer restrictions are in place for the latter. (MIRA 2007) comes up with a supply of 3TWh on the low end, while a (CREG 2007) uses a supply of 14.44TWh on the high end for Belgium. (Ode Vlaanderen 2007) shows figures ranging from 1.7 to 7.3TWh for Flanders.

Photovoltaic energy

The pessimistic view for Belgium is given buy (Ruyck 2006) with only 57GWh production. This low figures would be caused due to growth restrictions. On the optimistic side a figure of 2.92TWh is specified by (Edora 2010). For Flanders (Ode Vlaanderen 2007) states a generation of 0.28GWh, which is insignificant to the other estimates. (Briffaerts, et al. 2009) estimated an electricity supply of 935GWh or 0.935TWh.

Given the effort made by the government these estimates are quite modest compared to the other renewables.

Biomass energy

For biomass the estimates range from 0.92TWh (MIRA 2007) to 8.87TWh (Edora 2010) in Belgium. To put this in perspective, according to the latter study, the availability of biomass (Forestry, agriculture, fishery and waste) is about 60TWh a year. In Flanders estimates are made of 1TWh according to (Ode Vlaanderen 2007) and 6.7TWh is used in (Neyens, et al. 2004) which is based on (Palmers, et al. 2004). The possible implementation of fytoremediation in northern part of Limburg can increase this figures as indicated in the biomass section for the technical limitation.

Hydro energy

This is a renewable with some advantages, with an important being storage capacity. But according to the literature a rather low generation is to be expected from this source. Ranges go from 0.33TWh (Palmers, et al. 2004) to 0.77TWh (CREG 2007) for Belgium and 0.004TWh (Briffaerts, et al. 2009) and (MIRA 2007) to 0.15TWh (Ode Vlaanderen 2007) for Flanders. (ODE Vlaanderen 1997) indicates a generation of 4.5GWh for Limburg.

This does not list all the scientific literature considered as is already mentioned, but all are listed in annex 10.4.

6.2.3 Limburg potentials

Onshore wind energy

To install wind turbines the only spatial requirement is enough room for the foundation where the turbine is to be built upon. So one limit is that the land has to be vacant or open. Although new technologies exist and can be installed on or even integrated in buildings, these are not considered due to the short run view and the otherwise too elaborate nature. Geographic statistics are used to compare land characteristics. Data from (Lokale statistieken 2009) is used as it gives a good breakdown of the built on areas as well as the vacant land consequently for the 3 districts in Belgium (Flanders district, Walloon district and the Brussels capital district[75]). And most importantly, it also gives the same insights for Limburg in particular. As it uses a consequent manner of depicting the figures calculation could be made to obtain figures for Belgium. The data used for Limburg can be found in annex 10.5, the other data is not mentioned as it is in the same form, can easily be accessed and hence gives no further insights.

[75] Data for Belgium were derived by adding the figures for these 3 districts

The vacant land used for comparison is arable land, grassland, orchards, waste land, and other land. Sorts of land neglected were gardens and parks, forests, recreational domains, rivers and streets as these are not suitable to implement wind turbines due to divers reasons as no room, too expensive, disturbing natural habitats, or unwanted view, -noise and -cast shadow. The share of Limburg compared to Flanders is 17.17% and compared to Belgium is 8.19%. These figures can be found in Table 6-2 which was derived from annex 10.5.2 using the above mentioned vacant land types and data for Belgium and Flanders from (Lokale statistieken 2009).

Table 6-2: Vacant Land[76] ratio's of Limburg to Flanders and Belgium

Allocation key onshore wind			
	Belgium	**Flanders**	**Limburg**
surface *(in ha)*	1,787,118	851,806.47	146,290.49
Limburg *(share)*	8.19%	17.17%	100.00%

Source: (Lokale statistieken 2009)

This now means that the potentials from Belgium or Flanders can be allocated to Limburg using the 8.19% and the 17.17% respectively.

Offshore wind energy

Offshore wind energy gives a whole other view on this issue. The method of finding an allocation key here is different from the onshore wind energy. Offshore wind turbines are mountain preferably in shallow water on sand banks. Surface would not be a good allocation key as the sea banks where the offshore wind turbines are mounted on can be considered communal property. A fair allocation method is when electricity generation is divided evenly among the provinces. But as some provinces are more electricity intensive caused by demographic or industrial drivers, this electricity generation will be allocated based on the electricity usage. Hence each province will have a same percentage of their usage at once disposal. With a usage of 95TWh for Belgium (FOD Economie 2009) and a consumption of 48TWh (VREG 2009) for Flanders, the corresponding ratios for Limburg are 7.7% and 15.3% using the consumed 7,31TWh. Although the figures of Belgium and Flanders are on a 2007 base and those of Limburg are based on 2009 data this will not lead to significant differences. Especially due to the economic crisis it is assumed that no major changes occurred in that period.

[76] Not all vacant land is considered, only those that are assumed to be suitable for the deployment of wind turbines

Photovoltaic energy

Solar panels used to covert solar energy into electricity are most efficient when exposed to the sun. Common practice is to install these panels on the roofs of buildings. This way it does not require extra space and objects causing shadow are less likely. Although there are some sites where these panels are mounted on land that otherwise lies fallow, this is not taken into account as this decision is rather arbitrary and individual. The total built over area is the allocation key to divide the electricity generation from solar energy. After all, all the structures on this built-over area can be appropriate for solar panel deployment as they all have roofs. The considered built-up area consists of flats, buildings, houses, side buildings, industrial buildings, storage locations, public buildings, etc (Lokale statistieken 2009). Table 6-3 shows figures of the built-over land of Belgium, Flanders and Limburg.

Table 6-3: Built-over land ratio's of Limburg to Flanders and Belgium

Allocation key PV			
	Belgium	**Flanders**	**Limburg**
surface *(in ha)*	395,074	253,538.80	40,435.64
Limburg *(share)*	10.23%	15.95%	100.00%

Source: (Lokale statistieken 2009)

This means that in Limburg there is about 1/10th of the built-over land of Belgium available. For the former and Flanders this is almost 16%. This is a much lower figure than currently is the case. As indicated in section 3.2 the share of Limburg compared to Flanders is over 30%. This difference might be caused by the behavior towards solar panels, local policy measures, better oriented buildings and so on. The former figures is taken however as it is difficult to find out the real cause of the difference and this may be only a temporary difference.

Biomass energy

Biomass actually is a generic term and refers to different kinds of biologic waste. It can be wood waste from pruning branches, sawdust from wood industry, agricultural crop remainders or even grown for energy purposes, fishery, residential waste or even sewage waste is possible. Things like wood, agricultural crops and fishery products are imported as well (Edora 2010), so it is hard to find a good allocation key for everything as a whole. Splitting up the difference sources of biomass would lead to a too extensive division and the costs of collecting extra data would outweigh the error made with a simpler allocation key. As the majority is economy driven the added value of biomass producing sectors[77] of Limburg will be compared to Flanders and Belgium to allocate the biomass potential. A part is driven by the number of inhabitants (mainly residential waste), but as this is only a small fraction that is misallocated, it will not be taken into account. (ERSV Limburg 2007) calculates the added values on the basis of data from the institute of national accounts and shows a contribution of 10.4% of Limburg to the added value of Flanders in these sectors. Limburg causes 7.3% of the added value of Belgium regarding these sectors.

Hydro energy

Energy can only be extracted from water when it is moving[78], so here to rivers are of importance. Watercourses can be used for implementing turbines for electricity generation. The more rivers there are, the more room to deploy these turbines. Table 6-4 shows the surface of rivers in Belgium, Flanders and Limburg.

Table 6-4: Watercourse ratio's for Limburg compared to Flanders and Belgium

Allocation key hydro			
	Belgium	**Flanders**	**Limburg**
surface *(in ha)*	23,219	13,267	4,461
Limburg *(share)*	19.21%	33.62%	100.00%

Source: (Lokale statistieken 2009)

The table shows that Limburg has a pretty large share of watercourses considering the other energy sources. This will not have a major impact however because of the small potentials for hydro energy.

Table 6-5 provides a summary of the allocation shares used to calculate the potentials (in GWh) for the area of Limburg given the figures of Flanders or Belgium.

