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Final Report

Perspectives for Alternative Energy Carriers in Austria up to 2050

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Abstract

The current energy supply is mainly relying on fossil fuels. Alternative energy carriers (AEC) – based on renewable, CO_2-poor or CO_2-free sources of energy - are of central importance for the transition towards a sustainable energy system and economy.

The **core objective** of this project is to analyse the economic prospects and the likely future of ecological and energetic performance of different types of AEC in Austria. It is important to note that we do not focus on energy sources but on energy carriers.

The most important AEC considered in this study are: (i) AEC from 1st generation biofuels (bio-ethanol and biodiesel) and biogas (ii) 2nd generation biofuels; (iii) hydrogen from renewable energy sources; (iv) electricity from renewable energy sources (RES); (v) other biomass-based energy carriers. In this context it is important to note that 2nd generation biofuels currently are expected to offer the largest biofuel quantity potential since the range of raw materials includes all plant components and waste products.

We investigate in detail under which circumstances, to which extent and when these AEC may enter the market. Their potentials, costs, environmental aspects, cumulated primary energy demand and necessary promotion strategies are analysed in a dynamic context, whereby technological learning effects are considered. To answer these questions various scenarios have been created up to 2050. A major question in these scenarios is: Do we use arable land for biofuel production and how much? And to what extent can biomass-based resources at the utmost contribute to energy supply?

The **method of approach** of the analysis consists in principle of a dynamic economic comparison of the AEC among themselves as well as with the conventional energy carriers, whereby mutual reciprocal effects and factors of influence are considered. In order to evaluate the long-term perspectives of AEC in our scenarios the following framework conditions are considered:

- possible developments of the energy price level and the energy demand;
- technology developments (particularly regarding learning effects);
- energy and environmental policies.

Depending on these framework conditions scenarios are developed, depicting which AEC are technically feasible on a long-term basis until 2050 in Austria, and which can achieve critical mass and relevant potential. From these analyses it is derived which market diffusion of the AEC is to be expected in a dynamic context and which AEC has a special relevance in Austria in the medium to long term.

The most important **results** of this project are in detail:

For AEC based on non-conventional biogene resources there is a remarkable but also clearly limited potential that at the utmost can quadruple the currently used quantities, see Fig. 0-1.

To harvest this potential in an optimal way from society's point-of-view the introduction of a CO_2-based tax on all energy carriers is the most elegant and efficient solution. This CO_2-based tax subsitutes in transport the current excise tax (MöSt) and is added in other sectors to the fuel price.

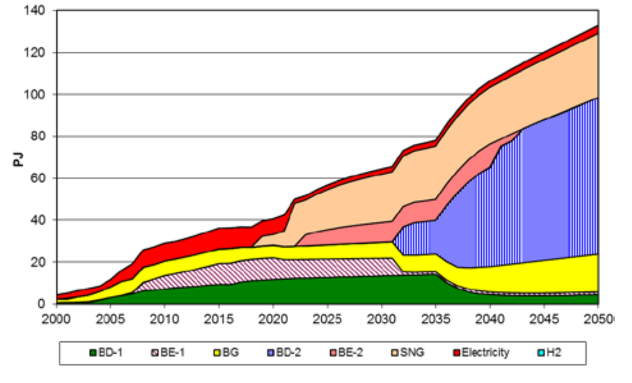

Fig. 0-1: The dynamic potential of AEC in Austria up to 2050 based on non-conventional biogene resources

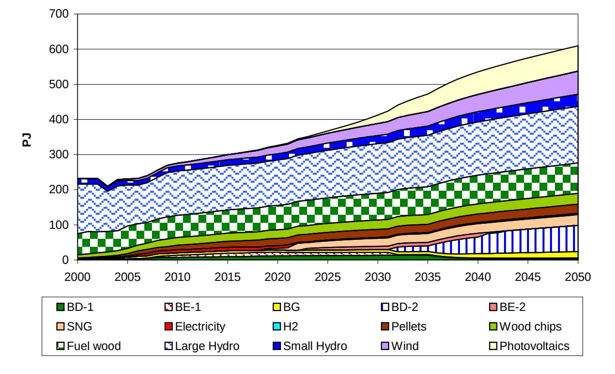

Fig. 0-2 The dynamic potential of all AEC in Austria up to 2050

We can clearly see that after about 2020 2nd generation biofuels lead to an increase of the use of mainly lignocellulosis based resources. Yet, this takes place only if it can be managed that these technologies – BTL, FT-Diesel, SNG – become mature and if significant learning effects are achieved. Moreover, the implementation of the CO_2-based tax is necessary. Otherwise, most 1st generation biofuels will remain in the market, with a worse energetic performance and much lower overall energetic output.

However, the full potentials of the 2nd generation biofuels will be achieved only after 2030. Their major advantage is that they can be produced also from resources such as lignocellulose based wood residues, waste wood or short-rotation copies, which are not dependent on food production-sensitive crop areas. Moreover, the ecological and energetic life-cycle performance of 2nd generation biofuels can bring about a significant improvement. Especially with FT-biodiesel the biogene resources can also be used more efficiently and higher CO_2-savings can be realized. Yet, till 2030 the 1st generation biofuels will be cheaper than 2nd generation biofuels, which will remain in the market at least until 2030.

Fig. 0-2 shows the potential of AEC based on all available RES in Austria up to 2050. We can see that hydro power, PV and wind can also deliver a substantial contribution. In total the potential for 2050 is about 600 PJ (165 TWh). That is about 60% of final Austrian energy consumption in 2009.

The three major steps towards harvesting an optimal portfolio of AEC in Austria up to 2050 are:

1. Introduction of a CO_2 based tax: This tax ensures that depending on the dynamic ecological performance of different AEC their market introduction will bring about the mix from which society benefits most;

2. A tightening of the standards for CO_2 emissions of these AEC and introduction of a rigorous continuous corresponding monitoring and certification process;
3. A focussed R&D programme for 2^{nd} generation biomass and for fuel cell with an accompanied dynamic performance evaluation from economic, technical and environmental point of view.

Finally we state that only if this portfolio of measures is implemented in a tuned mix it will be possible to exploit the potential of AEC up to 2050 in Austria in an optimal way for society.

Kurzfassung

Der Umstieg vom derzeitigen, vorwiegend auf fossilem Kohlenstoff basierenden Energiesystem auf ein Energiesystem mit alternativen Energieträgern (AET) – erneuerbare, CO_2-arme oder -freie Energieträger – ist von zentraler Bedeutung für ein nachhaltiges Energie- und Wirtschaftssystem.

Die **zentrale Zielsetzung** dieses Projekts ist es, die wirtschaftlichen Zukunftsperspektiven AET zu analysieren, und ihre mögliche ökologische und energetische Entwicklung abzuschätzen. Es ist wichtig zu betonen, dass wir in diesem Projekt Energieträger und nicht Energiequellen analysieren. Die wichtigsten analysierten AET sind: (i) Bioethanol und Biodiesel erster Generation und Biogas, (ii) Biofuels zweiter Generation wie z.B. Bioethanol aus Lignozellulose, FT-Diesel und SNG; (iii) Strom und (iv) Wasserstoff aus erneuerbaren Energiequellen. Biofuels zweiter Generation bieten nach heutigem Kenntnisstand unter den Biokraftstoffen das größte Mengenpotential, da die Palette der in Frage kommenden Rohstoffe sehr groß ist und alle Pflanzenbestandteile und Abfälle verwertet werden können. Es gibt aber auch mögliche alternative fossile Energieträger wie z.B. LNG, CTL, GTL die wir in dieser Arbeit nicht näher analysieren, da sie für Österreich in den nächsten Dekaden keine Bedeutung haben werden.

Im Detail analysieren wir in dieser Arbeit, ob und unter welchen Randbedingungen in welchem Ausmaß und wann welche dieser AET in Österreich in Zukunft von Bedeutung sein können. Es werden deren Potentiale, Kosten, Umweltaspekte, der kumulierte Energieaufwand und notwendige politische Rahmenbedingungen in einem dynamischen Kontext untersucht, wobei auch technologische Lerneffekte analysiert werden.

Der **methodische Ansatz** zur Analyse besteht im Prinzip aus einer dynamischen ökonomischen Gesamtbetrachtung der AET untereinander sowie mit den konventionellen Energieträgern. Um die langfristigen Perspektiven von AET bewerten zu können, werden die folgenden Einflussparameter in Szenarien berücksichtigt:

- mögliche Entwicklungen des Energiepreisniveaus und der Energienachfrage;
- globale Entwicklungen (vor allem in Bezug auf Lerneffekte)
- Umwelt-, energie- und verkehrspolitischen Rahmenbedingungen in Österreich und auf EU-Ebene.

In Abhängigkeit von diesen Parametern werden Szenarien entwickelt, in denen dargestellt wird, welche alternativen Energieträger langfristig, bis 2050 in Österreich unter verschiedenen Entwicklungen dieser Einflussparameter machbar sind und eine kritische Masse sowie ein relevantes Potential erreichen können. Aus diesen Analysen lässt sich ableiten, welche Marktdiffusion der AET in einem dynamischen Kontext zu erwarten ist und welche AET in Österreich mittel- bis langfristig eine besondere Relevanz haben.
Im Folgenden sind die wichtigsten **Ergebnisse** dieses Projekts im Detail beschrieben. Für AET basierend auf nichtkonventionellen biogenen Rohstoffen existiert ein merkliches aber

auch deutlich beschränktes zusätzliches Potenzial, das maximal bei ca. dem Vierfachen des heute genutzten liegt, vgl. Abb. 0-1.

Um dieses zusätzliche Potenzial aus gesellschaftlicher Sicht optimal zu erschließen, ist die Einführung einer CO_2-spezifische Steuer auf alle Energieträger, die die heutige MöSt ersetzt, eine elegante und effiziente Lösung.

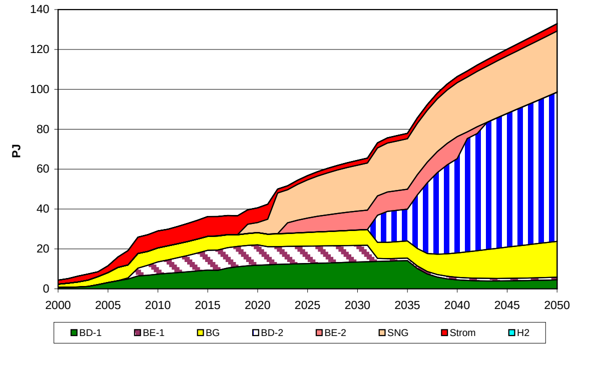

Abb. 0-1: Das dynamische Potenzial AET in Österreich bis 2050 basierend auf nichtkonventionellen biogenen Rohstoffen

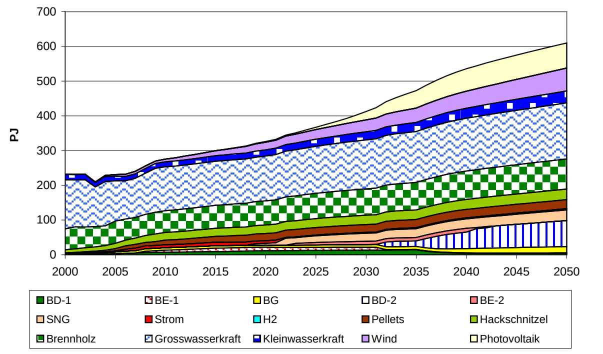

Abb. 0-2: Dynamisches Potenzial aller AET in Österreich bis 2050

Es ist deutlich zu sehen, dass nach ca. 2020 Biofuels der 2. Generation – sofern entsprechende Lerneffekte bezüglich der Kosten erzielt werden und die Technologien technische Reife erreicht haben – zu einer deutlichen Steigerung der Nutzung dieser vor allem auf Lignozellulose basierenden Rohstoffe führen können. Dies wird allerdings nur dann realisiert, wenn die beschriebene CO_2-spezifische Steuer auf alle Energieträger implementiert wird. Damit – vor allem mit Biodiesel auf FT-Basis – können die biogenen Rohstoffe auch effizienter genutzt und höhere CO_2-Einsparungen realisiert werden.

Abb. 0-2 zeigt das Potenzial an AET basierend auf allen verfügbaren erneuerbarer Energieträgern in Österreich bis 2050. Wir erkennen, dass Wasserkraft, Wind und Photovoltaik einen deutlich größeren Beitrag liefern können. Insgesamt würde das Potenzial für 2050 – ca. 600 PJ (ca. 165 TWh) – in etwa 60% des österreichschen Endenergieverbrauchs des Jahres 2009 entsprechen.

Die drei wichtigsten Maßnahmen, um das Potenzial AET in Österreich bis 2050 optimal zu erschließen, sind:

1. Einführung einer CO_2-basierten Steuer: Diese Maßnahme stellt sicher, dass die Markteinführung zusätzlicher EET in Abhängigkeit von deren dynamischer ökologischer Performance in dem Mix mit dem größten gesellschaftlichen Nutzen erfolgt;
2. Eine Verschärfung der Standards bezüglich der CO_2 Emissionen verschiedener AET und Einführung eines rigorosen kontinuierlichen Monitoring- und Zertifizierungsprozesses;

3. Ein fokussiertes F&E-Programm für *2nd generation biofuels* und für Brennstoffzellen mit begleitender dynamischer ökonomischer, technischer und ökologischer Evaluierung.

Nur wenn dieser Mix von Maßnahmen sorgfältig aufeinander abgestimmten eingeführt wird, ist es möglich, das Potenzial AET in Österreich bis 2050 aus gesellschaftlicher Sicht optimal zu erschließen.

1. Introduction

1.1 Motivation

The current energy supply is mainly relying on fossil fuels. Alternative energy carriers (AEC) – based on renewable, CO_2-poor or CO_2-free sources of energy - are of central importance for the transition towards a sustainable one.

The most important AEC currently under discussion are: bio-ethanol, biogas, biodiesel, and other AEC based on biomass, e.g. like hydrogen and electricity, 2nd and 3rd generation biofuels like e.g. bioethanol from lignocelluloses (raw materials are all cellulosic materials, e.g. grass, straw, wood and different residuals and waste products from agriculture and wood industry as well as local wastes and residual substances), BtL fuels – they offer the largest quantity potential after current level of knowledge under the biofuels, since the range of raw materials is very large and all plant components can be used – as well as electricity and hydrogen from renewable energy sources. In addition, there are possible AEC from fossil sources like e.g. LNG, CTL, GTL.

1.2 Core objective

The core objective of this project is it to analyze whether and under which circumstances, to which extent and when AEC could be economically of importance in Austria in the future (inclusive external costs). Of special interest are the energetic (gross vs. net) potentials of AEC in a dynamic context. Furthermore, their costs, environmental aspects and cumulative life-cycle energy balances is analysed and assessed whereby technical progress (mainly with respect to conversion efficiency) and technological learning (TL) effects (with respect to future economic performance) are considered.

Finally, necessary promotion strategies are derived and summarized in Action plan.

1.3 Survey on important literature

The major national and international literature on AEC is summarized in the following. The most important works conducted so far in this context are:

In the report „ How much bioenergy can Europe produce without harming the environment?" published by EEA in 2006 it is described in detail by feedstock and by country which potentials of biomass can be used in an environmentally friendly way in EU countries. Kaltschmitt (2004) document the technical potentials for biofuels and hydrogen in EU countries. An economic and ecological assessment of hydrogen is conducted in the project "ÖKO-H2" [Jungmeier et al 2006]. The results of a modeling framework for the supply of Europe with synthetic fuels from biomass are shown in Funk (2009). Panoutsou (2009) gives a view of bioenergy's role in the EU market up to 2030. Kranzl/Haas (2008) provide a comprehensive assessment of bioenergy in Austria and describe different scenarios for the exploitation of biomass potentials in Austria up to 2050. In the project ALPOT [Kalt/Kranzl, 2011] a specific analysis for biomass resources from arable land is provided. Finally, an important analysis with respect to the technological choices for the use of biomass in Europe has been conducted by Faaij (2006).

1.4 Structure of this work

This report is organized as follows:

A survey on AEC is provided in Section 2. In Section 3 the general method of approach applied in this work is described. The results of the ecological and energetic assessment are documented in Section 4. The major assumptions regarding price developments and the (dynamic) potentials of areas and other resources that are available for producing AEC are sketched in Chapter 5. A dynamic economic assessment of alternative energy carriers (based on TL) is conducted in Chapter 6. Chapter 7 describes the model and Chapter 8 the results of the scenarios. The Action plan is described in Chapter 9 and conclusions in Chapter 10 complete this work.

2. Alternative Energy Carriers: a survey

In this chapter we present some basics on AEC. We document definitions of AEC, their position in the energy chain and we show their current role in the Austrian energy system.

2.1 Definition: What is an energy carrier and what is an AEC?

An energy carrier serves as a vehicle to bring the energy content of an energy resource (as efficient as possible) to the location where it is used/purchased (final energy/commercial energy). Moreover, in this study energy carriers are defined to be tradable on markets. So for example we do not consider solar thermal heat.

Since various forms of energy inputs are required by the various sectors there is a wide range of liquid, solid and gaseous energy carriers used nowadays. However, it is important to make distinction between energy carriers and primary energy sources – primary energy is an energy form found in the nature and an energy carrier is an energy form which is result of a conversion or transformation process and which can be used to produce mechanical work, heat or to operate chemical or physical processes.

Actually, only in a few cases energy is already available in a form which can be directly used to provide energy services. In most cases primary energy has to go through one or more energy-transformation steps before it can be used, see Figure 2-1. In this figure the term ”Final energy” refers to energy carriers.