[77] The agricultural, forestry and fishery sector, the nutrition-, wood- and paper industry.
[78] With the exception of still waters used for heat pumps (warming and cooling)

Table 6-5: Allocation rates from either Belgium to Limburg or Flanders to Limburg

Allocation keys			
	From:		*to:*
	Belgium	**Flanders**	**Limburg**
wind onshore	8.19%	17.17%	100%
wind offshore	7.70%	15.30%	100%
PV	10.23%	15.95%	100%
biomass	7.29%	10.37%	100%
small hydro	19.21%	33.62%	100%

Table 6-5 summarizes all the allocation rates discussed in this section.

The method used to allocate the potentials does not represent real available areas for each renewable electricity generating method, rather an area where the potentials are mainly based upon. By transferring it, it is assumed that the land composition is equal across Belgium. For example; it implies that the same percentage of the buildings in Limburg is suitable for solar panel installation. Stated differently, a same percentage should have the same (south) orientation that is preferable for solar panels. The same accounts for wind energy, where not all open land is suitable. Open land can be just adjacent to a park or buildings. This former has social issues and the latter can for example prevent good wind availability. But again, it is assumed that these issues occur equally over Belgium, which is not necessarily exact.

So far, mostly potentials for broader regions are mentioned, combining this with the allocation keys determined, the potentials for Limburg can be explicitly calculated. The method of calculation is taking the potential to be allocated to Limburg but from a larger region and multiplying it with the right allocation key. For example to allocate the onshore socio-economic wind potential of Flanders (i.e. 1.2 and 2.5TWh) the figures are to be multiplied with the figures that allocates the potential from Flanders to Limburg (i.e. 17.17%). The results are to be interpreted that 17.17 percent of the Flanders potential could be implemented in Limburg, which is 0.206TWh or 206GWh on the downside and 429GWh on the upside. But these are not the figures noted in Table 6-6, as the allocation from the Belgian potentials give a broader range (can be calculated analogously). The highest and lowest figures are taken each time whether they are allocated from Belgium or Flanders. This way the ranges from the studies as a whole are maintained.

The Table 6-6 summarizes the used potentials and gives for each energy source the corresponding potentials that were found for Limburg. The underlying method is that a potential for Belgium for example (expressed in TWh or GWh) is multiplied by the allocation rate (Table 6-5) from Belgium to Limburg (a certain percentage obtained by an allocation key) for a particular generation method as is just explained using the example.

Table 6-6: Limburg renewable potential figures

Potentials			
		tech pot	eco - mar pot
wind onshore	*low*	900.00	98.28
	high	2500.00	630.63
wind offshore	*low*	916.30	260.10
	high	3388.00	1116.90
PV	*low*	1228.15	0.04
	high	2700.72	298.72
biomass	*low*	665.50	121.00
	high	1573.00	810.70
small hydro	*low*	134.48	63.39
	high	336.20	147.92

Figures in GWh. Table derived from the potentials discussed in section 6.2.1 and 6.2.2 and Table 6-5. Tech pot: technical potential; socio-eco pot: socio-economic potential

The figures in this table are either allocated from the Belgian or Flanders potentials depending either on the availability of the data, which was mainly the case for the potential figures. Secondly it depends on the spread of the figures, the table is composed to give the most pessimistic view (low) and on the most optimistic view (high) given in the existing scientific literature.[79]

[79] So the figure can represent an allocation either from Belgium or Flanders to Limburg, if only it corresponds with the view

7 Limburg's electricity market by 2020

So far an answer is provided on all de sub questions stated in section 1.2. To provide a conclusion of this thesis and hence to answer the central question it is necessary to combine the matter discussed so far to see what is possible in the electricity market by 2020 and off course at what cost. Therefore, different scenarios, which are based on different costs, are built to provide a clear view of the possible outcomes by 2020. Once these scenarios are established, a benchmark is created to be able to compare the results. This is done by looking at the costs and emissions with the current energy mix, but 2020 electricity usage. Then the scenarios will be linked to the potentials in Limburg. The potentials are in fact also scenarios. The first reason is that it is possible to define a high and a low figure for each generation method. Secondly all these figures are based on scenarios used in different studies and so, each figure in fact provides an outcome of a scenario. When the costs (scenarios) are linked to the potentials an overview will be given of the total cost of the potentials in Limburg and the abatement possibility.

7.1 Cost scenarios

To build these scenarios, there are many possibilities. The two most extreme cases will be taken to set boundaries to the possibilities. The cost of either renewables, conventional energy sources and externalities can be high or low. Not every possibility is checked because this would be too cluttering due to an overflow of data (all possible combination can be seen in annex 10.6). On the one side an optimistic view towards renewables is established, called the pro scenario. This is assumed to be with a high cost for conventional energy sources, a low cost for renewables and a high cost of the externalities[80]. The pessimistic view on the other hand is established with a low costs for fossil fuel consuming methods, high costs for renewables and low costs of externalities. This scenario is called the bau[81] scenario. It is not considered that externalities can be high for conventional energy sources and low for renewables or vice versa. This is because the valuation of externalities is the same for both cases. If this is not the case and a different method for both is used this would not stroke with reality.

Table 7-1 lists the costs of each energy source for the scenarios just described. The elaborate tables can be found in annex 10.6. It is clear that when the externalities are internalized the cost

[80] As conventional generating methods cause more external costs, a high cost of the latter is unfavorable

[81] Bau stand for business as usual. It is assumed that this implies a pessimistic view as with little extra policy measures, costs of renewables will not go down as fast (no economies of scale for example), the costs of the conventional nowadays are low (but can rise due to fuel price increases) and the external cost are not fully internalized.

pictures changes. However, this table can give a distorted view as the costs used for the renewables and conventional sources are not all taken from an optimistic or pessimistic view; rather the figures are taken to correspond with the scenario.

Table 7-1: Total costs of electricity generation according to a pro and bau scenario

Cost scenario's			
	in €/MWh	**pro**	**bau**
energy source	*wind onshore*	58.5	99
	wind offshore	70	129
	PV	217	359
	biomass	52	108
	MSW	13.21	13.21
	small hydro	58	82
	coal	88.3	41
	nuclear	53.7	32.7
	gas	76	51.38

Own processing as described in this section

The pro scenario favors the renewables as it assumes low renewable costs, high costs of conventional energy sources and a high external cost. The bau scenario favors the conventional generating methods. It assumes the opposite of the composition of the pro scenario.

7.2 The benchmark

It is hard to imagine what figures mean if they cannot be compared. Therefore a benchmark is created using the same costs that are used with calculations for futures views. This is done by multiplying the costs per MWh with the MWh's produced by the corresponding energy sources. The former can be found in Table 7-1. The latter figures are obtained from Table 3-1. The results can be found in the following table.

Table 7-2: Costs of electricity generation for 2020 usage (in thousands $€_{2009}$)

Benchmark costs		
	pro	***bau***
nuclear	€ 240,562.58	€ 146,487.83
gas	€ 192,489.00	€ 130,132.70
coal	€ 54,635.63	€ 25,368.75
oil	€ 6,556.28	€ 3,044.25
renewable fuels (biomass)	€ 11,154.00	€ 23,166.00
waste	€ 1,634.74	€ 1,634.74
extra gas	€ 7,177.50	€ 10,147.50
other renewables	€ 8,322.19	€ 13,798.13
total	**€ 522,531.90**	**€ 353,779.88**

This calculation assumes that the current energy mix also applies in 2020

The total costs of electricity generation for Limburg in 2020 would range between 523 million euro and 354 million euro. These figures form a benchmark and evaluate the economic feasibility of the different scenarios. These figures also confirm the scenarios that were built. The pro scenario assumes higher costs from conventional generation methods, which here reflect in a higher total cost. The table does not represent the cost that energy generating firms face though as these figures based on a high degree of internalization of external costs. These figures should also not be taken as the only possibility and are more a tool to compare the competitiveness of the other possibilities.

The emission levels originated by this electricity mix are the same as listed in Table 4-2, being about 1.8 million ton of CO_2.