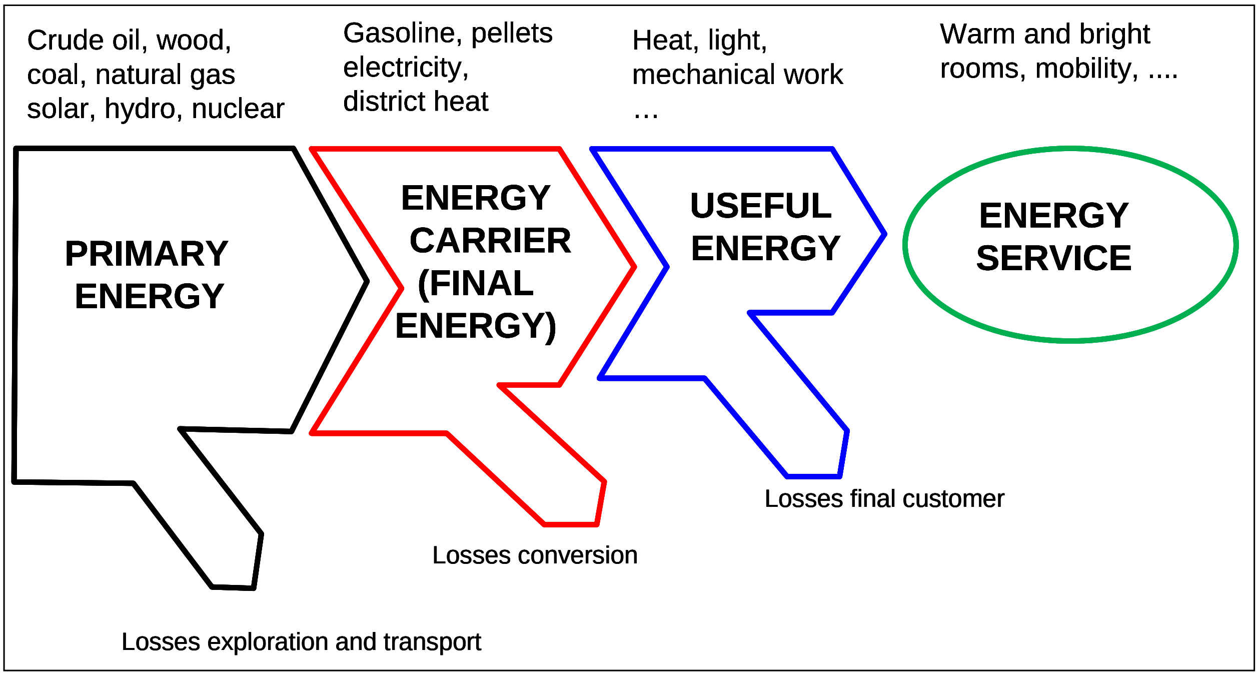

Figure 2-1 Elements of the energy service providing chain

Currently, the world’s energy system is based mainly on fossil energy – oil, gas and coal – which together supply around 80% of our primary energy. The share of renewable energy in total energy consumption is about 13% and rather constant over time since 1973 [IEA, 2011a]. Due to the problems related to the use of the conventional energy carriers such as increasing GHG emissions, climate change and air pollution, interest in alternative energy carriers is rapidly increasing. Alternative energy carriers (AEC) are energy carriers which could contribute to the reduction of GHG emissions. The most important AEC are produced from renewable energy sources. However, some energy carriers produced from fossil fuels could also be considered as AEC if they are more environmentally friendly comparing to conventional fossil fuels, e.g LNG, CTL.

Since the transport sector is one of the major contributors to the increasing GHG emissions, most of AEC have main implementation in vehicles.

Energy carriers could be produced and used on different ways, so that we can have more or less complicated energy supply chains. However, each energy-conversion step in the supply chain invokes additional costs for capital investment in equipment, energy losses and carbon emissions. These directly affect the ability of an energy path to compete in the market place [Sims et al, 2007].

2.2 AEC and energy chains

One of the main problems of the energy use is loss of energy in the long chain from the energy extraction of primary energy (PE) up to the energy service (ES), see Figure 2-1 and Figure 2-2. Loss of energy depends of the efficiency of the conversion process (T_C) at the each transformation stage as well as efficiency of the finally used technology (T_u), e.g. cars.

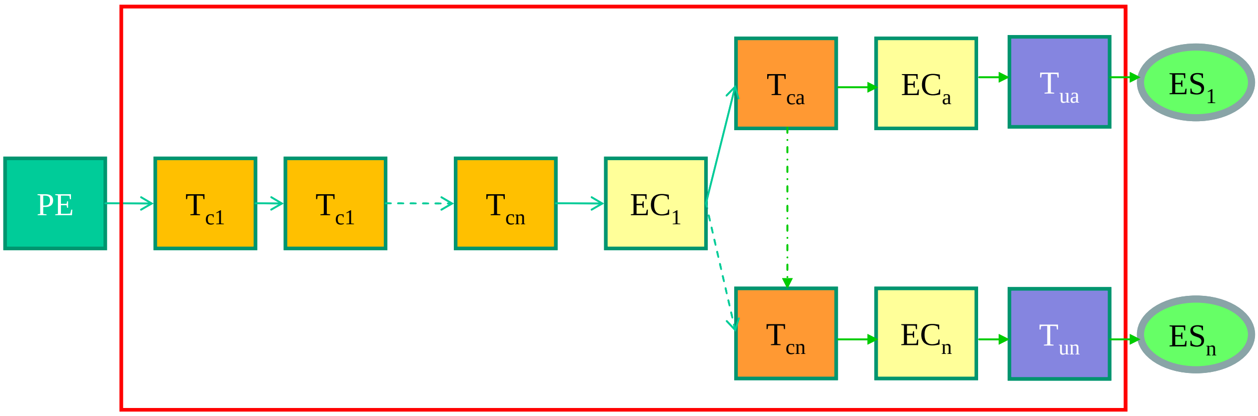

Figure 2-2 Basic principle of an energy chain

Some examples for chains assigned to the AEC pellets, electricity and hydrogen are depicted in Figure 2-3. For example, hydrogen can be used as storage for electricity from renewable energy sources and than according to requirements again converted to electricity. Unfortunately, in case of the long energy chains – due to many conversion process and corresponding energy losses – total energy and environmental balances could be relatively poor.

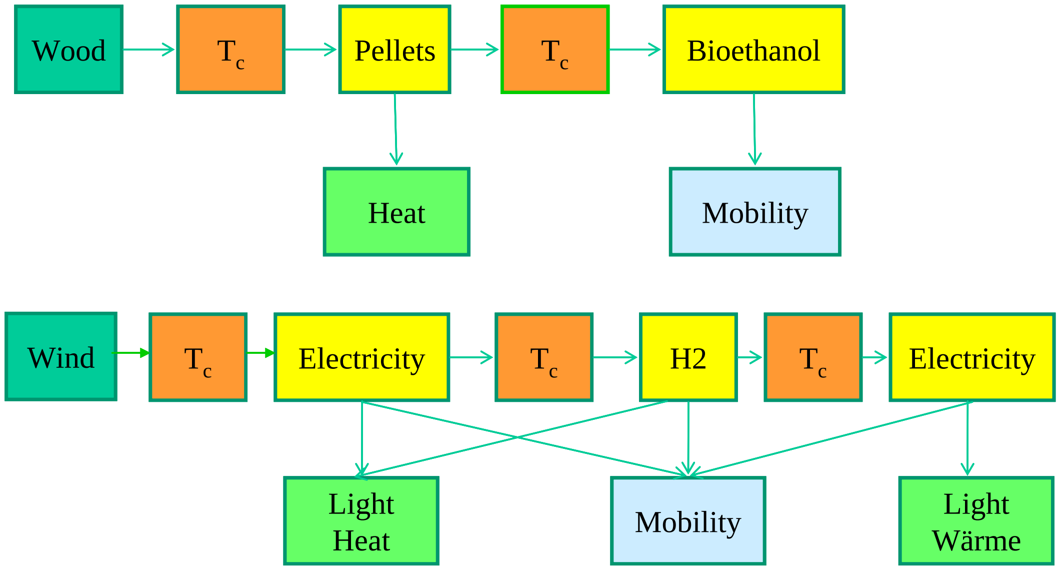

Figure 2-3 Examples for energy chains assigned to the AEC pellets, electricity, bioethanol and hydrogen

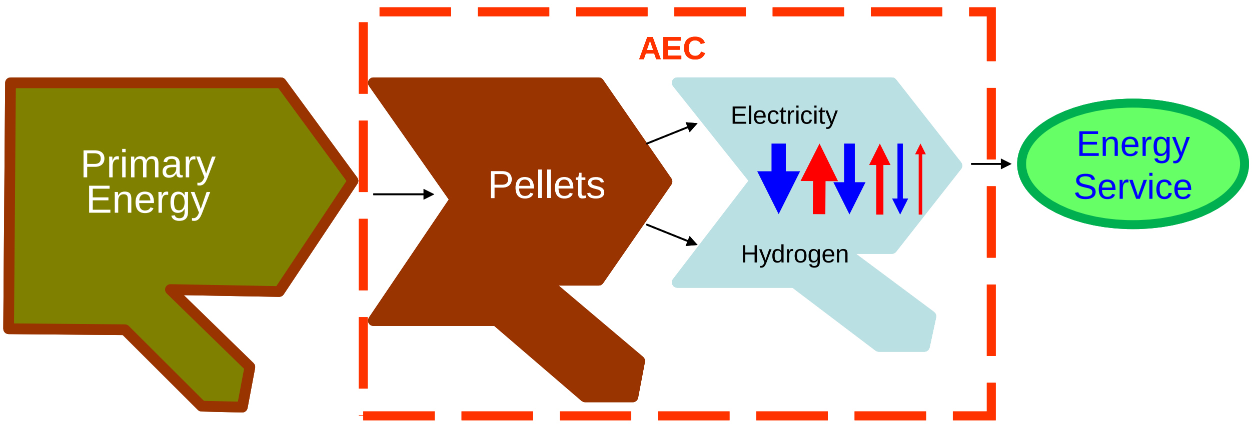

Figure 2-4 Example for the cascadic use of AEC: Electricity can be converted into hydrogen and vice versa again and again before it is converted into a service

2.3 An overview on alternative energy carriers

The most important alternative energy carriers used nowadays are electricity from renewable energy sources, wood products (fuel wood, pellets…) and first generation biofuels. The use of biofuels in transport sector is continuously increasing and forced by policy. In the EU the goal is to have 10 % of biofuels in transport by 2020. Although, conventional biofuels are already mature, they are not able to solve all the existing problems in transport, such as increasing energy import dependency or increasing GHG emissions. At the same time, using these biofuels some new problems have appeared. Currently, the most discussed problems are sustainability of biofuels and competition with food production.

Some of these problems could be solved with the 2nd and 3rd generation biofuels. These, advanced biofuels could be produced from wood residues from industry and other ligno-cellulose feedstocks (e.g. woody and herbaceous plants such as perennial grasses and fast growing tree species). Advanced biofuels have also higher energy yields and higher GHG reduction potential. The only problem is that these biofuels are still in the developing stage and may become commercially available only in the next 10 to 20 years [OFID, 2009].

Alternative energy carriers from renewable energy sources (RES) can be divided in four groups: (i) mature AEC which are already in use; (ii) immature AEC which are still in the developing stage; (iii) AEC in the labour stage; and (iv) technology surprise, see Figure 2-5.

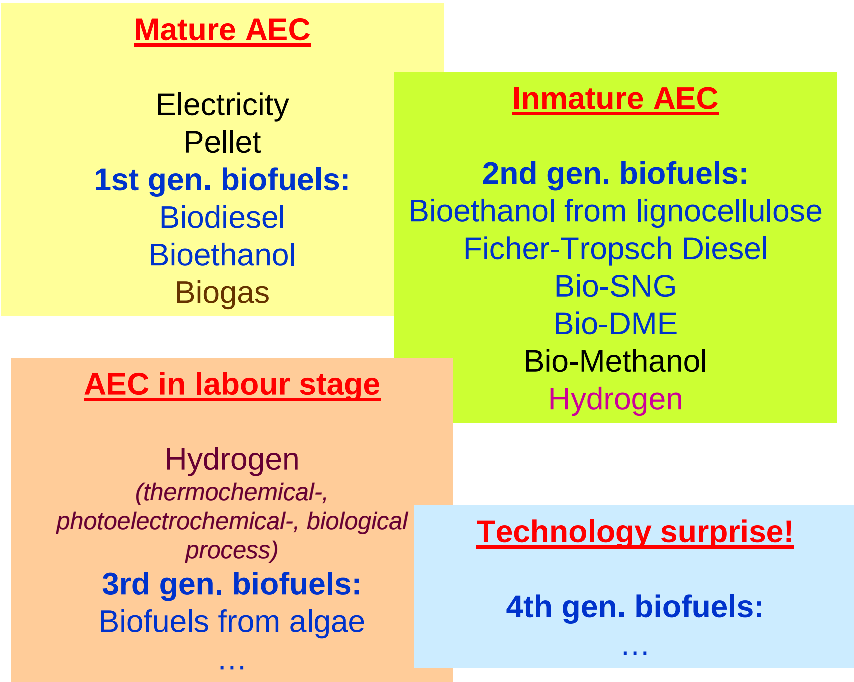

Figure 2-5 Maturity stage of different alternative energy carriers

2.3.1 Mature AEC

A key strategy of Austrian energy policy is the permanent promotion of renewable energy sources, accompanied by the enhancement of a rational utilisation of energy, which resulted in a mix of energy sources characterised by a significant share of RES. With 65 % of electricity from RES Austria is the European leader in gross electricity consumption from RES. The most significant sources of renewable energy in Austria are hydropower and biomass. Since about 47 % of the Austrian territory is covered by forests, the use of biomass has been extensive.

The largest solid wood fraction, logwood is used by individual households. Wood chips, bark and industrial timber residues are used in combined heat and power plants and district heating plants, while pellets are increasingly being used primarily in household heating systems [EREC, 2009].

Due to the tax exemption and biofuels targets, biofuels use has increased significantly in last years. The big advantage of biofuels is that they can be used in conventional internal combustion engines and that no additional infrastructure is needed. They are currently most important alternative energy carriers for transport sector.

The 1st generation biofuels are mostly produced from agricultural feedstocks, such as sugar cane, corn, soy, palm oil, rapeseed, sunflower and wheat. There are still some problems associated with conventional biofuels ranging from GHG emissions to the competition with food production.

The most important 1st generation biofuels are bioethanol, biodiesel and biogas.

Bioethanol could be used directly as a motor fuel or blended with gasoline. It is produced through fermentation of sugar of starch. Most important feedstocks for bioethanol production are sugar cane in Brazil, corn in the US and wheat in Europe.

Bioethanol can also be used for the production of ETBE which blends more easily with gasoline.

Biodiesel is a substitute for fossil diesel. It is derived from vegetable oils - mostly rapeseed oil, sunflower oil and soybean oil - through transesterifiction. Also residual oils and fats are suitable for biodiesel production.

Biogas could be produced through anaerobic digestion of manure and other digestible feedstocks like green maize or grass. It can be used for heat and power generation. With slight adoptions, upgraded biogas (bio-methane) can be used in gasoline vehicles[1].

2.3.2 Emerging AEC

There are high expectations for the future related to the 2nd generation biofuels. These advanced biofuels could be produced from different lignocellulosic materials (e.g. woody and herbaceous plants such as perennial grasses and fast growing tree species). 2nd generation biofuels have also higher energy yields and significantly higher GHG reduction potential. The only problem is that these biofuels are still in the developing stage and may become commercially available only in the next decades.

The most important 2nd generation biofuels are: bioethanol based on lignocellulosis, Fischer-Tropsch diesel, Bio-SNG (Synthetic Natural Gas) and Bio-DME (Dimethyl Ether).

Advanced **bioethanol** could be used in the same way as conventional bioethanol. In case of hydrolysis, sugars are at first extracted from lignocellulosic materials, and then fermented into ethanol.

Fischer-Tropsch diesel (BD-2) could be a full substitute of fossil diesel. In this case lignocellulosic feedstocks are gasified to produce syngas which is than transformed into liquid hydrocarbons, mostly diesel and kerosene.

Bio-SNG is a fuel that can be used in gasoline vehicles with slight adaptations. It is produced in two steps, lignocellulose materials are gasified to produce syngas which is than transformed into methane.

Bio-DME is produced in a similar way as bio-SNG, but bio-DME can be used as a fuel in diesel vehicles. Some slight modifications of vehicles are needed.

In category emerging AEC belong also bio-methanol and hydrogen.

[1] In the following biogas is used as synonym for upgraded-biogas.

Methanol is also one option to be considered as an energy carrier for a clean and sustainable energy future. Currently, the major feedstock for the methanol production is natural gas and in some regions e.g. China coal. However, recent research is focused on production of methanol in more sustainable way. A promising method is the production of bio-methanol from synthesis gas produced out of biomass. Methanol can be used as a fuel in conventional fuel cells. In that case, methanol has to be reformed to hydrogen that is converted in the fuel cell. The advantage of methanol is that it contains low energy chemical bonds and therefore it can be reformed to hydrogen at relatively low temperatures (250-350°C) [Breure, 2005].

Since methanol was originally recovered from wood as a by-product of charcoal manufacture, synonyms for methanol are wood alcohol, wood naphtha, woos spirits or methyl alcohol.

Currently, bio-methanol from RES is not on the market [DMA, 2011].

Hydrogen is considered as one of the cleanest and most innovative energy carrier to supply energy services. It is the simplest, lightest and most abundant element in the universe. It constitutes about three-quarters of the mass of the universe, but it does not exist on the earth in elemental form in quantities associated with energy use. However, it can be produced from different energy sources: fossil energy, nuclear energy as well as renewable energy sources. The main requirement for worldwide hydrogen energy long term vision is the production of hydrogen from renewable energy sources.

Hydrogen has potential to reduce greenhouse gas emissions, climate change, global warming, and to increase energy diversity and supply security. In the last fifteen years the number of hydrogen vehicles, stationary fuel cell systems and refuelling stations is growing.

Today, the largest part of hydrogen, about 60%, is directly produced from fossil fuels and about 40% of it is a by-product of the petrochemical industry and the electrolyses for chlorine production.

The different processes of hydrogen production can be grouped into three categories: thermal, electrochemical and biological process, see Table 2-1. Some of these processes are well developed, such as steam reforming of natural gas, coal gasification and electrolysis. The steam reforming of natural gas has been used in chemical, petroleum and other industries process for years. Coal gasification is one of the oldest methods of producing hydrogen and very suitable for coal producing countries like China and South Africa. However, biomass gasification process needs additional improvements. Water electrolysis is also well developed technology. Then again all biological processes are still under fundamental research.

Table 2-1 Major hydrogen production processes [Ajanovic, 2006]:

Primary Method	*Process*	*Feedstock*	*Energy*	*Emissions*	*Stage of Development*
Thermal	*Steam Reforming*	*Natural Gas*	*High temperature steam*	*Some emissions. Carbos sequestration can mitigate their effect.*	*Developed commercial technology*
	Thermochemical Water Splitting	*Water*	*High temperature heat from advanced gas-cooled nuclear reactors*	*No emissions*	*Fundamental research*
	Gasification	*Coal*, Biomass***	*Steam and oxygen at high temperature and pressure*	*Some emissions. Carbos sequestration can mitigate their effect.*	**Developed commercial technology **Proven technology*
	Pyrolysis	*Biomass*	*Moderately high temperature steam*	*Some emissions. Carbos sequestration can mitigate their effect.*	*Proven technology*
Electrochemical	*Electrolysis*	*Water*	*Electricity from wind, solar,hydro and nuclear*	*No emissions.*	*Developed commercial technology*
	Electrolysis	*Water*	*Electricity from coal or natural gas*	*Some emissions from electricity production.*	*Developed commercial technology*
	Photoelectrochemical	*Water*	*Direct sunlight*	*No emissions.*	*Fundamental research*
Biological	*Photobiological*	*Water and algae strains*	*Direct sunlight*	*No emissions.*	*Fundamental research*
	Anaerobic Digestion	*Biomass*	*High temperature heat*	*Some emissions.*	*Fundamental research*
	Fermentative Microorganisms	*Biomass*	*High temperature heat*	*Some emissions.*	*Fundamental research*

One possibility to avoid some problems with hydrogen such as storage and refuelling infrastructure could be use of carbazole. Carbazole itself is not burned; it only discharges the hydrogen [Renzenbrink, 2011]. It is actually an energy-carrying substance which will be recycled and not consumed. The new technology has a marked advantage in allowing existing service station infrastructures to be used. Another advantage is that no pressure is required; the substance N-ethylcarbazole is similar to diesel in many ways. One liter of N-ethylcarbazole allows almost twice as much hydrogen (54 grams) to be stored as in the equivalent volume of a 700-bar hydrogen tank. The range and power would be equivalent to today's vehicles [Elector, 2011].