7.3 Future possibilities

To look in the future the pro and bau scenarios are used to reflect the possible price impacts as is done with the current view. But here an extra dimension is created by taken the potentials into account. First the possibilities are explored when considering the technical potentials. So; that what is possible without looking at the barriers other than technical. This will indicate whether it is at all possible for Limburg to foresee in its own electricity needs using sustainable energy sources. Secondly more constrains are considered by looking at the socio-economic potentials. After all, these will determine if the target (CO2 neutral by 2020) is met since the barriers are not that easily removed. So it is assumed that on the short run this will be a limiting factor.

The method described in section 2.6 does not represent the reality as it assumes an equal costs of each energy generating method for the whole implementation potential. In real life, the costs of for example one MWh generated by an onshore wind turbine will be low at first as people will seek the cheapest ground to build the turbine, use the areas with most wind hours etc. In the end, to use all the space, the ground will be more expensive than the first piece, the areas with high wind availability or wind speed will be gone and the turbine will not work as efficient, etc. This error made here was an additional reason to discharge the upper and lower quartile of the costs data as is done in section 5.1.

7.3.1 Technical limitation

According to the method described in section 2.6, the technical potentials of the energy sources will be 'filled'. As hydro energy is the cheapest method according to the scenarios[82] this is first used to replace a part of the most polluting method, which is coal according to Figure 4-1. Hydro can replace 134 to 336GWh of the 618GWh of coal fired generation. The second cheapest renewable is onshore wind turbines. This method will be able to further and fully replace the coal fired power plants as these generate only 618GWh compared to the 900 or 2500GWh for the technical onshore wind potential. The rest of the wind potential will be used to replace the second most polluting method, being oil. As this only has a small contribution to the electricity supply, it can also be fully covered by onshore wind energy. The rest of the wind energy potential will therefore be used to replace the third most polluting method, which is gas. This logic can be extended until all polluting methods[83] are replaced or the renewable potentials are all used up. Although nuclear energy can be viewed as a conventional energy source, it does not belong to the polluting ones[84] in the context of this study. So the electricity generated by nuclear power plants does not have to be replaced. This means that only the coal-, oil- and gas fired power plants have to be replaced, or a total electricity generation of 3226GWh instead of the total 8250GWh. This mechanism is applied to both the low and high technical potentials and can be found in annex 10.7.1 and 10.7.2. The difference between the two is that the high potential vision will be cheaper as there is more potential for the cheaper methods and consequently the more expensive methods have to be implemented less. A version where the offshore wind potential is not taken into account can be found in annex 10.9**Fout! Verwijzingsbron niet gevonden.**.

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[82] When an average of the pro and bau scenario is considered

[83] A method is considered polluting if there is a significant emission of CO_2 equivalents. This is only coal, oil and gas (mentioned in descending order)

[84] None or low CO_2 emissions

The high technical potential has a capacity to generate about 10.5TWh, which is more than the total consumption. The lower limit of this potential equals to 3.8TWh[85]. The real value is hard to pinpoint and will probably be somewhere in between given the current technology availability. In either case it is possible to fully replace the major CO_2 producing methods, i.e. coal-, oil- and gas fired power plants. This still does not imply that all the emissions are abated, but they will be declined from about 1.8 million tons to 0.11 million ton CO_2 if the high technical potential is assumed. The low potential results in an emission of 0.14 million ton. This is a decrease with about 93% of the total emission that would occur in 2020. The percentage of renewable usage compared to the total generation is then around 44% with waste incineration and nuclear power the only other generation methods. The total cost for the upper limit of the potential is 464 million euro for the pro scenario and 528 million for the bau scenario. For the lower limit this is 605 and 773 million euro respectively.

For the version without offshore wind energy it is still possible to ‘fully' abate the carbon dioxide considering the upper limit. With the lower limit however it is not possible to fully replace the coal- oil- and gas fired power plants. But with a share of 37% it only exhausts 25,000 ton CO_2 more than the upper limit. The costs in total rise for each case as more expensive renewables are to be used to reach an implementation level as high as possible.

7.3.2 Socio-economic limitation

Analogue with the technical limitations, the figures for the socio-economic limitation are derived. It is clear that where there were no problems in obtaining full replacement by renewables when considering the technical limits. This contrasts with the socio-economic limit as could be expected. With an upper limit of 3TWh and a lower limit of only 0.54TWh it is obvious that not the whole fleet of polluting generation methods can be replaced (totaling to 3.23TWh). Nevertheless there is a significant abatement potential in both cases. The upper limit here can cover an abatement of almost 1.5 million tons of CO_2 bringing the total emission level to 340 thousand ton for electricity generation. It also increases the renewables share to 38% compared to the total generation level. The lower limit would abate 0.43 million or 430 thousand ton, lowering the CO_2 emissions from about 1.8 million to 1.4 million ton. This entails a renewables share of just over 10%.

The costs of the deployment of renewables over the upper limit total to 520 million euro in the pro scenario and just under 600 million euro for the bau scenario. For the implementation according to

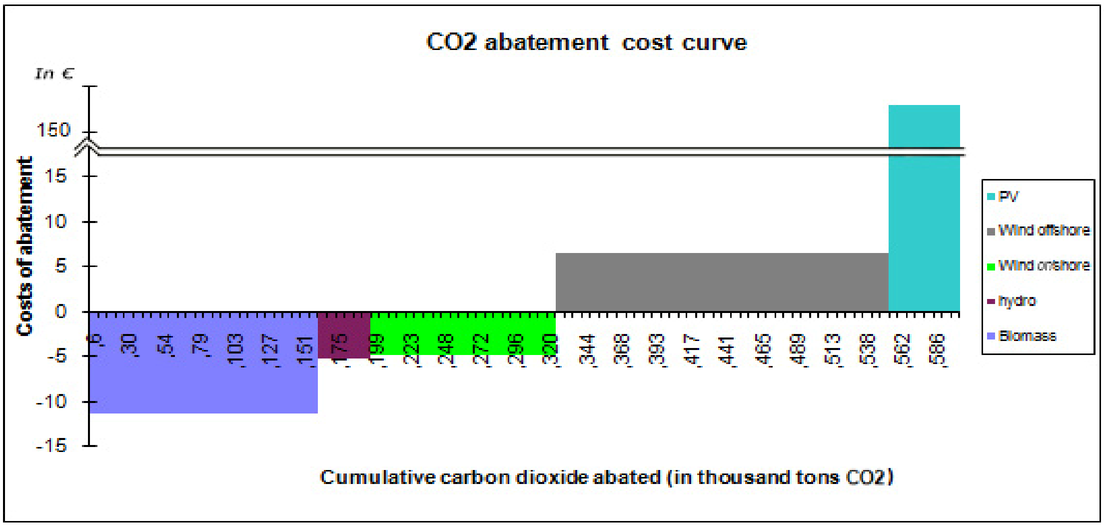
[85] Values derived from Table 6-6 by adding up all the low values for the technical and socio-economical potential and analogously the figures for the high potentials can be derived

the lower limit the figures total to 508 million (pro) and 382 million euro (bau). Again, the calculations can be found in annex 10.7.3 and 10.7.4.

Without offshore wind energy the overall trend is that a lower renewable share can be reached. The prices for the pro vision stay more or less the same as this vision assumes the offshore wind is rather competitive to coal fired power plants. The costs in the bau vision are much less as in this case the offshore wind energy is much more expensive.

As already indicated earlier in this thesis, some studies regarding CO_2 emissions construct a carbon dioxide abatement curve. This basically shows how much it costs with given technologies to abate carbon emissions. It takes a look at the costs incurred to replace a technology, but also to the costs saved by not longer using the replaced technology. The same goes for the abatement of carbon dioxide. It looks at the omitted pollutants of the replaced technology, but also at the emissions of the replacing technology. But the reasoning of first replacing the most polluting technology cannot be used here as it would not give a fully objective view. If for example biomass and hydro energy are almost equally competitive, and one is used to replace a coal fired power plant, the other to replace a gas fired power plant. The technology replacing the coal plant will be better off as for almost the same money more CO_2 is abated. Therefore the renewables are measured against the average CO_2 emission of one MWh and the average cost per MWh the current fleet generates. The average CO_2 emission is calculated by dividing the total carbon dioxide emissions of 1,823,621 ton by the total generated amount (8250GWh in 2020). This gives an average of 221kg CO_2 per MWh. The average price is calculated for both scenarios by dividing the total cost (520 million and 320 million respectively) by the generated amount of 8250GWh. This results in an average costs of 63€ in the pro, and 43€ in the bau scenario. Each renewable is compared to the average costs by subtracting the average costs from the cost of the renewables. This is the relative price, compared to the current situation, it costs to abate carbon dioxide. The abatement potential then is calculated by subtracting the renewable emissions from the emissions from the replaced source (this is an abated CO_2 emission per MWh replaced) and multiplying the result with the potential of the renewable to get to a total abatement potential. This is subsequently done for all five renewables considered to be of value to Limburg given the socio-economic upper limit view and can be seen in following graphs.