However, experiments with carbazole use in cars are in their initial stages but hold a lot of promise for the future [Hudston, 2011]. Carbozole can also be used for the stabilization of the electricity system and for energy storage in solar powered homes [Elector, 2011].

2.3.3 AEC in the labor stage

Beside the hydrogen production using thermochemical water splitting, photoelectrochemical or biological processes, which are shown in Table 2-1 in category AEC in the labour stage are also biofuels produced from algae.

Fuels produced from algae are considered to be third generation biofuel. Third generation biofuels seek to improve the feedstock rather than improving the fuel-making process.

The algal organisms are photosynthetic macro- or micro-algae growing in aquatic environments. Macro-algae or ‘‘seaweeds” are multicellular plants growing in salt or fresh water. Microalgae are microscopic organisms that that could also grow in salt or fresh water. Optimal temperature for growing many microalgae is between 20 and 30°C. Macro- and micro-algae are currently mainly used for food, in animal feed, in feed for aquaculture and as bio-fertiliser. However in the future they could be used for bioenergy generation (biodiesel, biomethane, biohydrogen), or combined applications for biofuels production and CO_2 mitigation. Theoretically, algae are a very promising source of biofuels. Some algae produce up to 50% oil by weight [Demirbas et al, 2011]. However, mass algal production for biofuels is still an unproven technology [Campbell, 2011].

According to Seaweed Energy Solutions AS (SES), which is a Norwegian registered company focused on large-scale cultivation of seaweed primarily for energy purposes, bio-energy production utilizing the Earth’s vast oceans offers tremendous opportunity as a worldwide renewable energy resource. Current advanced and proven technologies in marine biology, offshore structures, aquaculture and biomass processing are bringing this promise ever closer to commercial reality.

The European offshore area (Exclusive Economic Zone, EEZ) is about 7 million km2. A seaweed farming cluster covering an area of 500 km2 would yield about 10 million tonnes of wet weight seaweed per year (assuming 200 tonnes/ha). For example, five such farming clusters (2,500 km2) spread around in the European waters from Norway to Portugal would represent only 0.03 % of the European EEZ, and would yield 50 million tonnes seaweed annually. This biomass may be converted to about 2.1 billion litres of bioethanol or alternatively 1 billion m^3 bio-methane (12.6 TWh). 2.1 billion litres from seaweed would represent about 26 % of European bioethanol production and 2.5 % of global production in 2010 [SES, 2011].

According to the U.S. Department of Energy, algae can produce up to 30 times more energy per acre than land crops such as soybeans, which are currently used for biofuel production. The main reason is that they have a simple cellular structure, a lipid-rich composition and a rapid reproduction rate. Many algae species also can grow in saltwater and other harsh conditions - whereas soy and corn require arable land and fresh water. To replace all diesel in the USA with soy biodiesel, it would be necessary half the land mass of the U.S. to grow those soybeans. On the other hand, if algae fuel replaced all the petroleum fuel in the United States, it would require 15,000 square miles (about 39,000 square kilometers), which is roughly the size of Maryland [Hartmann, 2008].

Algae could be used for making vegetable oil, biodiesel, bioethanol, biomethanol, biobutanol and other biofuels.

In the last decades biofuels are considered to be a good way to reduce GHG emissions. But, the problems with first generation biofuels are numerous and well-documented in the last few years, ranging from net energy losses, high greenhouse gas emissions to increasing food prices. Taking into account the sustainability and economic factor biofuel from algae seems to be very promising fuel for future.

However, further research and development are necessary to establish an economical industrial scale production of algal biofuels [Singh et al, 2011].

2.3.4 Technology surprise

Although 2^{nd} generation biofuels are still in developing stage and 3^{rd} generation in labour stage, there are already efforts toward 4^{th} generation biofuels.

Fourth generation technology combines genetically optimized feedstocks, which are designed to capture large amounts of carbon, with genomically synthesized microbes, which are made to efficiently make fuels. Key to the process is the capture and sequestration of CO_2, a process that renders fourth generation biofuels a carbon negative source of fuel. However, the weak link is carbon capture and sequestration technology, which continues to elude the coal industry [Rubens, 2008].

However, scientists at the University of Essex have discovered a new mechanism that regulates the process of carbon fixation in plants. This research could lead to improvements in so-called fourth generation biofuels by letting scientists design feedstocks that capture more carbon.

2.4 AEC from fossil energy

Nowadays our energy system is based on fossil energy and a continuing use of fossil fuels is also expected in the near future. Unfortunately, during combustion, fossil fuels release significant amount of carbon and have direct impact on GHG emissions and climate change. Use of fossil energy is responsible for about 85% of total CO_2 emissions. To reduce this problem we can use some AEC from fossil energy such as CTL, LNG, LPG. Comparing to AEC from RES these energy carriers have still poor GHG balances.

For countries with large coal resources such as US, Russia and China, CTL could be an interesting option. Coal liquefaction can be performed by direct solvent extraction and hydrogenation of the resulting liquid at up to 67% efficiency [DTI, 1999] or indirectly by gasification then producing liquids by Fischer-Tropsch catalytic synthesis as in the three SASOL plants in South Africa. These produce 0.15 Mbbl/day of synthetic diesel fuel (80%) plus naphtha (20%) at 37–50% thermal efficiency. However this efficiency is dependent on quality of coal [Sims et al., 2007]. CTL is well understood and regaining interest, but it could be interesting option for the reduction of GHG emissions only in combination with CCS. CTL indicates negative techno-economic and resource-related features, such as high capital costs, high greenhouse gas discharges and high water consumption. Therefore, the technology's diffusion strongly depends on a favourable framework of policies [Vallentin, 2009].

The increased use of natural gas has recently occurred in the Asian region, in the United States and the European Union [BP, 2006]. Recently a liquefied natural gas (LNG) market has emerged especially in Japan, South Korea and Spain. To meet future natural gas demand for direct use by the industrial and commercial sectors as well as for power generation is also required development and scale up of liquefied natural gas (LNG) as an energy carrier. The Pacific Basin is the largest LNG-producing region in the world, supplying around 50% of all global exports in 2002 [US EIA, 2005]. The share of total US natural gas consumption met by net imports of LNG is expected to grow from about 1% in 2002 to 15% (4.5 EJ) in 2015 and to over 20% (6.8 EJ) in 2025. Losses during the LNG liquefaction process are estimated to be 7 to 13% of the energy content of the withdrawn natural gas [Sims et al., 2007].

LPG is a mixture of propane, butane, and other hydrocarbons produced as a by-product of natural gas processing and crude oil refining. Total global consumption of LPG amounted to over 10 EJ in 2004 [MCH/ WLPGA, 2005], equivalent to 10% of global natural gas consumption [Venn, 2005]. Growth is likely to be modest with current share maintained [Sims et al., 2007].

Due to higher oil prices gains GTL process renewed interest. GTL is especially interesting for developing uneconomic natural gas reserves such as those associated with oil extraction at isolated gas fields which lie far from markets. As by CTL, also by GLT the natural gas is turned into synthesis gas, which is converted by the Fischer-Tropsch process to synthetic fuels. The most of commercial GTL projects are in gas-rich countries such as Qatar, Iran, Russia, Nigeria, Australia, Malaysia and Algeria with worldwide production estimated at 0.58 Mbbl/day [FACTS, 2005]. GTL conversion technologies have an efficiency of around 55%. Production costs are dependent on gas prices, but where stranded gas is available at 0.5

US$/GJ production costs are around 30 US$ a barrel [IEA 2006a]. However GTL produced with current technology is not solution for the reduction of CO_2 emissions.

2.5 AEC analysed in this study

In this study our major focus is on AEC, which could contribute to the reduction of GHG emission and be competitive on the market till 2050. Since AEC could be produced from different primary energy resources and with different technologies, we have chosen mostly the promising chains for Austria regarding resource potentials, costs and environment. Table 2-2 provides an overview on AEC and primary energy resources considered in this study.

Table 2-2 AEC and primary energy resources considered

AEC / Resource	BD-1	BE-1	BG	BD2	BE2	SNG	Electri-city	H2*	Pellets	Wood chips	Fuel wood
Feedstock											
Rapeseed	x										
Sunflower	x										
Soy beans	x										
Wheat		x									
Corn maize		x									
Sugar-beet		x									
Green maize (incl. cover crops)			x								
SRC				x		x	x	x			
Corn stover				x		x	x	x			
Grass			x								
Forest wood											x
Residue											
Straw		x		x	x	x	x	x			
Forest wood residues				x		x	x	x		x	
Wood industrry residues				x	x	x	x	x	x		
Liquid manure			x								
Dry manure			x								
Waste wood							x				
Organic waste (incl. waste fat)	x		x								
Black liquor							x				
RES (non biomass)											
Wind on-shore							x				
Hydro power							x				
Photovoltaics							x				

* Of course, hydrogen can also be produced by electrolysis from electricity from wind, hydro and photovolotaics.

As shown in Table 2-2 there are different resources which could be used for the production of AEC. For example for biofuels production we can use different feedstocks. Basically the major characteristics of the ideal energy crop are high yield, low inputs, low costs, low composition of contaminants and nutrients and high pest resistance. However, not one crop has all these characteristics and therefore a choice must be made from available crops to select the most optimal crop-mix that can be cultivated in Austria [Breure, 2005].

2.6 The current role of AEC in Austria

As a starting point for the following analyses in this chapter the current role of AEC in Austria is documented.

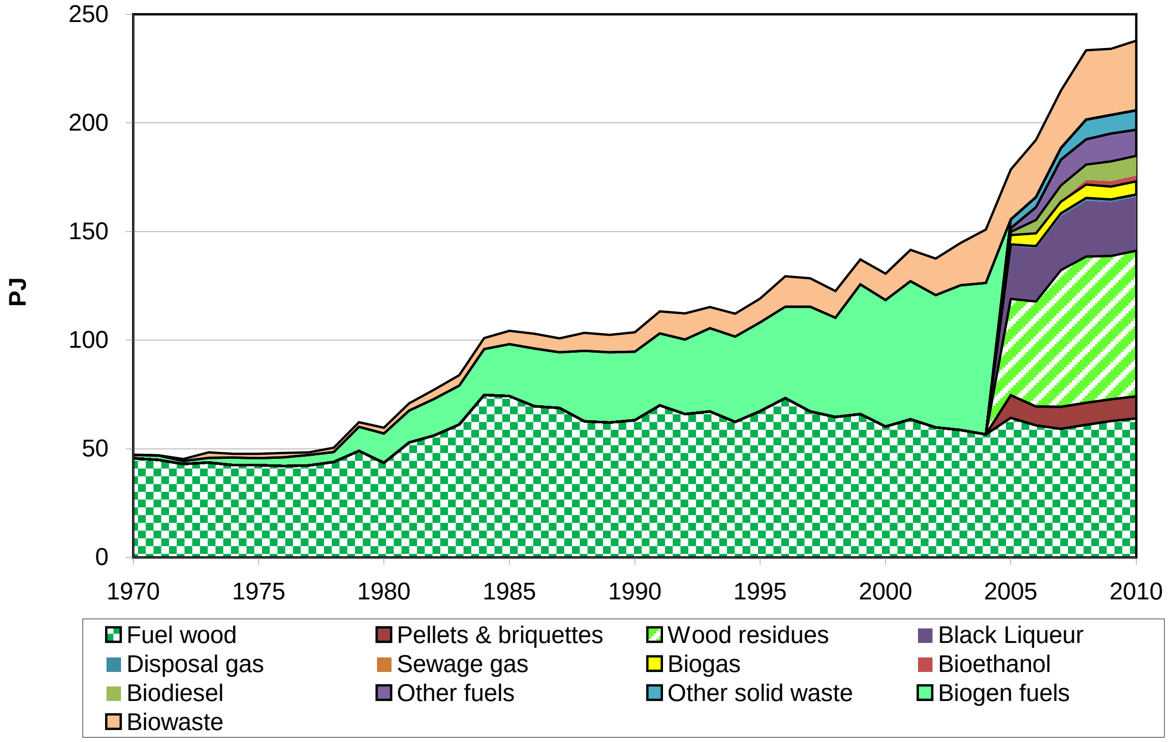

Figure 2-6 State-of-the-art of the energetic use of biomass-based primary energy resources in Austria 1970-2010 (Source: Statistic Austria)

Figure 2-6 depicts the development of biomass-based resources in Austria in period 1970-2010. We can see over time an almost continuous increase. Yet, most remarkable is the steep increase in recent years.

The development of biomass-based AEC is depicted in Figure 2-7 for the time period 2000-2010. From this figure it can be seen that the steep increase in the last decade was brought about mainly by pellets, electricity from biomass, bioethanol and biodiesel.

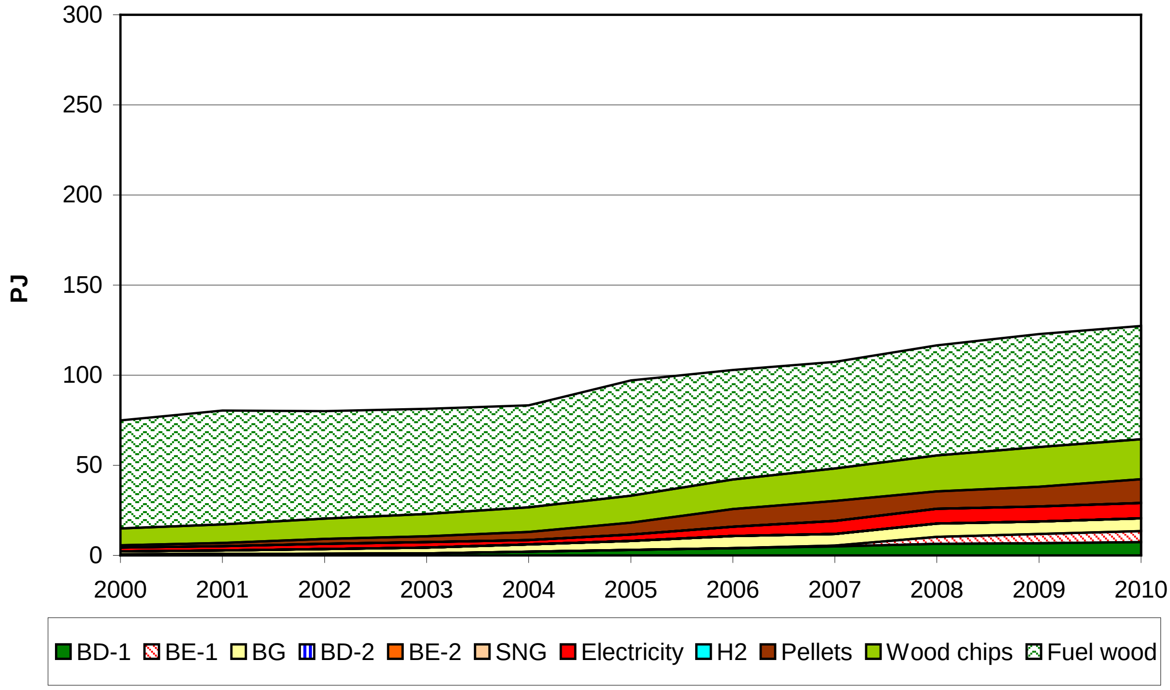

Figure 2-7 State-of-the-art of biomass-based alternative energy carriers in Austria 2000-2010 (Source: Statistic Austria, numbers for 2010 are preliminary) (Source: Statistic Austria and own investigations)

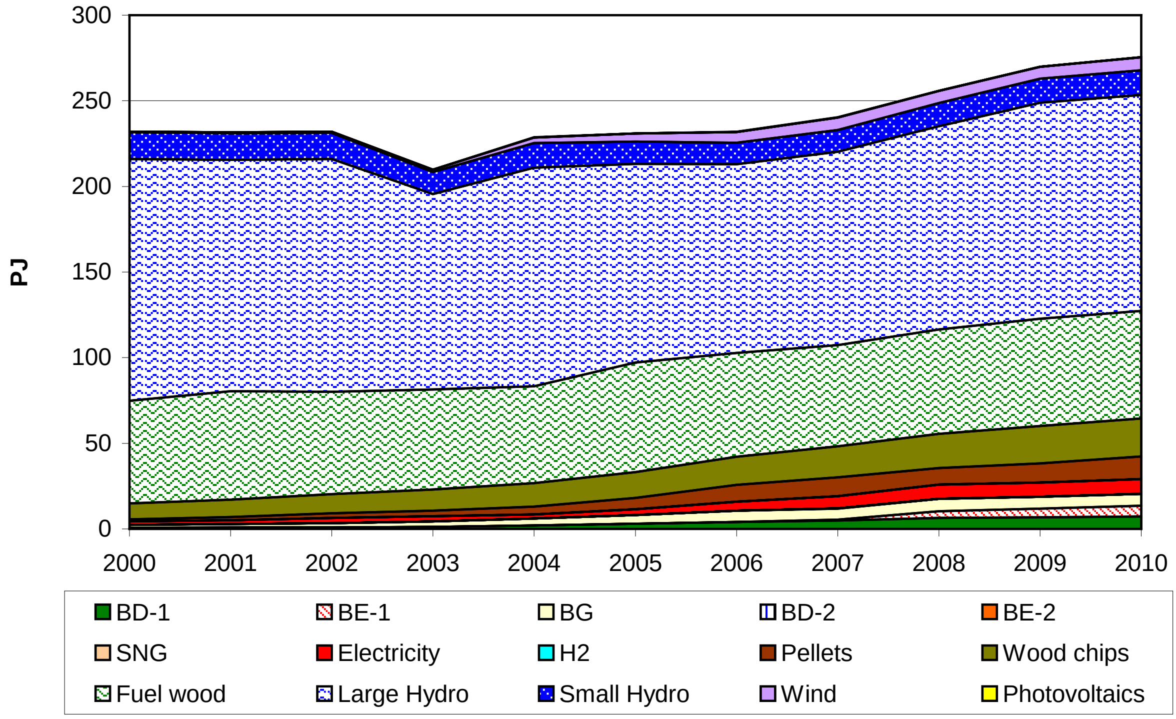

Figure 2-8 State-of-the-art of all alternative energy carriers in Austria 2000-2010 (Source: Statistic Austria and own investigations)

The state-of-the-art of all alternative energy carriers in Austria in period 2000-2010 is shown in Figure 2-8. In addition to the biomass-based AEC in this figure we can also recognize a slight increase of wind.

3. Method of approach

The method of approach applied in this study consists of the following major steps:

- Firstly, based on literature we have done a survey on AEC and then based on availability of feedstocks and resources in Austria we have extracted the most promising energy chains and AEC for a further detailed analysis;
- Next we have considered different technologies regarding technological learning which is expected to be of high relevance for future cost decreases of the analysed AEC. The major investigations regarding technological learning are summarized in Annex A;
- For all considered AEC dynamic ecological and energetic assessment is conducted based on LCA (Life Cycle Assessment) up to 2050 (for details see Section 3.1 and 3.2);
- For all considered AEC dynamic economic assessment is conducted based on technological learning up to 2050 (for details see Section 3.3);
- In order to be able to evaluate the long-term perspectives of AEC the following major influence parameters are considered in scenarios:
    - possible developments of the energy price level and the energy demand;
    - global developments (particularly regarding learning effects);
    - environment and energy policy in Austria and at EU level;
- Finally, based on our analysis in the scope of this project an Action Plan with the major recommendations for policy makers has been derived.

The major steps of our work are shown in Figure 3-1.

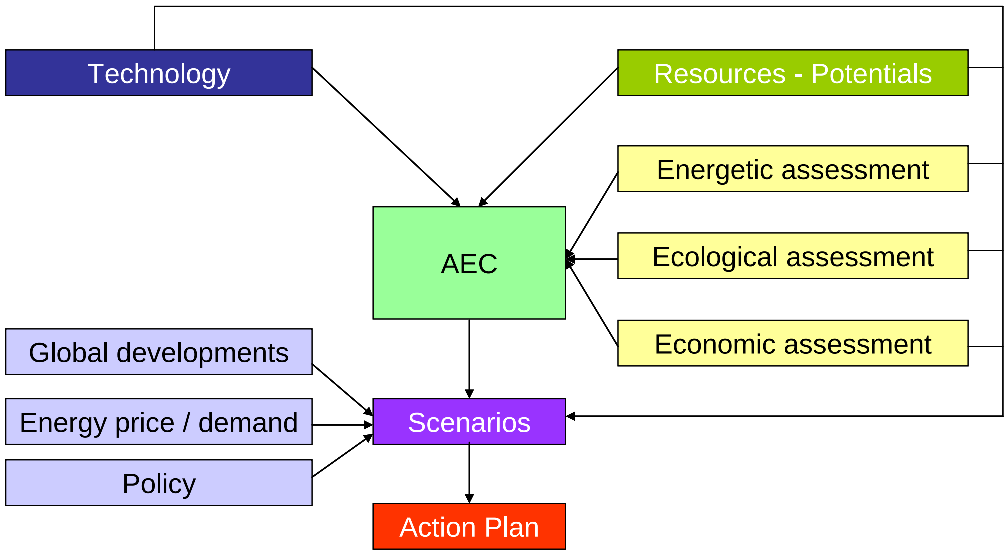

Figure 3-1 Method of approach

3.1 Ecological and energetic assessment

In this chapter we describe the method of approach of the ecological and energetic assessment.

However as described in Chapter 2 in several cases (e.g. for hydrogen) the assessment of the energy carriers alone does not provide sufficient information without looking at the service (e.g. transport service to be provided by a fuel cell vehicle). For this reason and because most of the AEC considered in this analysis are especially used for transport – mainly biofuels, hydrogen, but except electricity which can be universally used – in this chapter we present both: an ecological and energetic analysis of the AEC and for the example of transport the total chain including energy service provision.

The calculation of greenhouse gas (GHG) emissions and primary energy demand is based on the method of Life Cycle Assessment (LCA). According to EN ISO 14040:2006 "Environmental management - life cycle assessment - principles and framework" the environmental impacts are calculated along the supply chain of a product or service: from extraction of raw materials for its production through its use to its disposal (from cradle to grave). In LCA are included all relevant materials, energy inputs and emissions related to the environment and to the extraction of the primary resource, transportation of the resource to a conversion facility, conversion of the resource into a final energy carrier (AEC) that can be used, distribution of the final energy carrier and use of the energy carrier to provide an energy or transport service.

For the comparison of different systems by means of a LCA, the methodological steps described in the Chapters 3.1.1 to 3.1.5 are necessary to ensure that all systems provide the same product or service and that the comparison is valid.

3.1.1 System boundary definition

The system boundary outside which environmental impacts are ignored must include all life cycle stages, significant energy uses, material flows and GHG emissions. In addition, for a valid comparison, the system boundaries should be set so that the same energy and product services are provided by both the study and the reference systems (Bird, 2011). In addition to a cradle-to-grave analysis (Well-to-Wheel analysis for fuels) including the entire supply chain from primary energy to energy or transport service, the systems were also analysed cradle-to-gate (Well-to-Tank analysis for fuels) including the supply chain from primary energy to final energy (AEC), see Table 3-1and Figure 3-2.

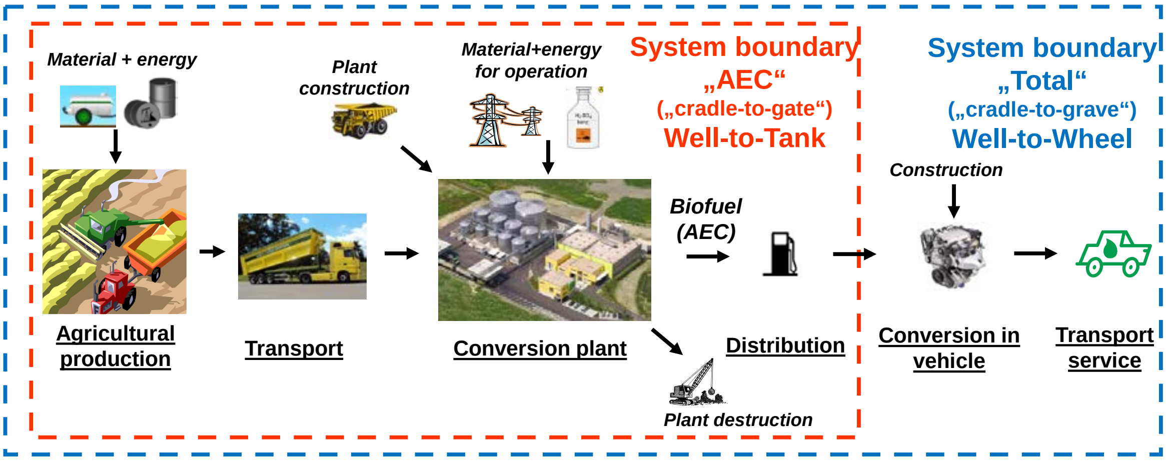

Figure 3-2 System boundary definition - example of a biofuel supply chain

The supply chains of those AEC which are considered most relevant for the Austrian situation are presented in Table 3-1. The results of the ecological assessment of these systems (AEC-systems) are presented in an overview in chapter 4 and in detail in Annex B.

Table 3-1 Selected AEC-systems relevant for Austria

System boundary "Total": Cradle-to-grave (Well-to-wheel)					
System boundary "AEC": Cradle-to-gate (Well-to-Tank)					
Primary energy	**Conversion**	**Final energy (AEC)**	**Conversion**	**Energy service**	
				Transport	Electricity
Rape	Pressing + Biodiesel plant	**Biodiesel**	ICE vehicle	X	
Wood from forestry	Gasification + FT-synthesis	**Biodiesel (FT-Diesel) + electricity**	ICE vehicle	X	X
Wheat	Bioethanol plant	**Bioethanol**	ICE vehicle	X	
Wood from forestry	Bioethanol plant	**Bioethanol + electricity**	ICE vehicle	X	X
Straw, corn stover	Bioethanol plant	**Bioethanol + electricity**	ICE vehicle	X	X
Corn silage	Biogas plant + gas treatment	**Biomethane**	ICE vehicle	X	
Wood from forestry	Gasification + methanisation	**SNG**	ICE vehicle	X	
Wood from forestry	CHP station	**Electricty**	Electric vehicle	X	X
Sun	PV-station	**Electricity**	Electric vehicle	X	X
Wind power	Wind power station	**Electricity**	Electric vehicle	X	X
Hydropower	Hydro power station	**Electricity**	Electric vehicle	X	X
Wood from forestry	Gasification + H2-separation	**Hydrogen**	Fuel cell vehicle	X	
Wood from short rotation crops	Gasification + H2-separation	**Hydrogen**	Fuel cell vehicle	X	
Corn silage	Biogas plant + gas treatment + reforming	**Hydrogen**	Fuel cell vehicle	X	
Sun	PV-station + electrolysis + compressor	**Hydrogen**	Fuel cell vehicle	X	
Wind power	Wind power station + electrolysis + compressor	**Hydrogen**	Fuel cell vehicle	X	
Hydro power	Hydro power station + electrolysis + compressor	**Hydrogen**	Fuel cell vehicle	X	

3.1.2 Choice of reference systems

The choice of reference systems to which the investigated energy systems are compared is critical since the benefits of renewable energy systems can differ widely depending on the assumed energy system replaced. Ideally the reference system should be the energy system most likely to be replaced. In bioenergy systems the particular aspects of land use change and co-products need to be considered with respect to reference systems (Figure 3-3). A change in land use to produce biomass for bioenergy can have an impact on the greenhouse gas emissions associated with bioenergy supply chains, in particular when this land has been used for agricultural production related to other purposes (e.g. animal feed production). Some bioenergy conversion facilities produce non-energy co-products (e.g. DDGS used as animal feed) that substitute products from conventional production. Emissions, energy and material input related to the substituted products as reference system are considered. If in biofuel production the co-product is heat or electricity, the reference system for conventional heat or electricity generation is based on the energy system most likely to be replaced.

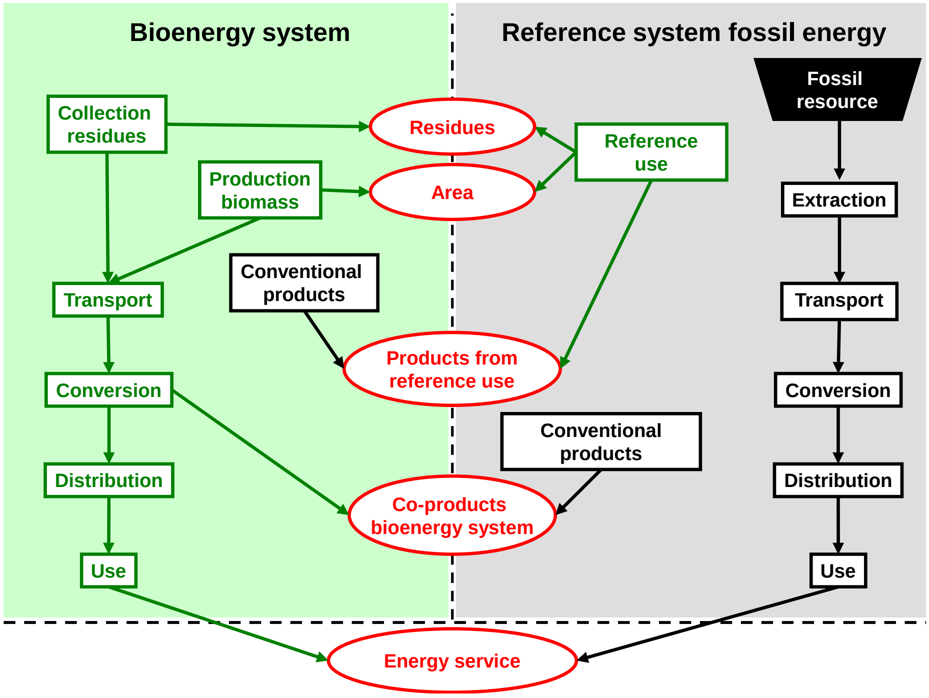

Figure 3-3 Scheme for ecological assessment of a bioenergy system compared to a reference system in a LCA

3.1.3 Definition of units for comparison – functional unit

Comparing two systems requires a metric for comparison. In LCA this is called functional unit to which input and output process data and environmental impacts are normalised. In this study the functional unit is output-related, based on the service provided by the different systems. As shown in Table 3-2 the functional unit is “1 kWh AEC” (fuel or electricity), in case of polygeneration (co-products fuel and electricity) the environmental impacts are related to the sum of the shares of fuel and electricity (sum of shares is 1). For cradle-to-grave analysis which includes the use of final energy to provide transport service, results have also been calculated related to the functional unit “1 km” in a passenger car. This unit is commonly used for Well-to-Wheel analysis and therefore supports the discussion of the results. Summary results are presented for both functional units in Chapter 4. The results related to 1 km consider the energy demand (kWh/km) and thus the efficiency of the different vehicle powertrains whereas results related to 1 kWh AEC do not include it.

Table 3-2 Functional units for LCA

System boundary „AEC“ Cradle-to-gate / Well-to-Tank	System boundary „Total“ Cradle-to-grave / Well-to-Wheel
Solid, liquid, gaseous fuels 1 kWh_{AEC} (z.B. kg CO_2-eq / kWh_{AEC})	Liquid, gaseous fuels 1 kWh_{AEC} (z.B. kg CO_2-eq / kWh_{AEC})
Electricity 1 kWh_{el} (z.B. kg CO_2-eq / kWh_{el})	Electricity 1 kWh_{el} (z.B. kg CO_2-eq / kWh_{el})
Polygeneration (fuel + electricity as co-products) $x*kWh_{AEC} + y*kWh_{el}$ (x+y=1) (z.B. kg CO_2-eq / ($x*kWh_{AEC} + y*kWh_{el}$))	Polygeneration (fuel + electricity as co-products) $x*kWh_{AEC} + y*kWh_{el}$ (x+y=1) (z.B. kg CO_2-eq / ($x*kWh_{AEC} + y*kWh_{el}$))
Functional unit for summary results in chapter 4: 1 passenger-car km	

The LCA was performed with the Global Emission Model of Integrated Systems (GEMIS) model, version 4.5 [GEMIS, 2009].

3.1.4 Greenhouse gas emissions

Carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) are considered in the LCA. These latter two gases are converted into the equivalent amounts of CO_2 (CO_2-eq.) using global warming potential (GWP) listed in Table 3-3.

Table 3-3 Global Warming Potentials

Gas	CO_2-equivalent
CO_2	1
CH_4	25
N_2O	298

CO_2-emissions from biomass used for energy service are balanced zero, according to IPCC [IPCC, 2006] guidelines. This is based on the assumption that the balance of net CO_2-fixation of biomass by photosynthesis and the CO_2-emissions during production and conversion of the fuel is zero. In LCA CO_2-fixation is considered as negative CO_2-emission during agricultural production. Carbon losses in fuel production processes (e.g. carbon in press cake from rapeseed pressing) are accounted as biogenic CO_2-emissions (Figure 3-4).

The calculation of WTT-net CO_2 emission balances described in detail in Figure 3-4 is based on the following equation:

$$WTT_{net} = WTT_{minus} + WTT_{plus} \tag{3.1}$$

WTT_{plus} .....CO_2 fixation due to biomass planting

WTT_{minus}... CO_2 emissions during fuel production

$$WTW = WTT_{net} + TTW \tag{3.2}$$

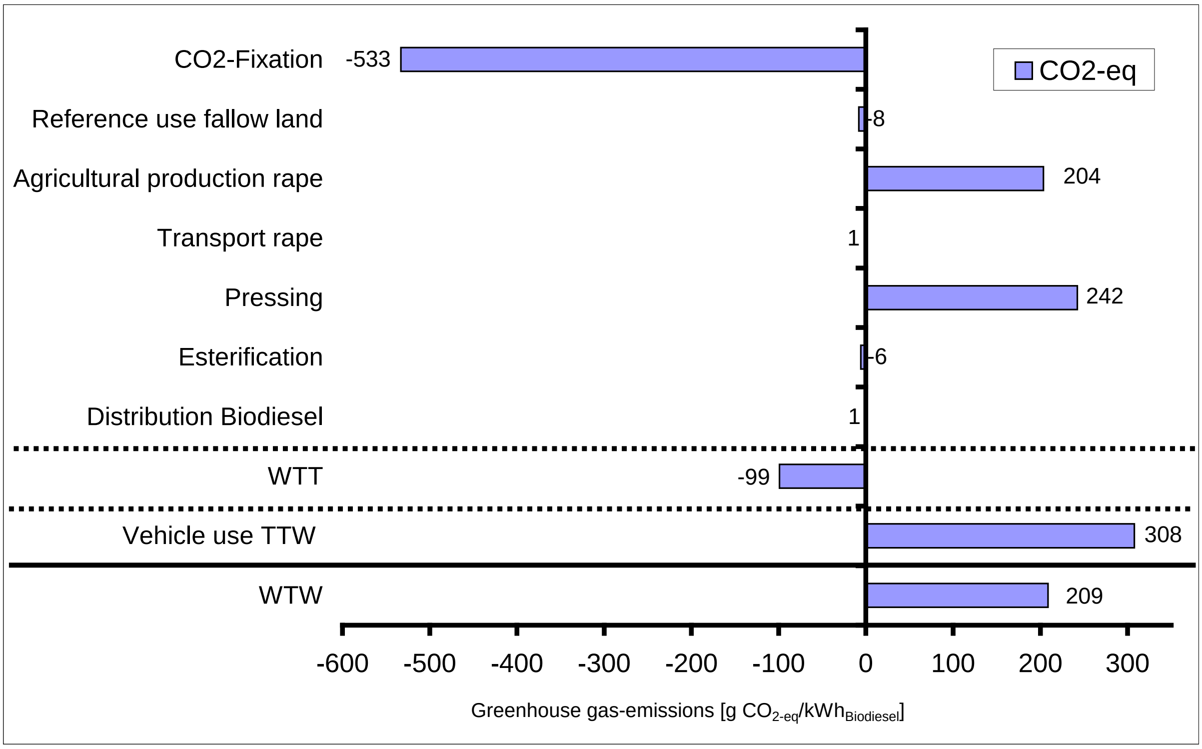

Figure 3-4 Balance of biogenic CO_2-emissions for biofuels (example biodiesel from rapeseed)

3.1.5 Cumulated primary energy demand

Primary energy demand includes all energy inputs which are needed to deliver an alternative energy carrier (AEC) or useful energy. The amount of primary energy demand is subject to feedstock and technologies used. In this analysis the primary energy demand is divided into:

- Fossil energy sources: coal, natural gas and crude oil
- Renewable energy sources: biomass, solar energy, water and wind
- Other energy sources: waste (e.g. waste combustion) and nuclear energy

Co-products as electricity and heat that substitute reference systems are considered by accounting the avoided cumulated primary energy demand of the substituted reference systems. In case non-energy co-products of the AEC-systems (e.g. fertilizer from biodiesel production) substitute reference systems the avoided primary energy demand is accounted zero since the co-product is not used energetically. In Figure 3-5 the contributions to the cumulated primary energy demand are shown on the example of biodiesel from rape.

The cumulated primary energy demand of an AEC is calculated as follows.

$$CED_{AEC} = \frac{input_{PE}}{\eta_{sys}} + \sum_{i=1}^{m} CED^{i}_{PE_{prod}} + \sum_{j=1}^{n} CED^{j}_{transp} + \sum_{k=1}^{o} CED^{k}_{Constr+Dism} + \sum_{k=1}^{o} CED^{k}_{Operat} \quad (3.3)$$

$$\eta_{sys} = \prod_{k=1}^{n} \eta^{k}_{process} \quad (3.4)$$

CED_{AEC}	Cumulated energy demand of AEC [kWh_{CED} / kWh_{AEC}]
$input_{PE}$	energy content (heating value) of the primary energy carrier (e.g. rape)
η_{sys}	system efficiency (energy out/energy in based on heating values) as product of k individual process efficiencies $\eta_{process}$
CED_{PEprod}	Cumulated primary energy demand related to I production processes of the primary energy carrier (machines, auxiliary energy and materials in agricultural production)
CED_{trans}	Cumulated primary energy demand related to j transport processes (machines, auxiliary energy and materials)
$CED_{Constr+Dism}$	Cumulated primary energy demand related to the construction and dismantling of k production facilities (energy and materials)
CED_{Operat}	Cumulated primary energy demand related to the operation of k production facilities (auxiliary energy and materials)

In general each individual contribution to the CED_{AEC} can be a sum of renewable, fossil and other energy sources. CED_{PEprod}, CED_{trans} and $CED_{Constr+Dism}$ commonly have a large share of fossil inputs, whereas CED_{Operat} can also have a large share of renewable input, e.g. process heat or electricity supplied by renewable sources.