Figure 7-1: Abatement cost curve[86] for the socio-economic upper potential in the pro cost scenario



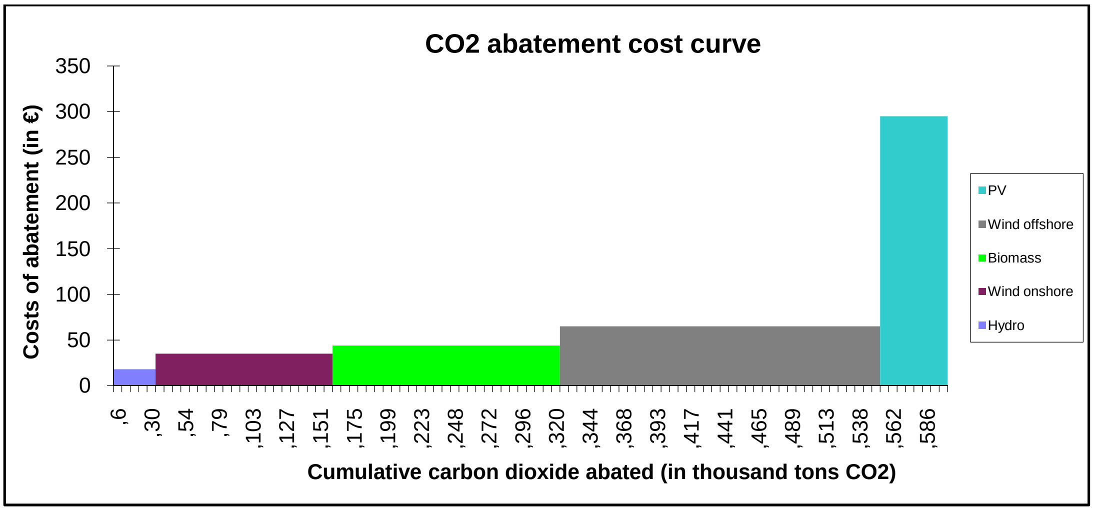
Own processing

These graphs only show the results for the socio-economic upper potential. The other potentials would provide the same graph, except that with the technical potential more CO_2 could be abated due to the higher potential. The lay-out regarding the costs would stay the same. For the pro scenario this implies that it is even beneficial to implement biomass, hydro and onshore wind energy electricity generation as it can be done at a lower cost than the conventional methods and it would abate emissions. For the bau scenario all the renewabes cost more than the conventional ones, but the abatement potential of course stays the same.

Figure 7-1 indicates that (given the pro scenario) if biomass is implemented it would be cheaper than the average cost of electricity generation, this is shown by a negative cost. So the average cost itself would also decline. On top of that this abates about 160,000 ton CO_2. PV on the other hand has a abatement potential that is much lower than the one of biomass and at a much higher cost. Figure 7-2 indicates that for the bau scenario each of the renewables considered cost more than the current average cost of electricity generation. The abatement potential stays the same however. Mind the different scale of the y-axis used and a change of color for the different techniques. These figures are merely included to improve insights and provide a base for comparison, and hence are solely for the sake of completeness.

[86] This graph is commonly used to indicate a potential and its corresponding cost. It is however not a standard graph that can be used in the conventional programs. To construct this graph the following was used as basis (Bullen 1997)

Figure 7-2: Abatement cost cruve for the socio-economic upper potential in the bau cost scenario



Own processing

8 Conclusions and recommendations

This section provides an answer on the central question that is posed in the beginning of this thesis. It also puts the findings in the right perspective and makes some recommendations to achieve this goal.

It is a known fact that the supply of fossil fuels is not inexhaustible. These are however consumed nowadays at a rapid pace, whilst it takes natural processes millions of years to form these fossil fuels. So to guarantee the future generations of energy supply and electricity supply in particular a quest for alternative ways to generate electricity is started. On top of that is the usage of fossil fuels one of the main causes of global warming. So the need for renewable and sustainable energy sources is high and keeps on rising.

Several technologies are already in use serving as an alternative method of electricity generation. The main technologies for Limburg are biomass, wind energy, solar energy and to a less extend hydro energy. Their share in the total electricity generation up until now is rather low. Therefore, a major challenge of the government is to put policy measures into place to increase the share of these renewables. This is not an easy task as they are generally thought of as way too expensive. When looking merely at the costs of electricity generation (without externalities), on average fossil fuel consuming technologies are cheaper. But this is not the whole story. Fossil fuels also cause damage that is not paid for by the originator, but in the end someone is paying this price. This is known as externalities. Taking these external costs into account increases the competitiveness of the renewables as they cause less 'damage'. In a pessimistic case they still are more expensive, but in an optimistic case they can become equally competitive as the conventional energy sources. This all depends on a variety of factors. Fuel costs is an important one regarding the cost as the price for most renewables' fuel is non-existing as opposed to the conventional methods' fuel. The location is another important factor. A good location can render renewables more efficient while conventional energy generating methods are not so liable to this issue. Also, the more effort is put into increasing the share of renewables, the lower the cost will become. This is due to economies of scale. This will not (so much) be the case with the conventional methods as these are already used on a rather high scale. Renewables are still liable to 'learning rates' as opposed to the convetional methods. This learning will put downwards pressure on the costs per unit of output. But as people tend to take solely their own wallet into account, a long run view is out of the question and the total welfare is harmed. Government tries to solve this problem by issuing subsidies to implement renewables.

The question often is, as is in this thesis: “assume we all do want to implement renewables and costs cause no concerns, would it be possible to meet the electricity demand” When talking about this question, the term potentials is not far behind. This term is used to indicate what is possible. But different kinds of potentials are used throughout the literature. The potentials used in this thesis are limited on the one hand by a technical potential, which only considers the spatial requirements and the conversion efficiency of a particular technology. And a socio-economic potential on the other hand, which considers all kinds of barriers like policy measures, human discomfort, disturbance of ecosystems, costs, and so on. As you can see, many variables take a role in these potentials en therefore some different ranges are encountered on potential calculations. The socio-economic potential can be seen as what is really possible taking all the real life barriers into account. If these barriers are removed, and the technology implementation is pushed to the limit, a technical potential could be achievable. Projections for the year 2020 indicate a need to replace about 3.6TWh of polluting electricity generating sources to become CO_2 neutral (of the total 8.25TWh supply, i.e. about 44%). This however is still not without exhausting any carbon dioxide, but lowering this figure even further is not possible within the same sector unless an illogic solution as stop using electricity, so this is considered as CO_2 neutral. The needed electricity supply is calculated by looking at the consumption of 2009 and transferring this to a 2020 supply. The technical potentials for 2020 range from 3.8TWh on the lower limit to 10.5TWh on the upper limit. This indicates that it is technically possible to supply Limburg with renewable energy, or better stated, CO_2 neutral energy as nuclear energy still is assumed to generate 54% of the total consumption. The share of the renewables would be increased to 44%. The remainder is generated by waste incineration. The socio-economic potentials for 2020 range from 0.5TWh on the lower boundary to 3TWh on the upper boundary. So in the worst case scenario renewables can only contribute 0.5TWh of the necessary 3.6TWh to become CO_2 neutral. At best it is still impossible to achieve CO_2 neutrality, although with 3TWh, the 3.6TWh goal is not that far off. The potential figures are usually not available for such small areas as Limburg. These are therefore allocated to Limburg from larger areas as Flanders or Belgium. The solar energy, mainly deployed on roofs, is allocated according to the built-over area. Consequently hydro energy is allocated according to the river surface, wind energy by open land surface and biomass according to the added value of the sectors directly involved with organic material. With only the technical limitation considered the total carbon dioxide emissions that would result in 2020 when the electricity mix is unchanged would decrease from over 1.8 million ton to about 100 or 150 thousand ton. With an abatement of 1.5 million ton, the upper socio-economic limit also does very well. The lower socio-economic limit, which has a low renewable share had a less impressive, but still respectable abatement of over 400 thousand ton a year. Attentive readers might have noticed that the amount of abatement is degressively related to the number of green GWh's generated. This is because it is assumed that first the most polluting energy methods are replaced. This is coal with about 950kg CO_2/MWh of generated electricity, followed by oil with 770kg CO_2/MWh and gas with 440kg CO_2/MWh. These are the only major carbon dioxide emitting energy sources, hence only these need to be replaced. An energy mix of Belgium is assumed to recalculate the amount of electricity each method generates for Limburg.

The full costs for the electricity generation in 2020 with an unchanged mix would be about 520 million euro in the pro scenario, which favors the renewables, and 350 million for the bau scenario, which favors the conventional methods. As most electricity with this mix is generated by fossil fuel consuming methods, the pro vision is more expensive than the bau as the former disfavors the conventional energy sources. If only a small amount of renewables can be implemented as is the case for the low socio-economic potential, the cost decline for the pro vision and rise for the bau vision. This means that in the pro vision renewables are deployed that are cheaper than the installations they replace (which strokes with the pro vision). The bau vision makes it more expensive as the renewables are not competitive and cost more. In general it makes sense to install renewables when the pro vision is assumed except for the solar panels. None of the renewables come even close to competitiveness when the bau scenario is assumed. Whatever scenario, the renewable energy sources most likely to become competitive and contribute significantly to the electricity generation are biomass energy (52-108€/MWh) and wind energy (58-99€/MWh). Hydro energy has too little potential to be really influential, although it can be competitive as well on the short term (58-82€/MWh). Solar energy will not be competitive, even not in the longer run (217-359€/MWh). To see this in the right perspective, the full costs for coal (41-88€/MWh) and gas (51-76€/MWh) are lower on average. But it depends on the evolution of the costs. The latter costs are not as low however as many would expect them to be.

First of all, all efforts have to be aligned to avoid ending up in the lower limit case from the socio-economic potential. A goal has to be set to obtain the upper limit socio-economic potential. By removing as much barriers as possible, potentials will be unlocked and the situation will evolve to higher potential levels. Given that the truth often lies between the upper and lower limits, it is unlikely that Limburg can achieve CO_2 neutrality by 2020. It can grow towards this goal however. Recently, this is done by subsidies. But this will not suffice as a huge problem is how people perceive this energy source. Many people are encouraged to deploy solar panels though this is one of the most expensive renewables. And many people view wind turbines negatively as they can cause discomfort but they have a much greater potential. People should be informed about the costs and benefits of the renewable energy technologies and the “not in my backyard”-attitude should be restrained by this. This can be viewed as improving the awareness of the advantages and disadvantages. While conducting this campaign, the implementation should already start in the places where no or only little trouble can arise. By walking this parallel path, the campaign should ease the attitude towards renewables and by the time the already started implementation would come across more troubling areas, this should be reduced. Additionally, many regulations and paper work is under discussion when you want to install a wind turbine. Barriers like these should be lowered or removed.

Given the nature of this topic, it is advised to take a view on a larger scale. More possibilities arise when collaborating with Flanders or Belgium as a whole, then to solely look at smaller regions. However assessments like this are necessary to map the possibilities. Then these potentials should be fully used to try and achieve national or even wider goals.

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10 Annex

10.1 Quantitative approach to estimate CO_2 emissions

CO2 emissions by fuel type																						
		data sources																			opti	pessi
	kg CO2/MWh	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*	*13*	*14*	*15*	*16*	*17*	*median*	*mean*	*25 perc*	*75 perc*
F	coal	815	891	974	990	949	755	968	980	900			878	951	955	1337	967	960	955	951	896	971
u	gas	362	356	469	653	485	385	440	450	400			420	600	599	307	468	456	450	457	393	477
e	solar PV	53		39	59	79		100	50				45	0					52	53	44	64
l	nuclear	20	16	15	21	8	16	15	6	5			15	0				0	15	11	6	16
	wind	7		14	37	14	24	22	6				12	0					14	15	7	22
t	hydro				18	3		14	3				6	0					5	7	3	12
y	geothermal				23						82	122		0	91		82		82	67	38	89
p	biomass												46	0					23	23	12	35
e	oil												630	894	893	719	708		719	769	708	893

1: (Krewitt, et al. 1997), 2: (UK sustainable development commission 2006), 3: (Meier 2002), 4: (Criepi 1995), 5: (Dones, Heck and Hirschberg 2003), 6: (UK government - department of trade and industry 2006), 7: (L. a. Spadaro 2000), 8: (Vattenfall 1999), 9: (British Energy 2005), 10: (Bloomfield and Moore 1999), 11: (IGA 2002), 12: (Commission of the european communities 2008), 13: (Environmental protection agency 2000), 14: (IPCC 2008), 15: (IEA statistics 2009), 16: (Bloomfield and Moore 1999), 17: (Synergrid 2009)

10.1.1 Methodology

As stated in section 2.2 there are many factors influencing the emission rates. That is why is opted for a second approach in gaining insights in the CO_2 emissions. There are many different assumptions made in these studies. The logic behind this method is that when a larger number of consulted sources is used, the more reliable the outcome will be (statistic reasoning). The problem here is that some use equivalent CO_2 figures in contrast to others. On the other hand, some will be biased toward a particular fuel type because the study was made by the company profiting from this type. So some will be overestimations and some will be underestimations. But globally these figures are representative for the CO_2 exhaustion as different factors tend to cancel each other out. So the mean value is used as representative figures throughout the thesis.

Some figures are derived from carbon emissions which is not the same than carbon dioxide. The correlation with carbon and carbon dioxide can be found in the molecule. One molecule carbon dioxide contains one atom carbon and two atoms oxide. One atom of carbon has a mass of about 12 whilst an atom oxide has a mass of 16. So if 12 gram of carbon is exhausted, this is proportional with (carbon: 12 + 2 times oxide: 16 times 2; 32) 44 gram carbon dioxide.

10.1.2 Direct and indirect CO_2 emissions

CO2 emissions (direct)						
		1	*3*	*2*	*4*	*5*
Fuel type	**coal**	781	902	944	664	952
	gas	348	506	389	330	547
	solar PV					
	nuclear	0				
	wind					
	hydro					
	geothermal					
	biomass					
	oil	858	689		444	786

CO2 emissions (indirect)						
		1	*3*	*2*	*4*	*5*
Fuel type	**coal**	34	88	30	92	142
	gas	14,8	147	80	59	95
	solar PV	51,3	84	39	30	17,5
	nuclear	19,7		9	15	9,5
	wind	6,5	124	14	19	
	hydro		18		23	15
	geothermal		23			
	biomass				46	
	oil	67	44		103	95

Figures in *kg CO2/MWh*.. Source: 1: (Krewitt, et al. 1997) – 2: (Criepi 1995) – 3: (Meier 2002) - 4: (Spadaro, Langlois en Hamilton 2000) - 5: (Dones, Heck and Hirschberg 2003)

10.2 Electricity generation cost data extraction

10.2.1 Original cost data

This table shows the original cost data is in the same form obtained from the different studies, undiscounted and in the currency used in the studies.

cost of energy sources (excl externalities)

energy source / study	1	2		3		4		5		6		7		8		9		10	
wind onshore	37	41	217	60	120	53	74	40	90	53	53	45	110	57	76	90	90	35	60
wind offshore	41	65	210	90	120									57	62	150	150		
PV	257	156	498	250	500	100	200	250	1600	250	400	250	350	115	288			150	300
Solar thermal	77	100	220	65	240	155	155	120	450										
biomass	35	31	102	110	110	50	200	30	120			40	90	70	160				
MSW	-10																		
small hydro	33	55	53	50	120			20	100	60	80								
coal		22	59	51				20	20	30	40							25	50
nuclear	31	47	62					10	120	25	35							21	31
geothermal		33	95	180	200			40	100	30		40	100						
gas	42,42	40	60	63				37		40	60							37	55
currency	EUR	USD		USD		USD		USD		USD		EUR		EUR		EUR		USD	
base year	2006	2010		2010		2005		2006		2010		2008		2009		2009		2010	