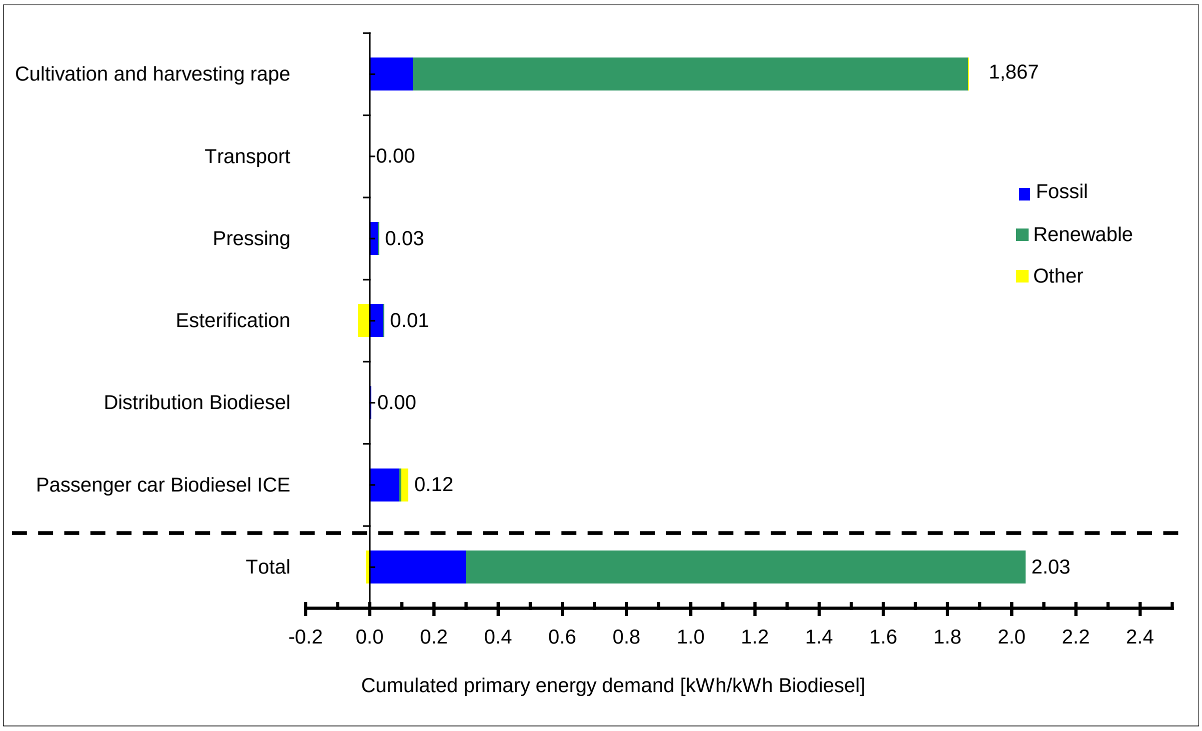

Figure 3-5 Contributions to cumulated primary energy demand (example biodiesel from rape)

3.2 Economic assessment

For all considered AEC dynamic economic assessment is conducted based on technological learning up to 2050. Detailed costs calculations are given below for biofuels and hydrogen as well as our considerations regarding technological learning and scaling effects.

3.2.1 Biofuels

Many factors, such as feedstock price, conversion costs, and different promotion policies, have an impact on biofuels costs. The largest part of the biofuels costs are feedstock costs and these are currently largely dependent on prices on agricultural markets. Feedstock costs are currently very volatile and they differ depending on the type of crop used, harvesting technologies, and agricultural subsidies for crops and regions.

Besides feedstock costs the scale of the conversion facility has a considerable impact on biofuels production costs. For all alternative fuels we have analysed two scales of the conversion facility, small and large scale, see Annex B.

We consider the following major cost components to calculate the costs of biofuels (see also Ajanovic et al, 2010):

- Net feedstock costs
- Gross conversion costs
- Distribution and retail costs
- Subsidies for biofuels

Firstly, the feedstock costs are identified for every year as the minimum production costs of all possible feedstocks considered for a specific area category (e.g. crop area) as:

$$C_{FS_t} = Min(C_{FS_{i\_t}}; i = 1...n) \qquad (3.5)$$

n… number of possible feedstocks.

Net feedstock costs C_{FS} are calculated for every year as:

$$C_{FS} = \frac{(P_{FS} * Q_{FS} * f_{TC} - R_{FS\_by-product})}{LHV}) \qquad \text{[EUR/kWh FS]} \qquad (3.6)$$

P_{FS}......................Feedstock market price [EUR/ton FS]

Q_{FS}……………….Feedstock quantity used per ton biofuels [ton FS/ton BF]

$R_{FS\_by-product}$……....Revenues for feedstock-by-product (e.g. rapeseed-cake) [EUR/ton BF]

f_{TC} ....Factor for considering transaction costs

LHV...................Lower heat value of feedstock [kWh FS/ ton FS]

The gross conversion costs C_{CONV} for converting feedstock into AEC are calculated as:

$$C_{CONV} = CC + C_{LABOUR} + C_{INP} + C_{OM} - R_{BF\_by-product} \quad \textit{[EUR/kWh AEC]} \qquad (3.7)$$

CC…………. Capital costs per year [EUR/year]

C_{LABOUR}………Labour costs

C_{INP} ………....Input costs (chemicals, energy, water…)

C_{OM}…………...Costs for maintenance and insurance

$R_{BF\_by\text{-}product}$….Revenues from biofuel production by-products (e.g. glycerine or DDGS)

Capital costs depend on specific investment costs IC and capital recovery factor (CRF). Specific investment costs are calculated as a sum of national (IC_{Nat}) and international (IC_{Int}) investments costs. It is assumed that 60% of the investment costs are same in all regions and 40% of investment costs are dependent on countries' or regions' specific circumstances.

Annual capital costs are calculated as:

$$CC = \frac{(IC_{Int} + IC_{Nat}) \cdot CRF}{P \cdot T} \quad \text{[EUR/kWh AEC]} \qquad (3.8)$$

IC…….Investment costs [€]

CRF…Capital recovery factor

P…….Capacity [kW]

T…….Full load hours [h/yr]

Finally total specific biofuel production costs (C_{BF}) for year t are calculated as follows:

$$C_{BF} = C_{FS} + C_{CONV} + C_{DR} - Sub_{BF} \quad \text{[EUR/kWh AEC]} \qquad (3.9)$$

C_{FS}……. Net feedstock costs

C_{CONV}….Gross conversion costs

C_{DR}……. Distribution and retail costs

Sub_{BF}…..Subsidies for biofuels

However, it has to be noted that taxation respectively tax exemption on (bio) fuels are not included in specific biofuel production costs.

Revenues from by-products (i.e. the sales value of rapeseed-cakes, electricity, glycerine, animal feeds etc.) produced in the chain of different biofuels processing ways play a minor role regarding the overall biofuels costs. However, the way in which by-products are used has a significant impact on total greenhouse gas emissions. The role of by-products could be even lower in the future due to oversupply. For example, currently demand for glycerine is limited for a number of food, beverage, personal care and oral products, as well as pharmaceutical and other industrial uses. With the increasing biodiesel production it will be necessary to create additional markets for the glycerine.

3.2.2 Hydrogen

Hydrogen, as a secondary energy carrier, could be produced using different primary energy sources: fossil energy, renewable energy or nuclear energy. In the scope of this project we have analysed hydrogen in competition with other AEC based on biomass. We have calculated potentials and costs of hydrogen produced from biomass.

Specific hydrogen production costs (C_{H2}) for year t are calculated as follows:

$$C_{H_2} = C_{INP} + CC + C_{OM}$$ [EUR//kWh H_2] (3.10)

C_{INP} …Input (energy, feedstock…) costs

CC….. Capital costs

C_{OM}…Operations and maintenance costs

However, to obtain total hydrogen costs distribution and retail costs as well as policies (subsidies, tax exemption) have to be included too.

It is assumed that fix operating costs are 4.5% of capital costs.

3.2.3 Considering technological learning and scaling effects

Future biofuel production costs or at least capital costs could be reduced through technological learning. Technological learning is illustrated for many technologies by so-called experience or learning curves. In this project the effects of technological learning play a major role for the dynamic of economics. An indepth analysis on technological learning is conducted and documented in Annex A.

In our model we split up specific investment costs $IC_t(x)$ into a part that reflect the costs of conventional mature technology components $IC_{Con\_t}(x)$ and a part for the new technology components $IC_{New\_t}(x)$.

$$IC_t(x) = IC_{Con\_t}(x) + IC_{New\_t}(x)$$ (3.11)

$IC_{Con\_t}(x)$…Specific investment cost of conventional mature technology components (€/kW)

For $IC_{Con\_t}(x)$ no more learning is expected. For $IC_{New\_t}(x)$ we have to consider a national and an international learning effect:

$$IC_{New\_t}(x) = IC_{New\_t}(x_{nat\_t}) + IC_{New\_t}(x_{\text{int}\_t})$$ (3.12)

$IC_{New\_t}(x_{nat\_t})$….Specific national part of $IC_{New\_t}(x)$ of new technology components (€/kW)

$IC_{New\_t}(x_{int\_t})$…..Specific international part of $IC_{New\_t}(x)$ of new technology components (€/kW)

For both components of $IC_{New\_t}(x)$ we use the following formula to express an experience curve by using an exponential regression:

$$IC_{New\_t}(x) = a \cdot x_t^{-b} \tag{3.13}$$

$IC_{New\_t}(x)$…Specific investment cost of new technology components (€/kW)
x_t …………Cumulative capacity up to year t (kW)
b …………Learning index
a …………Specific investment cost of the first unit (€/kW)

With respect to the development of the costs of biofuels the optimistic expectations prevailing about five years ago has been relatevated to some extent (e.g. as reported by Trechow (2009) neither the expected magnitude of investments in biorefinieries for BF-2 in Europe nor the promised technological progress took place since 2005).
Moreover, it is important to stress that currently only rough estimates for investment costs are possible. Reported investment costs of biorefineries in e.g. Toro et al (2010) vary strongly and are of course only available from pilot projects. From practical figures it is not always clear, whether they are influenced by subsidies and R&D money and to what extent.
In a very optimistic scenario BF-2 could become slightly cheaper than BF-1 and could become competitive with conventional fuels sometimes between 2020 and 2025. This would also encompass a scaling effect in addition to technological learning, see Figure 3-7. BE-2 could become earlier competitive than BD-2 mainly because cheaper straw is used as feedstock. Figure 3-6 documents the possible range of scenarios for the development of biofuels costs up to 2050 in a stylised way.
However today it is not possible to conduct a serious prediction about the realistic cost differences and cost levels in 2050. From today's point-of-view it can only be stated that the costs of biofuels 2nd generation will be in a favourable case close to the costs of biofuels 1st generation; in a less favourable one they will remain significantly higher, see Figure 3-6. This also coincides with other analyses, e.g. [Faaij, 2006].

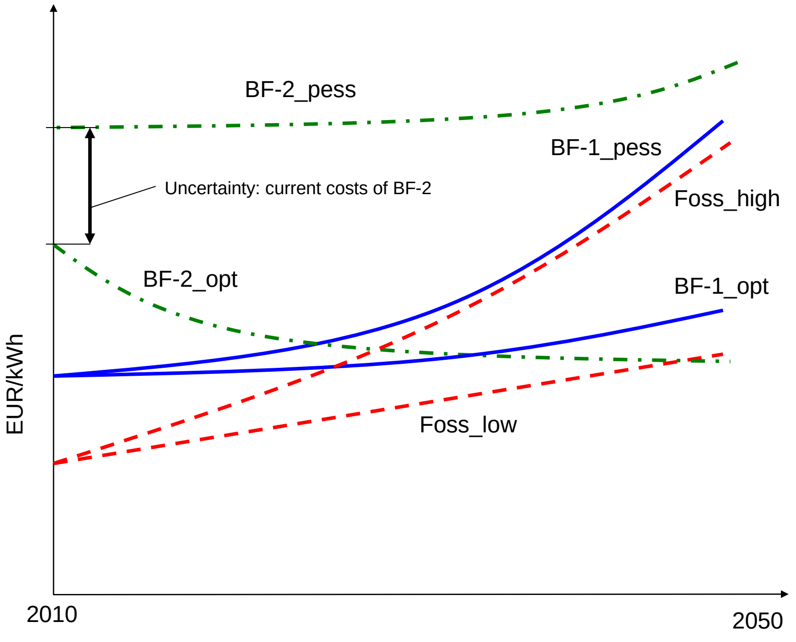

Figure 3-6 Possible range of scenarios for the development of fossil and 1st and 2nd gen. biofuels costs up to 2050

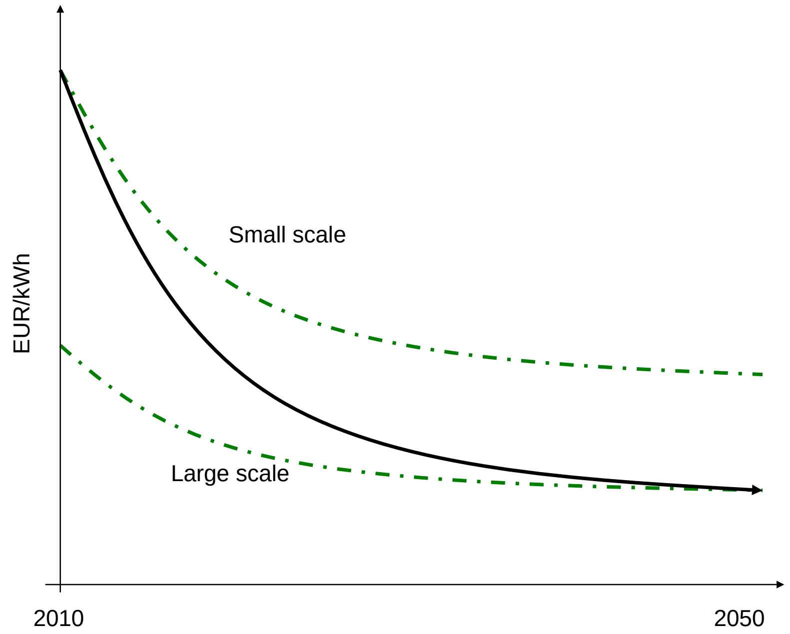

Figure 3-7 Possible range for the development of the capital costs of BF-2 due to scaling effects up to 2050

To estimate possible future cost developments in Austria we have considered relevant international scenarios such as scenarios done by International Energy Agency (IEA), see Figure 3-8.

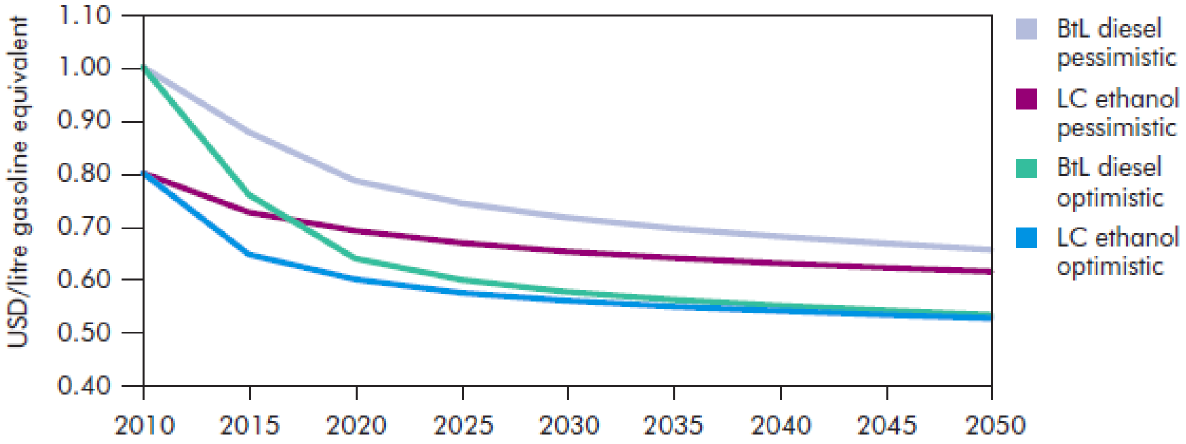

Figure 3-8 Second generation biofuels production cost assumptions to 2050 due to the IEA Energy Technology Perspectives (IEA, 2008) (BtL= Biomass to liquid; LC=lingo-cellulose)

4. Results of the ecological and the energetic assessment

In this chapter we document the results of the LCA for the greenhouse gas (GHG) emissions and primary energy demand of the selected AEC-systems, see Table 3-1. We show the outcomes for the final energy (functional unit “1 kWh AEC”) as well as for the energy service mobility (functional unit “1 km” in a passenger car). The discussion is mainly based on the results related to the functional unit “1 km” as it is commonly used in WTW-analysis. More detailed assessments are presented in Annex B and are related to the functional unit “1 kWh AEC”.

In the following we show the results of the Well-to-Tank (WTT), Tank-to-Wheel (TTW) and Well-to-Wheel (WTW) analysis for the different powertrains and vehicles these AEC are used. These are: vehicles with: liquid and gaseous biofuels used in internal combustion powertrains, electricity used in battery electric powertrains and hydrogen used in fuel cell electric powertrains

Fuel consumption of the different vehicles (comparable mid class vehicle combined with different powertrains) is summarized in Table 4-1. The LCA figures are documented for the years 2010 and 2050. Table 4-2 depicts the electricity mix assumed for Austria.

Table 4-1 Fuel consumption of the different vehicles in WTW-analysis

	2010	**2050**
Passenger car mid-class	[kWh/km]	
Gasoline-ICE	0.66	0.53
Diesel-ICE	0.59	0.51
Methane-ICE	0.71	0.58
Electric vehicle (EV)	0.22	0.19
Fuel cell EV (FCEV)	0.29	0.22

Table 4-2 Electricity mix assumed for 2010 and 2050 in Austria

Electricity mix Austria	**2010**	**2050**
Hydropower	53%	55%
Windpower	3%	5%
Biomass	2%	10%
CNG	22%	20%
Oil	1%	1%
Coal	14%	5%
Nuclear	5%	4%
Total	100%	100%

4.1 Greenhouse gas emissions

Table 4-3 to Table 4-5 and Figure 4-1 to Figure 4-4 show the GHG emissions in the life cycle related to the use of different AEC-systems compared to fossil reference systems. All AEC-systems reduce WTW - GHG emissions compared to fossil reference systems. There are considerable differences between the AEC-systems. The results are presented for three AEC-groups biofuels, electricity and hydrogen.

The AEC-systems based on biomass have mostly negative WTT-GHG emissions (Table 4-3, Figure 4-1), due to the uptake of CO_2 during photosynthesis accounted as negative CO_2-emissions (called CO_2-fixation, see chapter 3.1.4). Negative WTT-GHG emissions are also related to non-energy co-products of the AEC-system which substitute conventional products and thus avoid related GHG emissions. Another contribution to WTT-GHG emissions are processes providing auxiliary energy and materials in the biofuel production facilities. Relatively high WTT-GHG emissions for bioethanol production from wheat are mainly due to the electricity and process heat required in the ethanol plant and its distillation unit. It is assumed that in 2010 process heat is provided by CNG and electricity by the Austrian production mix (Table 4-2). As an example Figure 4-2 shows the contributions to GHG emissions of the processes included to provide the transport service with Bioethanol produced from wheat.

TTW-GHG emissions include the emissions for production, operation and disposal of the passenger cars with ICE which are about 10 to 15% lower for methane-vehicles compared to diesel-, gasoline- and ethanol-vehicles due to lower specific GHG emissions of methane.

AEC-systems based on wood (FT-Diesel, SNG) have the lowest WTW-GHG emissions compared to the other biofuel systems shown in Figure 4-1. These systems require relatively low energy and material input for collection of the wood as well as for the biofuel production plants and its gasification units.

WTW-GHG emissions for 2050 are lower than for 2010 for all AEC-systems. Biomass and biofuel production processes as well as the passenger cars are assumed to be more efficient by 2050. Electricity and process heat as input to the biofuel production processes have a higher share of renewable energy in 2050 (e.g. Bioethanol from wheat and Table 4-2). In AEC-systems with non-energy co-products substituting conventional products it is assumed that the avoided GHG emissions will be lower in 2050 due to more efficient conventional production processes. In AEC-systems with electricity as co-product the share of electricity will be lower in 2050 due to an increased biofuel-orientated production process (e.g. FT-Diesel from wood). The electricity-mix substituted by the co-product electricity has a higher share of renewable energy in 2050 (Table 4-2), therefore avoided GHG emissions will be lower in 2050.

Table 4-3 Life cycle GHG emissions per kWh biofuel compared to fossil fuels

AEC	Year	WTT	TTW	WTW
		[g CO2-eq/kWh]		
SNG Wood (forest)	2010	-176	231	55
	2050	-181	246	65
FT-Diesel Wood (forest)	2010	-240	314	74
	2050	-250	330	80
Bio-methan Corn (silage)	2010	-101	231	130
	2050	-114	247	132
Bio-ethanol Straw	2010	-122	289	167
	2050	-134	306	172
Bio-diesel Rape	2010	-127	314	187
	2050	-151	330	179
Bio-ethanol Wheat	2010	30	289	319
	2050	-57	306	249
CNG	2010	67	231	298
	2050	65	247	312
Gasoline	2010	61	299	360
	2050	53	316	369
Diesel	2010	28	305	333
	2050	26	321	347

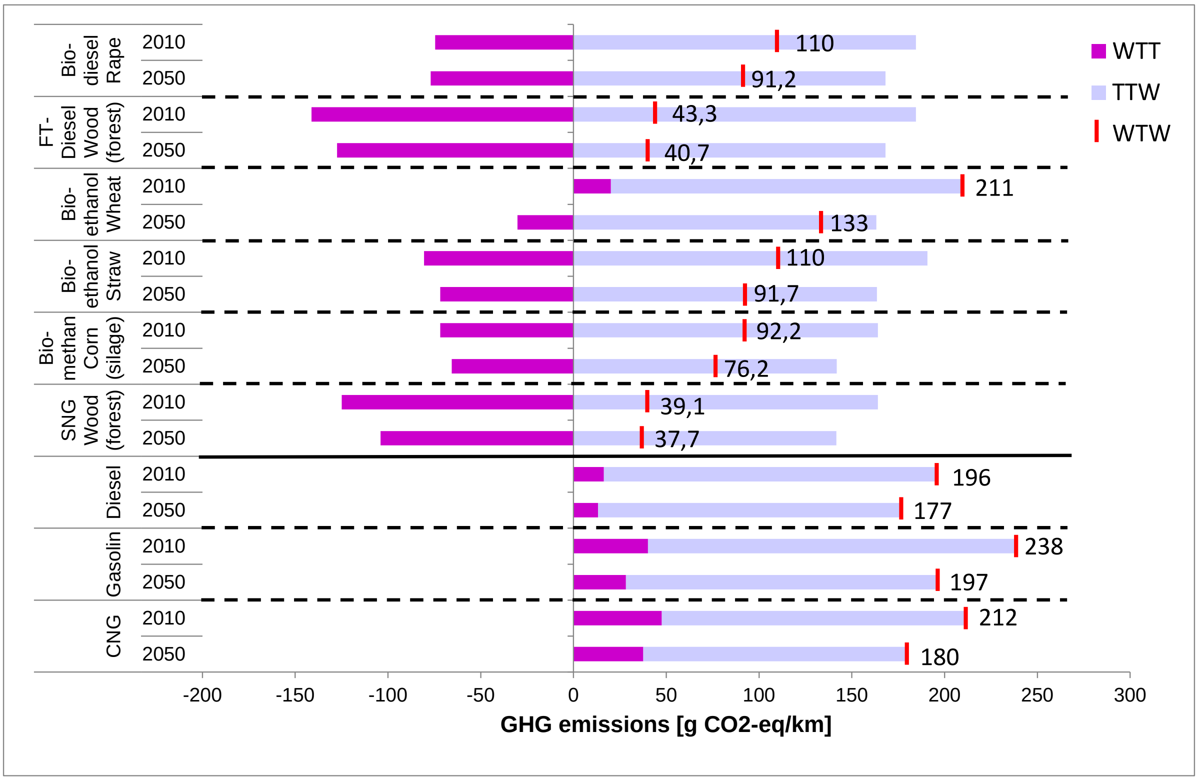

Figure 4-1 WTW - GHG emissions of transport service with biofuels compared to fossil fuels

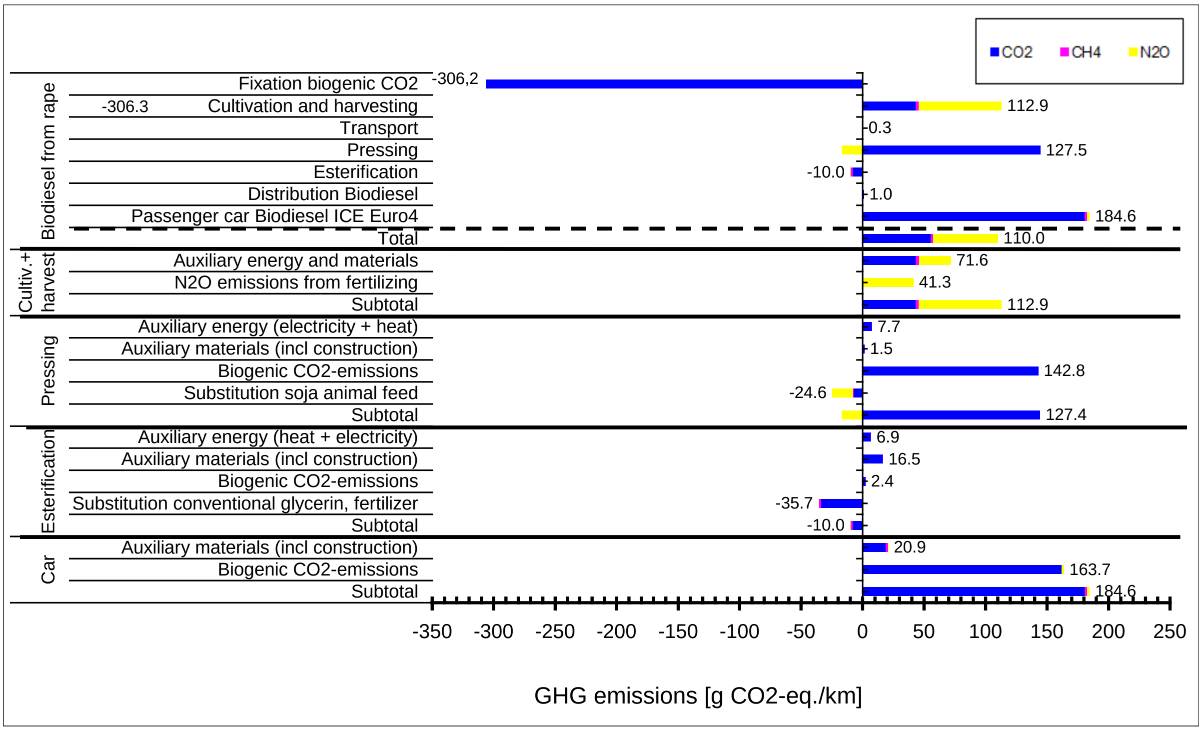

Figure 4-2 WTW - GHG emissions of transport service with bioethanol from wheat

Table 4-4 and Figure 4-3 show the GHG emissions of the AEC-systems supplying electricity. WTT-GHG emissions are similar for electricity from hydro- and windpower. Electricity from PV has higher WTT-GHG emissions due to the energy intensive production process of the PV-modules as well as to the low sunshine hours assumed for Austrian conditions (1.600 h/a). WTT-GHG emissions for electricity from biomass-CHP are negative as it is assumed that the co-product heat substitutes heat produced in conventional biomass heating plant, avoiding related life cycle GHG emissions. TTW-GHG emissions include the emissions for production, operation and disposal of the battery electric vehicle (BEV) and are the same for all systems in Figure 4-3.

Table 4-4 Life cycle GHG emissions per kWh renewable electricity compared to electricity from CNG

AEC	Year	WTT	TTW	WTW
		[g CO2-eq/kWh]		
Hydropower	2010	20	133	154
	2050	12	145	157
Windpower	2010	19	133	152
	2050	6	145	151
PV	2010	84	133	217
	2050	53	145	198
Wood (forest) CHP	2010	-25	133	108
	2050	-24	145	120
CNG CHP	2010	512	133	645
	2050	462	145	607

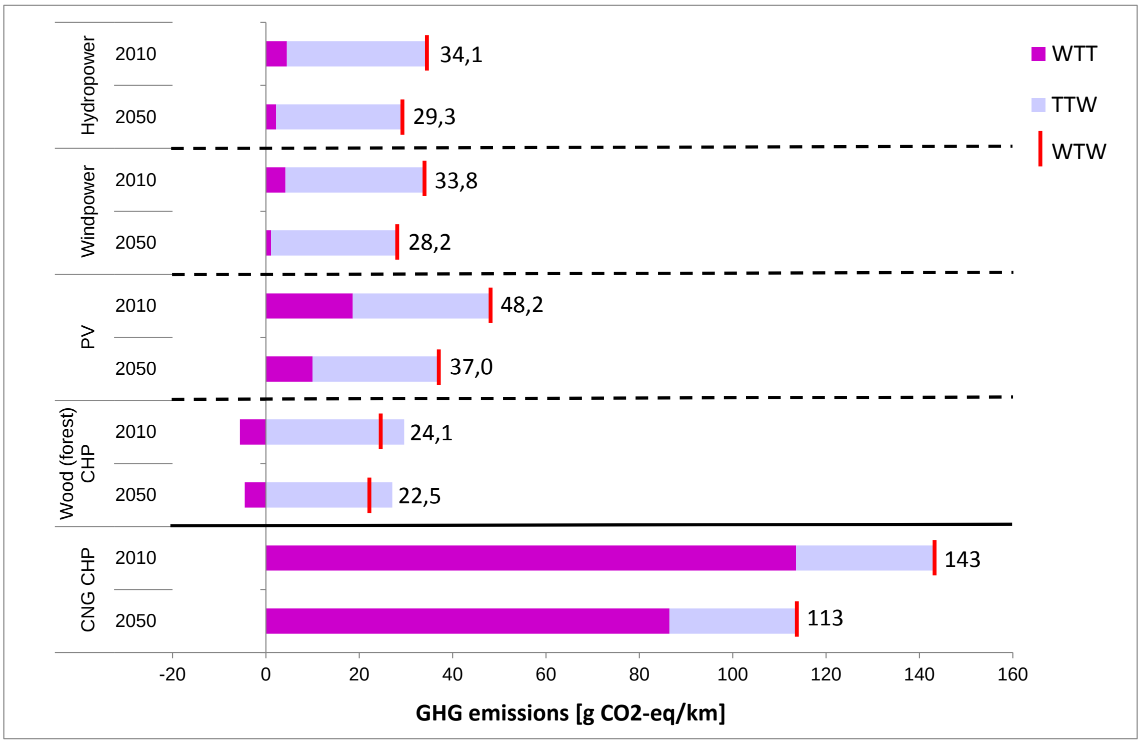

Figure 4-3 WTW - GHG emissions of transport service with renewable electricity compared to electricity from CNG

Table 4-5 and Figure 4-4 show the GHG emissions of the AEC-systems supplying hydrogen for transport service. WTT-GHG emissions include the hydrogen production processes as electrolysis or biomass gasification with hydrogen separation and hydrogen compressing for vehicle fuelling. TTW-GHG emissions include the emissions for production, operation and disposal of the fuel cell electric vehicle (FCEV) and are the same for all systems in Figure 4-4. The AEC-systems with hydrogen production by electrolysis with electricity from hydro- and windpower and by wood gasification have the lowest WTW-GHG emissions. If hydrogen is produced by CNG reforming, carbon capture storage (CCS) can reduce WTW-GHG emissions by about 50 %.

Table 4-5 Life cycle GHG emissions per kWh renewable hydrogen compared to hydrogen from CNG

AEC	Year	WTT	TTW	WTW
		[g CO2-eq/kWh]		
Hydropower + Electrolysis	2010	32	104	136
	2050	17	138	156
Windpower + Electrolysis	2010	30	104	134
	2050	9	138	147
PV + Electrolysis	2010	133	104	237
	2050	78	138	216
Wood (forest) gasification	2010	52	104	155
	2050	36	138	174
CNG reforming (no CCS)	2010	369	104	472
	2050	341	138	479
CNG reforming (with CCS)	2010	102	104	206
	2050	93	138	232

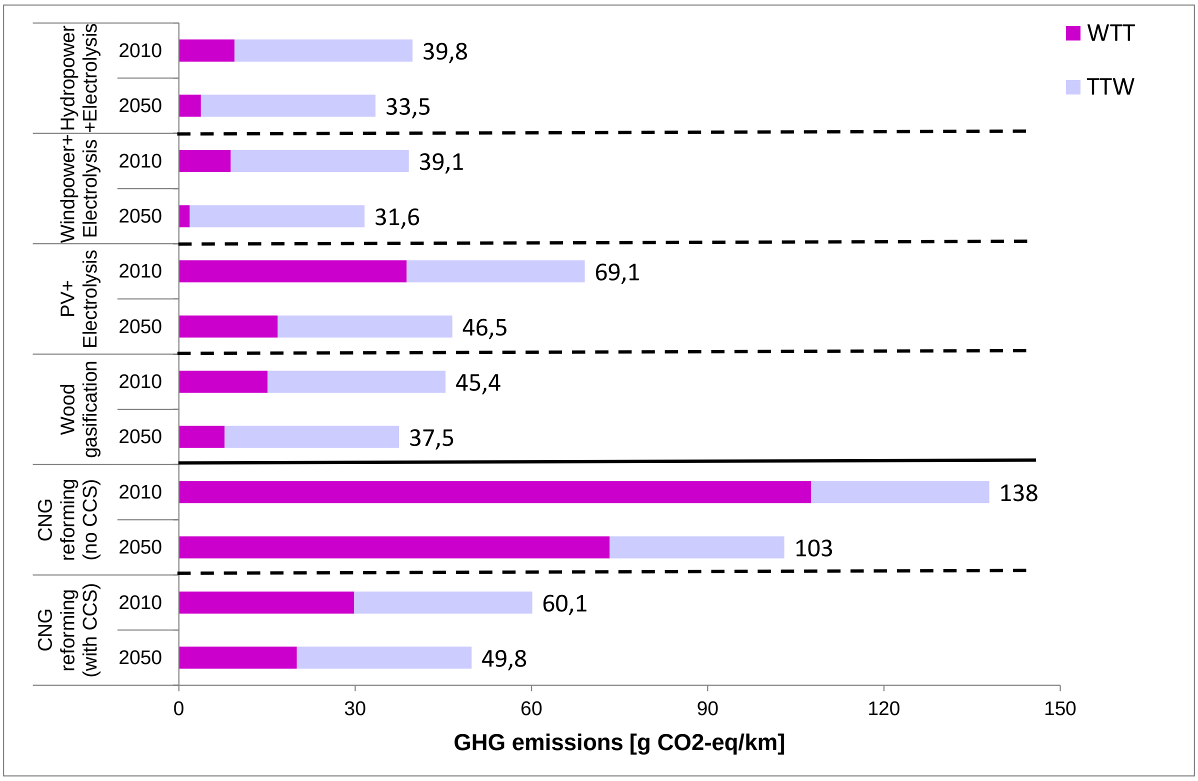

Figure 4-4 WTW - GHG emissions of transport service with renewable hydrogen compared to hydrogen from CNG

Table 4-6 presents the WTW GHG emissions of all AEC-systems investigated and compares the results of AEC supply chains based on different primary energy carriers (biomass feedstock and residues, other renewable sources). Biodiesel from sunflower could lower the WTW GHG emissions by about 50 % compared to rapeseed. However rapeseed is better suited for Austrian climate conditions. Bioethanol from corn or sugar beet can lower the emissions compared to wheat by 15 to 35 %, due to the energy intensive production process Bioethanol from agricultural crops is associated with the highest WTW GHG emissions in this comparison. The production of FT-Diesel, SNG and hydrogen by gasification of straw or corn stover has slightly higher WTW GHG emissions compared to the use of forest wood or industry wood residues. Straw removed from agricultural areas has to be replaced by fertilizer contributing to higher emissions. Wood from short rotation crops contributes to the highest and wood from industry residues to the lowest WTW GHG emissions of woody biomass supplied AEC systems.

Table 4-6 WTW GHG emissions of all AEC-systems investigated

WTW GHG-emissions 2010 [g CO2-eq / km]	Biodiesel	Bioethanol	Biomethan	FT-Diesel	SNG	Electricity	Hydrogen
Feedstock							
Rapeseed	110						
Sunflower	47						
Wheat		211					
Corn maize		188					
Sugar-beet		134					
Green maize			92				80
Short rotation crops (wood)				72	59	54	60
Grass			111				
Residue							
Straw, corn stover		110		67	56	37	58
Forest wood residues				43	41	24	51
Wood industry residues				28	34	20	45
Liquid manure			-126				
Waste fett	60		11				
Renewable sources (non biomass)							
Windpower						34	39
Hydropower						34	40
Photovoltaik						48	69

4.2 Cumulated primary energy demand

Table 4-7 to Table 4-9 and Figure 4-1 to Figure 4-4 show the Cumulated primary energy demand in the life cycle related to the use of different AEC-systems compared to fossil reference systems. All AEC-systems reduce the cumulated fossil primary energy demand compared to the fossil reference systems. However among the AEC-systems there are considerable differences for the cumulated primary energy demand, including renewable and other primary energy carriers. The results are discussed for the three AEC-groups biofuels, electricity and hydrogen.