1: (Ea Energy Analyses 2007), 2: (IEA 2008), 3: (European Renewable Energy Council and Greenpeace International 2007), 4: (Amarican Solar Energy Society 2007), 5: (Ralph E.H. Sims 2007), 6: (NEA - IEA 2005), 7: (IPCC 2008), 8: (ODE Vlaanderen 1997), 9: (EEA 2009), 10: (MIRA 2007)

10.2.2Cost data adjusted

This table shows the cost data when adjusted for different currency and different years as a base for the costs. The cost data used in the body of the thesis are derived from this table in the way mentioned in section 5.1.

cost of energy sources (excl externalities)																		
Study	*1*	*2*		*3*		*4*		*5*		*6*		*7*		*8*		*9*	*10*	
energy source																		
wind onshore	43	37	198	55	109	58	80	42	94	48		48	116	57	76	90	32	55
wind offshore	47	59	192	82	109									57	62	150		
PV	295	142	454	228	456	109	217	260	1663	228	365	264	369	115	288		137	274
Solar thermal	88	91	201	59	219	168		125	468									
biomass	40	28	93	100		54	217	31	125			42	95	70	160			
MSW	-11																	
small hydro	38	50	48	46	109			21	104	55	73							
coal		20	54	47				21		27	36						23	46
nuclear	36	43	57					10	125	23	32						19	28
geothermal		30	87	164	182			42	104	27		42	106					
gas	49	36	55	57				38		36	55						34	50
currency	EUR	EUR		EUR		EUR		EUR		EUR		EUR		EUR		EUR	EUR	
base year	2009	2009		2009		2009		2009		2009		2009		2009		2009	2009	

10.2.3 Cost data – statistical insights

These data are derived from the extensive table in annex 10.2.2 using basic statistical methods as the mean, first quartile (i.e. 25 percentile), second quartile (i.e. median or 50 percentile), third quartile (i.e. 75 percentile) and minimum and maximum values (for the sake of completeness).

Statistical insights of the generation costs					
mean	*1st quartile 25 percentile*	*median 2nd quartile 50 percentile*	*3th quartile 75 percentile*	*max*	*min*
57.00	47.51	90.00	72.74	197.90	31.92
72.04	58.71	119.58	94.80	191.52	47.11
263.92	217.24	364.79	344.95	1663.13	108.62
146.55	90.52	205.20	177.41	467.76	59.28
81.51	41.72	106.42	88.04	217.24	28.27
-11.49	-11.49	-11.49	-11.49	-11.49	-11.49
50.16	45.60	72.96	60.43	109.44	20.79
31.92	22.30	45.83	34.18	53.81	20.06
31.92	22.80	42.86	41.37	124.74	10.39
86.64	41.58	105.57	87.11	182.40	27.36
48.75	36.48	54.72	45.66	57.45	33.74

10.3 External cost: capacity credit, balancing and fuel security

Cost of capacity credit, balancing and fuel security		
energy source	*wind onshore*	9
	wind offshore	9
	PV	-6
	Solar thermal	-
	biomass	0
	MSW	0
	small hydro	9
	coal	2.3
	nuclear	5.7
	geothermal	-
	gas	7

10.4 Considered potential literature

In order to create a reliable base, many scientific studies are reviewed. From this data the lowest and highest data are mined. That way this data can serve as a scenario analysis to see what is possible. It was after all impossible to make own estimates concerning the potentials for renewables.

Considered literature (in random order):

- (Brussels instituut voor milieubeheer 2009)
- (CREG 2007)
- (Ruyck 2006)
- (Ode Vlaanderen 2007)
- (MIRA 2007)
- (ODE Vlaanderen 1997)
- (Neyens, Hernieuwbare energie: Potentieel in 2020 2008)
- (Briffaerts, et al. 2009)
- (Palmers, et al. 2004)
- (Edora 2010)
- (Neyens, Devriendt, et al. 2004)
- (Devriendt, et al. 2005)

10.5 Land coverage Limburg

10.5.1 Total land surface

Total surfaces								
Description	Class	Parcels	Taxable surf	Untaxable surf	Total surf	Taxable rateable value	Untaxable rateable value	Total rateable value
Total vacant land surface	1TOT	382.377	172.606,92	12.839,84	185.446,76	6.519.324	499.717	7.019.041
Total built on land surface	2TOT	431.867	37.890,72	2.544,92	40.435,64	480.060.433	76.444.363	556.504.796
Not normalized surface	3TOT	0	0	0	0	0	0	0
Non cadastral surveyed surface	5TOT	0	0	0	16.154,34	0	0	0
Totale oppervakte		814.244	210.497,64	15.384,76	242.036,74	486.579.757	76.944.080	563.523.837

10.5.2 Vacant land surface

Vacant land surface								
Description	Class	Parcels	Taxable surf	Untaxable surf	Total surf	Taxable rateable value	Untaxable rateable value	Total rateable value
Arable land (not yet mentioned)	1AE	126.125	59.354,42	667,3042	60.022	2.611.244	17.776	2.629.020
Grassland	1BC	114.244	48.495,92	1.541,91	50.038	1.472.620	39.445	1.512.065
Gardens and parks	1DI	19.949	1.656,18	152,9158	1.809	85.555	12.628	98.183
Orchards	1F	31.571	12.784,91	112,2501	12.897	1.011.791	8.586	1.020.377
Forests	1G	37.511	28.769,03	2.234,95	31.004	208.460	24.080	232.540
Rough terrains	1H	30.624	15.203,81	4.423,72	19.628	21.885	7.802	29.687
Recreational domains	1J	835	768,9129	89,3453	858	29.350	6.485	35.835
Cadastral surveyed rivers	1K	2.986	1.502,52	2.958,12	4.461	13.822	8.671	22.493
Cadastral surveyed roads	1L	6.186	894,9339	129,3768	1.024	7.479	1.508	8.987
Miscellaneous (vacant)	1MNOP	12.346	3.176,29	529,9551	3.706	1.057.118	372.736	1.429.854
Total vacant land surface		382.377	172.606,92	12.839,84	185.447	6.519.324	499.717	7.019.041

10.5.3Built-over land surface

Built-over land surface								
Description	Class	Parcels	Taxable surf	Untaxable surf	Total surf	Taxable rateable value	Untaxable rateable value	Total rateable value
Flats	2A1A2	27.674	2.140,88	3,3175	2.144,20	942.591	13.178	955.769
buildings	2B	34	1,2233	1,1622	2,3855	4.320	4.783	9.103
Houses and farmhouses	2C	78.895	661,9254	15,7779	677,7033	43.531.491	1.880.050	45.411.541
Outhouses including sun lounge - greenhouse	2DEF	282.390	25.576,08	32,4149	25.608,50	242.092.895	535.947	242.628.842
Crafts- and industrial buildings	2G	12.847	3.722,81	51,288	3.774,10	80.153.118	25.445.354	105.598.472
Storage space	2H	2	0,2723	0	0,2723	8.191	4.095	12.286
Office space	2I	333	81,3736	0,2613	81,6349	27.654.678	7.141.713	34.796.391
Commercial buildings	2JK	12.263	1.122,16	22,7546	1.144,92	32.743.866	960.801	33.704.667
Public buildings	2L	878	190,7711	40,1954	230,9665	6.612.880	2.522.441	9.135.321
Utility buildings	2M	7.122	2.254,53	1.415,11	3.669,64	37.381.327	14.200.566	51.581.893
Social care housing and hospitals	2N	590	125,8118	134,4874	260,2992	2.153.628	6.451.072	8.604.700
Schools, research and cultural buildings	2O	1.434	515,5403	407,3452	922,8855	563.687	12.259.666	12.823.353
buildings for worship	2P	1.522	67,382	133,0302	200,4122	274.418	2.180.856	2.455.274
Buildings for recreation and sports	2Q	5.429	1.366,03	271,9054	1.637,93	5.482.553	2.672.785	8.155.338
Miscellaneous (built-over)	2RST	454	63,9274	15,8698	79,7972	460.790	171.056	631.846
Total built-over surface		431.867	37.890,72	2.544,92	40.435,64	480.060.433	76.444.363	556.504.796

10.6 Cost scenario construction

Possible cost scenarios															
fossil	**RES**	**fossil**	**RES**	**fossil**	**RES**	**fossil**	**RES**	**fossil**	**RES**	**fossil**	**RES**	**fossil**	**RES**	**fossil**	**RES**
low	low	low	low	high	low	high	low	low	high	low	high	high	high	high	high
ext		**ext**		**ext**		**ext**		**ext**		**ext**		**ext**		**ext**	
low		high		low		high		low		high		low		high	

The dark gray shaded area forms the pro-scenario as in this case the renewables are most competitive. The light gray shaded area forms the bau scenario because the renewables are the least competitive.