Among the AEC-systems those based on biomass (Table 4-7, Figure 4-5) have the highest cumulated primary energy demand. Fossil energy carriers are supplied by the ecosphere and require energy for their large-scale extraction, transport and some processing in refineries, while no conversion processes are required. Biofuel production based on agricultural or forest biomass requires energy for its production and conversion processes associated with process efficiencies and thus energy losses (see Table 4-7). The AEC-systems are based on different renewable primary energy sources (referring to "renewable (biomass)" in Figure 4-5) like agricultural crops or wood and on different conversion technologies as thermochemical or biochemical processes. Therefore the results in Figure 4-5 cannot be compared directly in terms of energy efficiency.

Bio-methane from corn has a high WTW cumulated primary energy demand. The energetic system efficiency as the ratio between energy in the methane per energy input of corn (heating value) was about 33% in 2010 (39% in 2050). 67% (61%) of the primary energy content in the corn remains in the substrate which is commonly used as fertilizer in agricultural production systems. In addition, biogas production requires input of heat which is assumed to be produced in biogas heating plant, resulting in the “renewable (other)” share of the cumulated primary energy demand in Figure 4-5. Bioethanol from wheat in 2010 has a relatively high WTW fossil cumulated primary energy demand. As already shown for WTW-GHG emissions its production requires a high share of electricity (Austrian electricity mix assumed) and heat (supplied by CNG in 2010).

WTW-cumulated primary energy demand for 2050 is lower than for 2010 for all AEC-systems, see Table 4-7.

Table 4-7 WTW Cumulated primary energy demand per kWh biofuel compared to fossil fuels

		WTW			
AEC	Year	Fossil	Renewable	Other	Total
		WTW [kWh/kWh]			
SNG Wood (forest)	2010	0.2	1.5	0.0	1.7
	2050	0.2	1.4	0.0	1.6
FT-Diesel Wood (forest)	2010	0.2	3.1	0.0	3.3
	2050	0.2	1.8	0.0	2.1
Bio-methan Corn (silage)	2010	0.3	4.2	0.0	4.5
	2050	0.3	3.7	0.0	4.0
Bio-ethanol Straw	2010	0.3	2.4	0.0	2.7
	2050	0.3	2.2	0.0	2.5
Bio-diesel Rape	2010	0.3	1.7	0.0	2.0
	2050	0.3	1.7	0.0	2.0
Bio-ethanol Wheat	2010	0.8	1.7	0.0	2.6
	2050	0.5	1.7	0.0	2.3
CNG	2010	1.2	0.0	0.0	1.2
	2050	1.2	0.0	0.0	1.3
Gasoline	2010	1.3	0.0	0.02	1.3
	2050	1.3	0.0	0.03	1.4
Diesel	2010	1.3	0.0	0.0	1.3
	2050	1.3	0.0	0.0	1.4

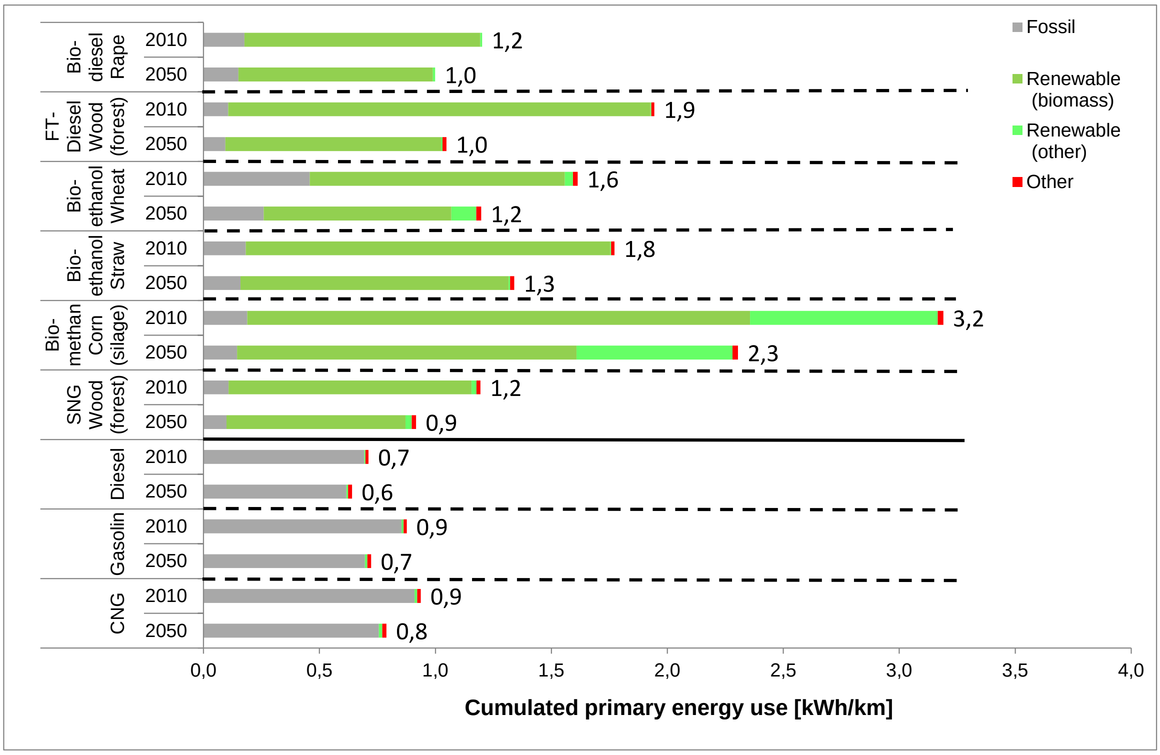

Figure 4-5 Cumulated primary energy demand of transport service with biofuels

All AEC-systems providing electricity for transport service have a lower fossil as well as a lower cumulated primary energy demand compared to the fossil reference system (Table 4-8, Figure 4-6). For hydropower-, windpower- and PV-stations the conversion efficiency is accounted with 100% since the energy potential of water, wind and sunlight is provided for free by the ecosystem. The WTW cumulated primary energy demand for electricity from wood includes avoided emissions from substituted reference biomass heating station.

Table 4-8 WTW Cumulated primary energy demand per kWh renewable electricity compared to electricity from CNG

AEC	Year	Fossil	Renewable	Other	Total
		[kWh/kWh]			
Hydropower	2010	0,4	1,1	0,09	1,5
	2050	0,4	1,1	0,09	1,5
Windpower	2010	0,4	1,1	0,10	1,6
	2050	0,4	1,1	0,10	1,5
PV	2010	0,6	1,1	0,16	1,8
	2050	0,6	1,1	0,11	1,8
Wood (forest) CHP	2010	0,2	1,0	0,02	1,3
	2050	0,3	0,7	0,03	1,0
CNG CHP	2010	2,4	0,0	0,0	2,4
	2050	2,3	0,0	0,1	2,4

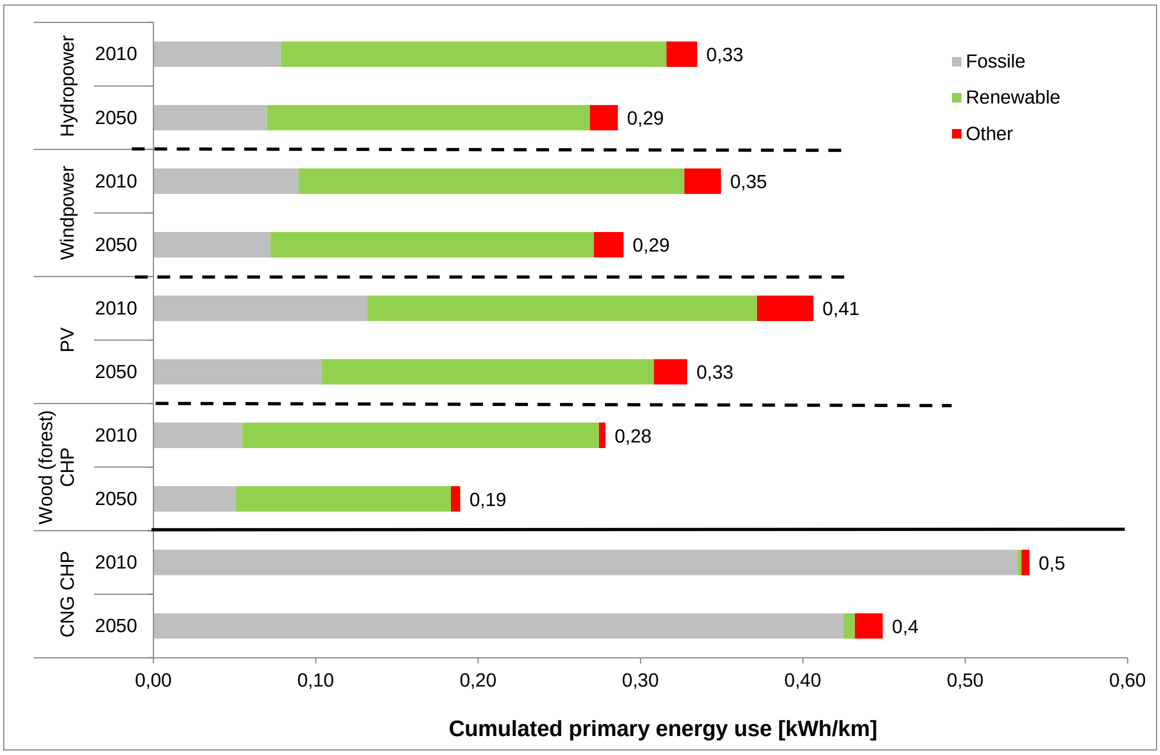

Figure 4-6 WTW Cumulated primary energy demand of transport service with electricity

All AEC-systems providing hydrogen for transport service have a lower fossil as well as a lower cumulated primary energy demand compared to the fossil reference system (Table 4-9, Figure 4-7).

Table 4-9 WTW Cumulated primary energy demand per kWh renewable hydrogen compared to hydrogen from CNG

AEC	Year	Fossil	Renewable	Other	Total
		[kWh/kWh]			
Hydropower + Electrolysis	2010	0,2	1,7	0,05	1,9
	2050	0,3	1,5	0,07	1,9
Windpower + Electrolysis	2010	0,3	1,7	0,07	2,0
	2050	0,3	1,5	0,08	1,9
PV + Electrolysis	2010	0,6	1,7	0,16	2,4
	2050	0,6	1,6	0,10	2,3
Wood (forest) gasification	2010	0,4	2,2	0,15	2,7
	2050	0,4	1,7	0,12	2,2
CNG reforming (no CCS)	2010	1,9	0,0	0,05	1,9
	2050	1,9	0,0	0,07	2,0
CNG reforming (with CCS)	2010	2,0	0,0	0,05	2,1
	2050	2,0	0,0	0,07	2,1

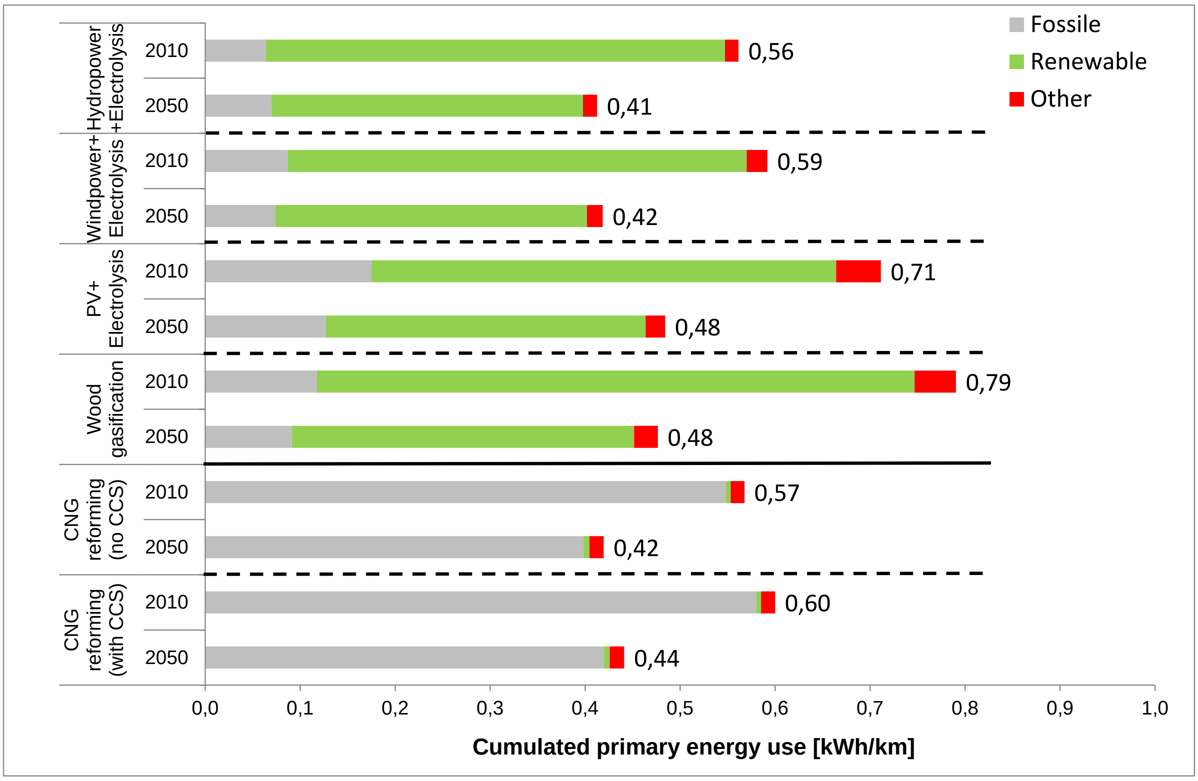

Figure 4-7 WTW Cumulated primary energy demand of transport service with hydrogen

Table 4-10 presents the WTW GHG emissions of all investigated AEC-systems and compares the results of AEC supply chains based on different primary energy carriers (biomass feedstock and residues, other renewable sources).

Table 4-10 WTW Cumulated primary energy demand of all AEC-systems investigated

WTW Cumulated primary energy demand [kWh / km]	Biodiesel	Bioethanol	Biomethan	FT-Diesel	SNG	Electricity	Hydrogen
Feedstock							
Rapeseed	1.2						
Sunflower	1.1						
Wheat		1.7					
Corn maize		1.7					
Sugar-beet		1.7					
Green maize			3.2				1.9
Grass			2.0				
Short rotation crops (wood)				2.0	1.2	0.9	0.9
Residue							
Straw, con stover		1.8		2.1	1.3	0.3	0.8
Forest wood residues				2.0	1.3	0.3	0.9
Wood industry residues				2.1	1.3	0.3	0.8
Liquid manure			1.3				
Waste fat	1.2		0.9				
Renewable sources (non biomass)							
Windpower						0.3	0.6
Hydropower						0.3	0.6
Photovoltaik						0.4	0.7

5. Assumptions for future scenarios of alternative energy carriers in Austria

In this chapter we document the major assumptions for the future scenarios of alternative energy carriers derived in Chapter 8. These assumptions encompass available resources, price developments and prospects for technological learning. With respect to the derivation of potentials for the production of AEC we split the types of resources in area-dependent (such as cereals, oil seeds, grass, short rotation coppice (SRC), forest wood residues) and area-independent ones (like waste fat, organic waste, wood industry residues, waste wood). The later are mainly based on residues and waste.

In the following, we firstly describe the maximum of land areas available for AEC in Austria up to 2050. Next, we document the availability of non-area dependent resources (mainly waste and side-products). Then the assumptions used for future developments of prices for fossil fuels, feedstocks and wood products are depicted. Finally, we document the data used for calculating the learning effects used for estimating future investment costs of the analysed AEC taking into account international and national learning.

Remark: In all following analyses no imports of biofuels or feedstocks are considered. We are focussing only on resources available in Austria.

5.1 Maximal area-based resources to be used in Austria

The major assumptions regarding the use of land areas and derived resources used for the scenario analysis are:

- Regarding the future land use we have assumed that maximal 30% of arable land in 2010, 10% of pasture land, 10% of meadows and 3% of wood and forest wood residues could be used for feedstock production for biofuels by 2050.
- Regarding non-area dependent resources: Additional 5% of wood industry residues could be used for biofuels production.

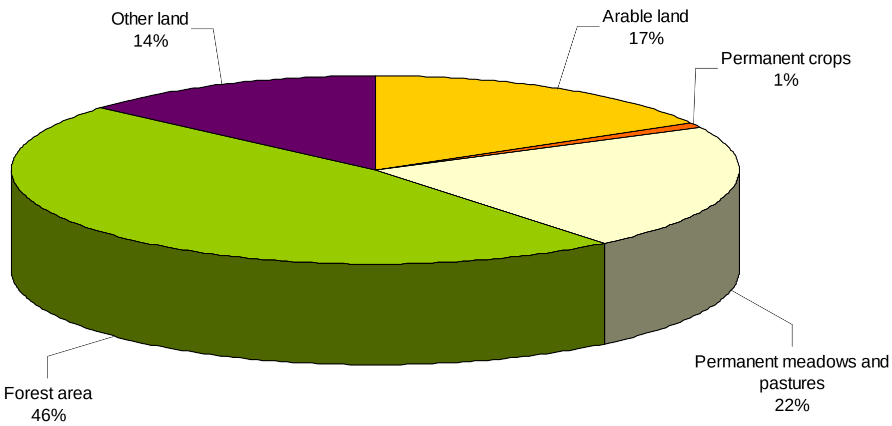

Figure 5-1 Land area in Austria 2010

The total land area in Austria is 8.2 Mill. hectares. This total land area can be divided in five groups: arable land (17%), permanent crop (1%), permanent meadows and pastures (22%), forest area (46%) and other land (14%), see Figure 5-3.