Pro and bau scenario costs

pro scenario				
		generating cost	external costs	**total costs**
energy source	*wind onshore*	48	10.5	**58.5**
	wind offshore	59	11	**70**
	PV	217	0	**217**
	biomass	42	10	**52**
	MSW	-5.5	18.71	**13.21**
	small hydro	46	12	**58**
	coal	46	42.3	**88.3**
	nuclear	43	10.7	**53.7**
	gas	54	22	**76**

bau scenario				
		generating costs	external costs	**total costs**
energy source	*wind onshore*	90	9	**99**
	wind offshore	120	9	**129**
	PV	365	-6	**359**
	biomass	106	2	**108**
	MSW	-5.5	18.71	**13.21**
	small hydro	73	9	**82**
	coal	22	19	**41**
	nuclear	23	9.7	**32.7**
	gas	37	14,38	**51.38**

10.7 Future possibilities

10.7.1 Technical optimistic scenario and calculative reasoning

High technical potential scenario								
				amount	**surplus**	**cost** *(in thousands)*		**CO2 emission**
to be replaced: *mix 2007 (% - GWh)*			***replaced by***	in GWh		*pro*	*bau*	*tons*
coal	7,50%	618,75	hydro	336,2		€ 19.500	€ 27.568	2465,47
		282,55	wind onshore	2500	2217,45	€ 16.529	€ 27.972	4269,64
oil	0,90%	74,25	wind onshore	2217,45	2143,2	€ 4.344	€ 7.351	1122,00
gas	30,70%	2532,75	wind onshore	2143,2		€ 125.377	€ 212.177	32386,13
		389,55	biomass	1573	1183,45	€ 20.257	€ 42.071	7791,00
nuclear	54,30%	4479,75				€ 240.563	€ 146.488	51143,81
waste	1,50%	123,75				€ 1.635	€ 1.635	0,00
renewable fuels	2,60%	214,5	biomass	1183,45	968,95	€ 11.154	€ 23.166	4290,00
pump	1,50%	123,75				€ 7.178	€ 10.148	907,50
other renewables	1,00%	82,5	solar PV	2700,72	2618,22	€ 17.903	€ 29.618	4382,81
			Total RES	3646,5		*€ 464.438*	*€ 528.193*	108758,37
			% RES	44,20%				

The table consists out of 3 sub tables, each of them are discussed in order from left to right. 'To be replaced' that represents the current mix (transferred to 2020) and amount of electricity generation which has to be replaced by the renewable energy sources (RES). The second sub table contains information from the RES, which are used to replace the current fleet, by which amount and whether there is a surplus that can be transferred to further replace the current fleet. With a shortage the left table was extended (in this case with coal and gas) to fully replace the current energy source with RES. The RES (second sub table) replace the conventional energy sources that are listed on the same line (first sub table). Each time the cheapest available RES replace the most polluting energy sources. This way the CO_2 is abated the least expensive way. The third sub table lists the costs corresponding with the RES that replace the conventional energy sources or the cost of those not replaced. The last sub table lists the corresponding CO_2 that is still emitted. The gray shaded area underneath the table contains the total RES installed (in GWh) and the share compared to the total generation. The total costs for the pro and bau scenario and the total still emitted CO_2. The % RES is calculated by dividing the sum of the contribution of the total RES (here i.e. hydro, wind onshore, biomass, pump and solar PV) by the total amount of electricity generated.

Renewable fuels are biomass fuels. Therefore this is replaced by other biomass. It is considered that other renewables are 'replaced' by solar panels. Although this is not necessary with the method of reasoning, it is known that that are solar panels already installed with many to follow. Thus this is taken into account.

10.7.2 Technical pessimistic scenario

Low technical potential scenario							
				amount	***surplus***	***cost*** *(in thousands)*		***CO2 emission***
to be replaced: *mix 2007 (% - GWh)*			***replaced by***	in GWh		*pro*	*bau*	*tons*
coal	7,50%	618,75	hydro	134,48		€ 7.800	€ 11.027	986,19
		484,27	wind onshore	900	415,73	€ 28.330	€ 47.943	7317,86
oil	0,90%	74,25	wind onshore	415,73	341,48	€ 4.344	€ 7.351	1122,00
gas	30,70%	2532,75	wind onshore	341,48		€ 19.977	€ 33.807	5160,14
		2191,27	biomass	451		€ 23.452	€ 48.708	9020,00
		1740,27	wind offshore	916,3		€ 64.141	€ 118.203	13846,31
		823,97	pv	1228,15	404,18	€ 178.801	€ 295.805	43773,41
nuclear	54,30%	4479,75				€ 240.563	€ 146.488	51143,81
waste	1,50%	123,75				€ 1.635	€ 1.635	0,00
renewable fuels	2,60%	214,5	biomass	214,5		€ 11.154	€ 23.166	4290,00
pump	1,50%	123,75				€ 7.178	€ 10.148	907,5
other renewables	1,00%	82,5	pv	404,18	321,68	€ 17.903	€ 29.618	4382,8125
Total	100,00%	8250	Total RES	3646,5		*€ 605.276*	*€ 773.897*	141950,03
			% RES	44,20%				

Via the same reasoning as in annex 10.7.1 this table can be formed. The total RES amount that can be implemented is the same, and so is its share, albeit at a higher cost and a higher emission level. The former is logical as more expensive RES had to be used to achieve full replacement of the conventional energy sources. The latter is solely coincidence though. It depends on the emission level of the more expensive RES. If this were lower for PV for example, this would not be as high.

10.7.3 Socio-economic optimistic scenario

High socio-economic potential scenario								
				amount	**surplus**	**cost** *(in thousands)*		**CO2 emission**
to be replaced: *mix 2007 (% - GWh)*			***replaced by***	in GWh		*pro*	*bau*	*tons*
coal	7,50%	618,75	hydro	147,92		€ 8.579	€ 12.129	1084,75
		470,83	wind onshore	630,63	159,8	€ 27.544	€ 46.612	7114,76
oil	0,90%	74,25	wind onshore	159,8	85,55	€ 4.344	€ 7.351	1122,00
gas	30,70%	2532,75	wind onshore	85,55		€ 5.005	€ 8.469	1292,76
		2447,2	biomass	596,2		€ 31.002	€ 64.390	11924,00
		1851	wind offshore	1116,9		€ 78.183	€ 144.080	16877,60
		734,1	pv	216,22		€ 46.920	€ 77.623	11486,69
		517,88				€ 39.359	€ 26.609	229315,43
nuclear	54,30%	4479,75				€ 240.563	€ 146.488	51143,81
waste	1,50%	123,75				€ 1.635	€ 1.635	0,00
renewable fuels	2,60%	214,5	biomass	214,5		€ 11.154	€ 23.166	4290
pump	1,50%	123,75				€ 7.178	€ 10.148	907,5
other renewables	1,00%	82,5	solar PV	82,5		€ 17.903	€ 29.618	4382,8125
			Total RES	3128,62		€ *519.367*	€ *598.317*	340942,11
			% RES	37,92%				

10.7.4 Socio-economic pessimistic scenario

Low socio-economic potential scenario								
				amount	***surplus***	***cost*** *(in thousands)*		***CO2 emission***
to be replaced: *mix 2007 (% - GWh)*			***replaced by***	in GWh		*pro*	*bau*	*tons*
coal	7,50%	618,75	hydro	63,39		€ 3.677	€ 5.198	464,86
		555,36	wind onshore	98,28		€ 5.749	€ 9.730	1485,12
		457,08	biomass	121		€ 6.292	€ 13.068	2420,00
		336,08	wind offshore	177,64		€ 12.435	€ 22.916	2684,34
		158,44				€ 13.990	€ 6.496	150734,36
oil	0,90%	74,25				€ 6.556	€ 3.044	57085,87
gas	30,70%	2532,75				€ 192.489	€ 130.133	1121492,74
nuclear	54,30%	4479,75				€ 240.563	€ 146.488	51143,81
waste	1,50%	123,75				€ 1.635	€ 1.635	0,00
renewable fuels (biomass)	2,60%	214,5				€ 11.154	€ 23.166	4290,00
pump	1,50%	123,75				€ 7.178	€ 10.148	907,5
other renewables	1,00%	82,5	pv+offshr	82,5		€ 5.781	€ 10.652	1248,187222
			Total RES	881,06		€ *507.498*	€ *382.672*	1393956,78
			% RES	10,68%				

10.8 Abatement potential of carbon storage in Limburg

For every molecule of methane (CH_4) gained, two molecules of carbon dioxide can be injected. So chemically it is equal to one mol methane that is replaced by two mol of carbon dioxide (CO_2). The density of methane under normal conditions equals to 0.717kg/m³ and the molecular mass equals to 16.042g/mol.[87]

The amount of mol of methane if one cubic meter is extracted is:

$$\frac{0.717 \,{}^{kg}/_{m^3}}{0.016042 \,{}^{kg}/_{mol}} = 44.7 \,{}^{mol}/_{m^3}$$

Given that the amount of carbon dioxide that can be injected is twice as high, the number of mol to inject is 89.4mol/m³ of methane extracted. This is recalculated to mass to have a more meaningful figure.

The molecular mass of carbon dioxide is 44.010g/mol so:

$$44.010 \,{}^{g}/_{mol} \cdot 89.4 \,{}^{mol}/_{m^3} = 3934g \frac{CO_2}{m^3} = 3.934kg \frac{CO_2}{m^3}$$

Multiplied by the total volume of methane that can be extracted this gives a abatement potential of carbon dioxide of 3.934kg CO_2/m³ times (7-31billion m³).

This equals to 27.5 million ton to 122 million ton CO_2.

[87] Values obtained from a periodic table

10.9 Future possibilities without offshore wind energy

10.9.1 Technical optimistic scenario

High technical potential scenario								
				amount	**surplus**	**cost** *(in thousands)*		**CO2 emission**
to be replaced: *mix 2007 (% - GWh)*			***replaced by***	in GWh		*pro*	*bau*	*tons*
coal	7,50%	618,75	hydro	336,2		€ 19.500	€ 27.568	2465,47
		282,55	wind onshore	2500	2217,45	€ 16.529	€ 27.972	4269,64
oil	0,90%	74,25	wind onshore	2217,45	2143,2	€ 4.344	€ 7.351	1122,00
gas	30,70%	2532,75	wind onshore	2143,2		€ 125.377	€ 212.177	32386,13
		389,55	biomass	1573	1183,45	€ 20.257	€ 42.071	7791,00
nuclear	54,30%	4479,75				€ 240.563	€ 146.488	51143,81
waste	1,50%	123,75				€ 1.635	€ 1.635	0,00
renewable fuels	2,60%	214,5	biomass	1183,45	968,95	€ 11.154	€ 23.166	4290,00
pump	1,50%	123,75				€ 7.178	€ 10.148	907,50
other renewables	1,00%	82,5	solar PV	2700,72	2618,22	€ 17.903	€ 29.618	4382,81
			Total RES	3646,5		€ *464.438*	€ *528.193*	108758,37
			% RES	44,20%				

10.9.2 Technical pessimistic scenario

Low technical potential scenario								
				amount	**surplus**	**cost** *(in thousands)*		**CO2 emission**
to be replaced: *mix 2007 (% - GWh)*			***replaced by***	in GWh		*pro*	*bau*	*tons*
coal	7,50%	618,75	hydro	134,48		€ 7.800	€ 11.027	986,19
		484,27	wind onshore	900	415,73	€ 28.330	€ 47.943	7317,86
oil	0,90%	74,25	wind onshore	415,73	341,48	€ 4.344	€ 7.351	1122,00
gas	30,70%	2532,75	wind onshore	341,48		€ 19.977	€ 33.807	5160,14
		2191,27	biomass	451		€ 23.452	€ 48.708	9020,00
		1740,27	pv	1145,65		€ 248.606	€ 411.288	17312,04
		594,62				€ 45.191	€ 30.552	31589,19
nuclear	54,30%	4479,75				€ 240.563	€ 146.488	51143,81
waste	1,50%	123,75				€ 1.635	€ 1.635	0,00
renewable fuels	2,60%	214,5	biomass	214,5		€ 11.154	€ 23.166	4290,00
pump	1,50%	123,75				€ 7.178	€ 10.148	907,5
other renewables	1,00%	82,5	pv	82,5	0	€ 17.903	€ 29.618	4382,8125
Total	100,00%	8250	Total RES	3051,88		€ *656.130*	€ *801.729*	133231,54
			% RES	36,99%				

10.9.3 Socio-economic optimistic scenario

High socio-economic potential scenario								
				amount	***surplus***	***cost*** *(in thousands)*		***CO2 emission***
to be replaced: *mix 2007 (% - GWh)*			***replaced by***	in GWh		*pro*	*bau*	*tons*
coal	7,50%	618,75	hydro	147,92		€ 8.579	€ 12.129	1084,75
		470,83	wind onshore	630,63	159,8	€ 27.544	€ 46.612	7114,76
oil	0,90%	74,25	wind onshore	159,8	85,55	€ 4.344	€ 7.351	1122,00
gas	30,70%	2532,75	wind onshore	85,55		€ 5.005	€ 8.469	1292,76
		2447,2	biomass	596,2		€ 31.002	€ 64.390	11924,00
		1851	pv	216,22		€ 46.920	€ 77.623	3267,32
		1634,78				€ 124.243	€ 83.995	723874,80
nuclear	54,30%	4479,75				€ 240.563	€ 146.488	51143,81
waste	1,50%	123,75				€ 1.635	€ 1.635	0,00
renewable fuels	2,60%	214,5	biomass	214,5		€ 11.154	€ 23.166	4290
pump	1,50%	123,75				€ 7.178	€ 10.148	907,5
other renewables	1,00%	82,5	solar PV	82,5		€ 17.903	€ 29.618	4382,8125
			Total RES	2011,72		€ *526.068*	€ *511.623*	810404,52
			% RES	24,38%				

10.9.4 Socio-economic pessimistic scenario

Low socio-economic potential scenario								
				amount	***surplus***	***cost*** *(in thousands)*		***CO2 emission***
to be replaced: *mix 2007 (% - GWh)*			***replaced by***	in GWh		*pro*	*bau*	*tons*
coal	7,50%	618,75	hydro	63,39		€ 3.677	€ 5.198	464,86
		555,36	wind onshore	98,28		€ 5.749	€ 9.730	1485,12
		457,08	biomass	121		€ 6.292	€ 13.068	2420,00
		336,08				€ -	€ -	0,00
		336,08				€ 29.676	€ 13.779	319734,94
oil	0,90%	74,25				€ 6.556	€ 3.044	57085,87
gas	30,70%	2532,75				€ 192.489	€ 130.133	1121492,74
nuclear	54,30%	4479,75				€ 240.563	€ 146.488	51143,81
waste	1,50%	123,75				€ 1.635	€ 1.635	0,00
renewable fuels (biomass)	2,60%	214,5				€ 11.154	€ 23.166	4290,00
pump	1,50%	123,75				€ 7.178	€ 10.148	907,5
other renewables	1,00%	82,5	pv	82,5		€ 5.781	€ 10.652	1248,187222
		8250	Total RES	703,42		€ *510.749*	€ *367.040*	1560273,02
			% RES	8,53%				

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Economic feasiblity study to provide Limburg of 100% green electricity, is it economically possible to work towards a CO2 neutral Limburg?

Richting: **Master of Management**
Jaar: **2010**

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Voor akkoord,

Daerden, Christophe

Datum: **14/06/2010**