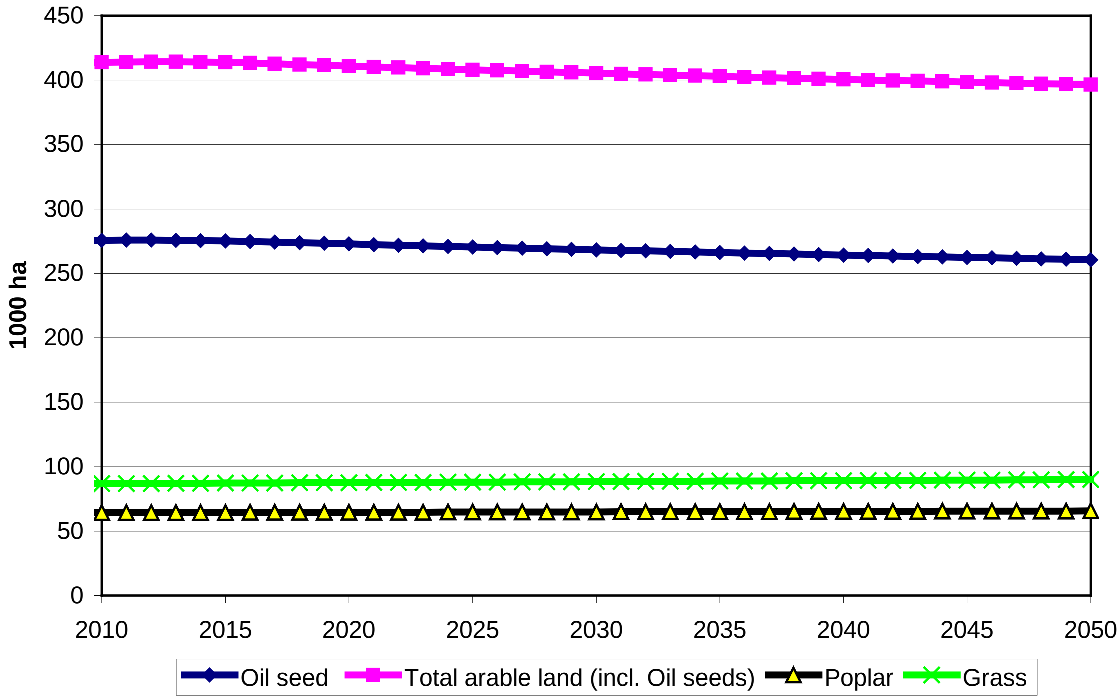

Figure 5-2 Maximum land areas for biofuels in Austria up to 2050

Figure 5-2 depicts the development of maximum land areas for biofuels in Austria up to 2050. It can be seen that because of arable land is decreasing in general also the land area for crops and oil seeds slightly decreases.

The conventional biofuels are based on the feedstocks grown on arable land, which is very limited in Austria, 1.4 Mill. hectares. However, with the second generation of biofuels, other land areas such as meadows, pastures and forest area could also be used for biofuels production, so that total land potential for alternative energy carriers could be significantly higher. In this work the share of arable land used for any type of biofuel is at the utmost assumed to be 30% in 2010 and 2050.

Figure 5-3 provides a comparison of total areas and the currently used areas for biomass-based AEC in 2010.

Remark: The forest area equivalent describes how many hectares of forest area are required to produce equivalently the same amount of forest wood used for alternative energy carriers as the total production of wood on one hectare.

Example: On an area of 1000 hectares 3 tons of biomass of various types (round wood for industry, fuel wood, bark, forest wood residues like thinning and logging residues) are produced per hectar per year. In total 3000 tons of biomass are produced of which we know that 600 tons are forest wood residues. We know that on average 0.33 hectares are needed for one ton of biomass (1000 hectares per 3000 tons). In that case the forest area equivalent for the production of forest wood residues is 200 hectares (0.33 hectares per ton times 600 tons).

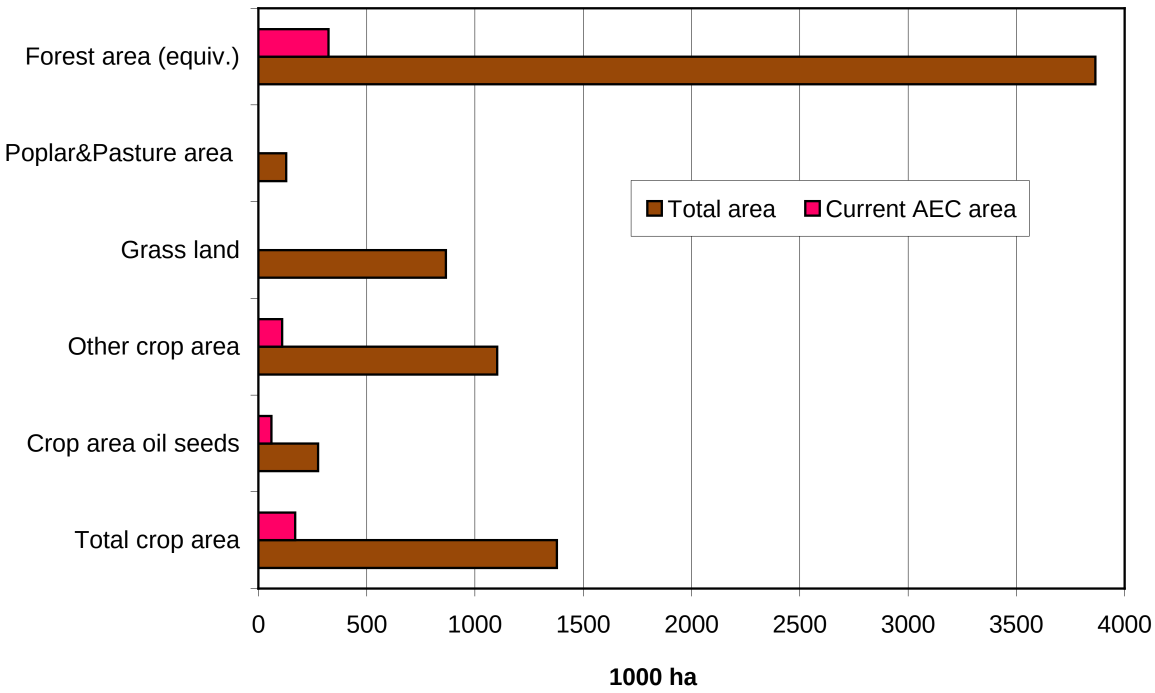

Figure 5-3 Total areas and currently used areas for AEC 2010

Figure 5-4 presents a comparison of total areas and maximal areas for AEC in 2050.

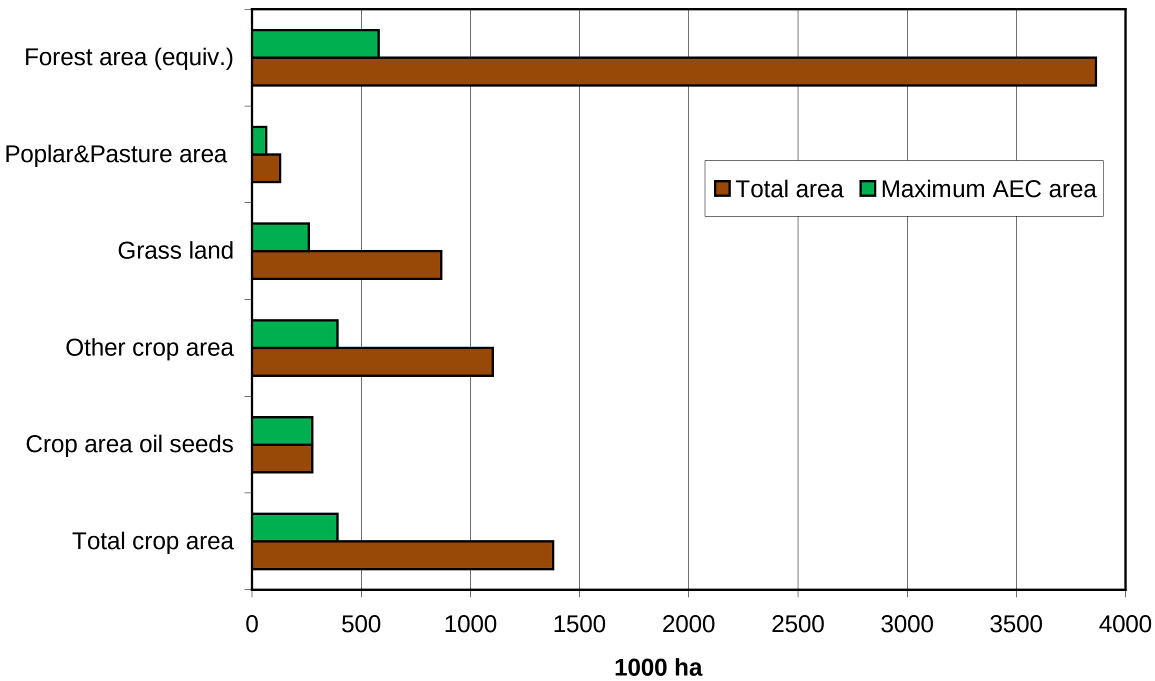

Figure 5-4 Total areas and maximum AEC areas in 2050

Area used in 2010 and maximal land area potentials in 2050 for the production of AEC are shown in Figure 5-5.

Figure 5-6 depicts the current and maximal potentials shares in percent.

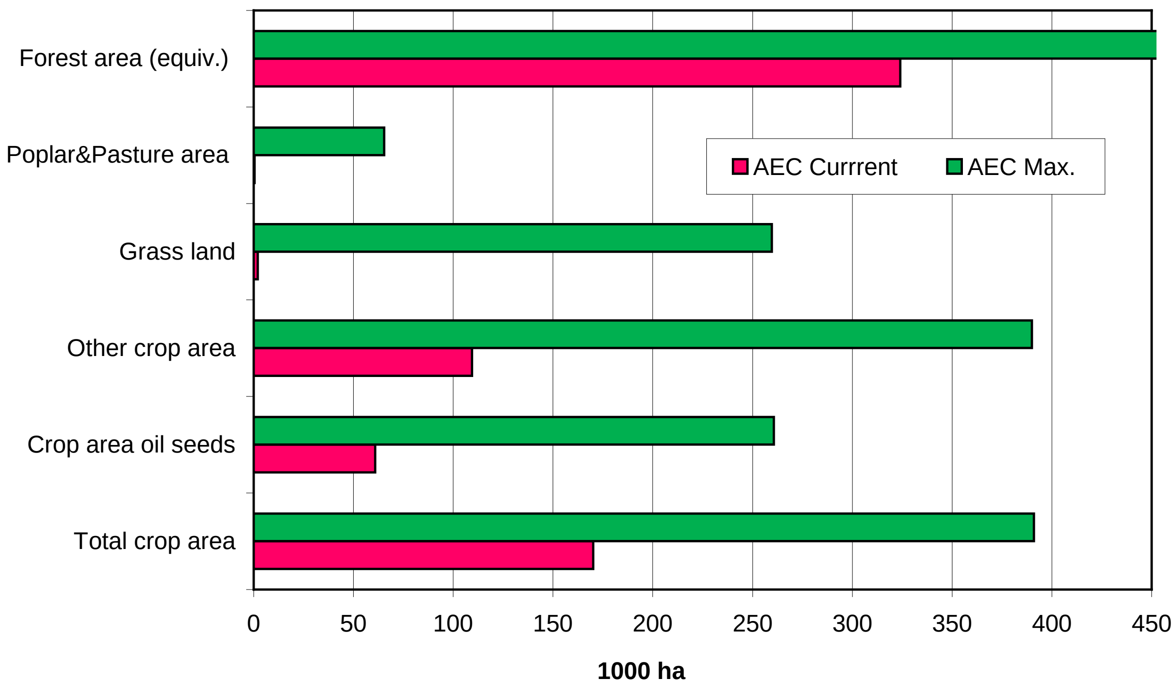

Figure 5-5 Current AEC areas and maximum land area potentials usable for producing AEC in 2050

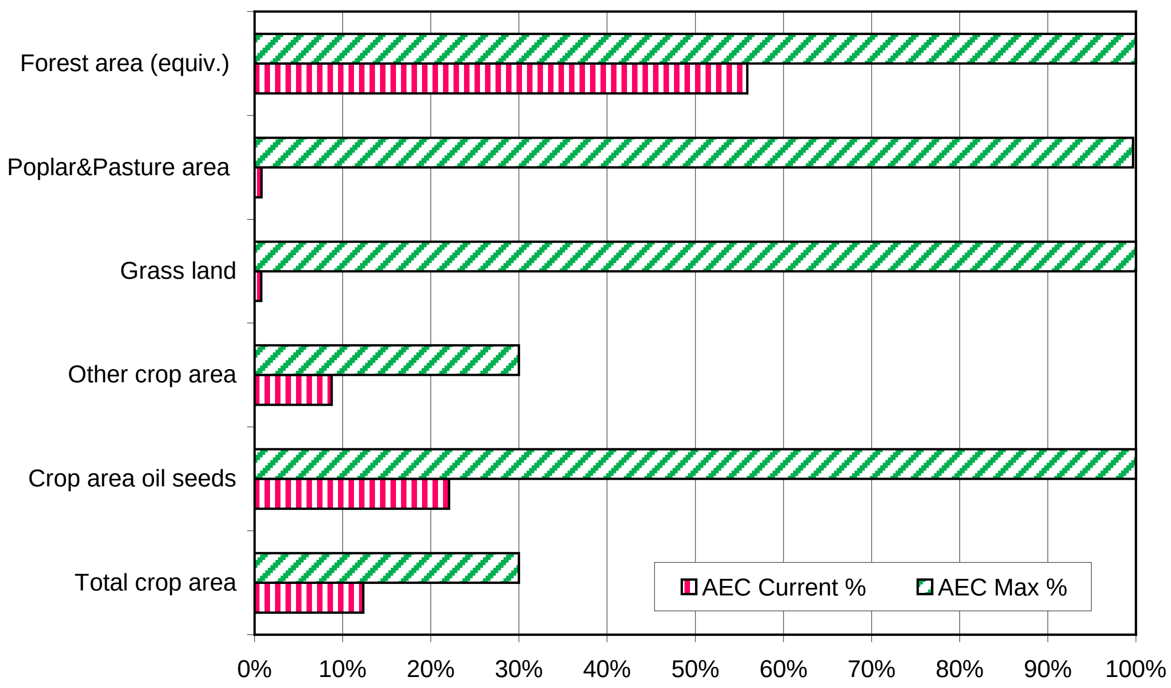

Figure 5-6 Share of current and maximal area used for AEC in percent

Table 5-1 Survey on maximum potentials for area-dependent resources (Sources: Kranzl/Haas et at., 2008; ARGE Kompost/biogas, 2009; Kalt/Kranzl (2011))

	2010			2050		
	Total area	AEC current		Total area	AEC max	
	(1000 ha)	(1000 ha)	(%)	(1000 ha)	(1000 ha)	(%)
Total crop area	1378	170	12%	1303	390	30%
Crop area oil seeds (BD-1)	276	60	22%	260	260	100%
Other crop area (BE-1 or BF-2 *)	1250	109	8%	1139	390	30%
Grass land (BG-1)	260	2	1%	260	260	100%
Poplar&Pasture (SRC for BF-2*)	64	1	1%	66	66	100%
Forest wood residues (for BF-2*)	3865	324	56%	3791	580	100%

*) BF-2: BTL, FT-Diesel, BE-2, SNG

5.2 Derivation of potentials of non-area-based resources

Aside from resources which need land areas for their production (and which are in principle in competition with food or feed supply or deployment for wind turbines or Photovoltaic systems) there are also area-independent ones (like waste fat, organic waste, wood industry residues, waste wood). The later are mainly based on residues and waste.

Table 5-2 depicts the maximal potentials for non-area-dependent resources for the years 2010, 2030 and 2050. The potentials are documented in tons of feedstock and in PJ primary energy. Figure 5-7 shows the maximum potentials for non-area-dependent resources in 2050. As it can be seen the by far highest quantities can be expected from wood industry residues (2.4 mill. tons) and forest wood residues (1.45 mill. tons). In total these two resources represent an energetic potential of about 65 PJ.

For the straw potential it is important to note that we consider only a potential of 2.3 tons/ha for energetic purposes. The rest is assumed to be needed for ground recovery and for other non-energetic purposes.

Table 5-2 Survey on maximal potentials for non-area-dependent resources (Sources: Kaltschmitt, 2004; EEA, 2006; Kranzl/Haas 2008; Panoutsou, 2009)

		2010		2030		2050	
	kWh/kg	1000 tons	PJ Prim.en.	1000 tons	PJ Prim.en.	1000 tons	PJ Prim.en.
Straw (2.3 tons/ha)	4.5	39	0.7	480	7.8	480	7.8
Forest wood residues	4.3	1450	22.4	1450	22.4	1450	22.4
Manure	8.33	215	6.4	240	7.2	280	8.4
Waste wood	5.30	300	5.7	500	9.5	600	11.4
Wood industry residues	5.00	830	14.9	1400	25.2	2400	43.2
Organic waste /Waste fat	7.60	230	6.3	370	10.1	420	11.5
Black Liqueur	3.36	200	2.4	220	2.7	240	2.9

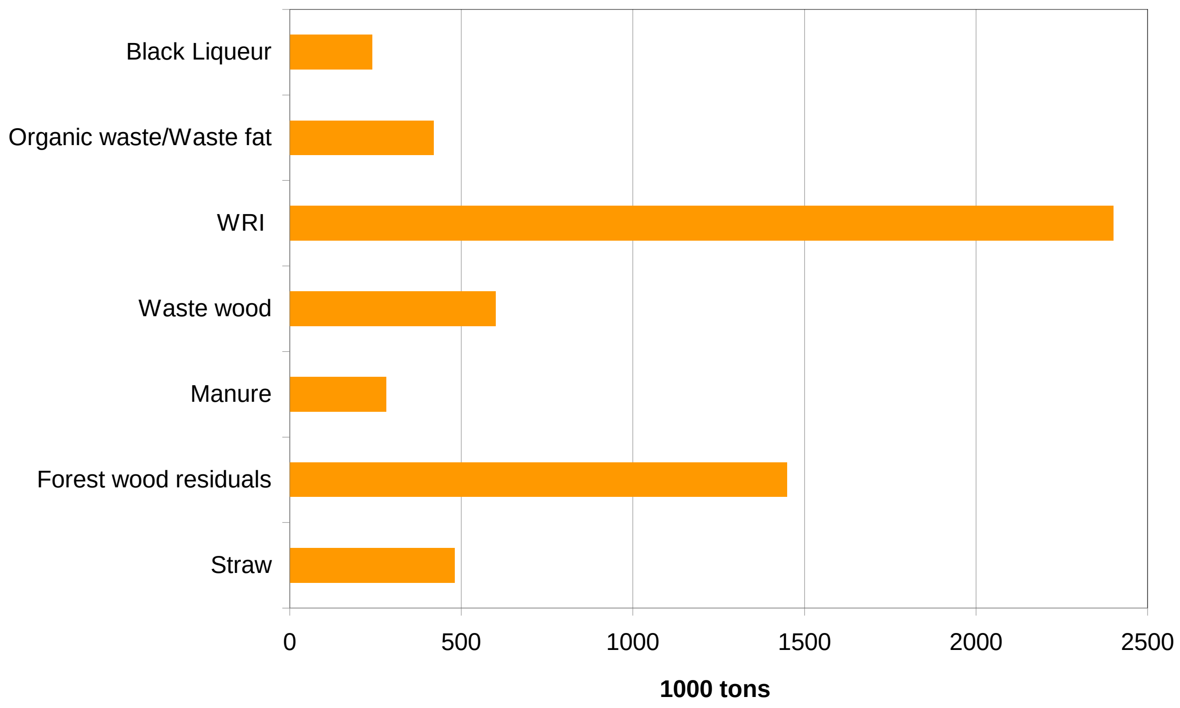

Figure 5-7 Maximal potentials for non-area-dependent resources 2050

5.3 Assumptions for price developments in the scenario analysis

In addition to the conditions for availability of resources, as described above, the major economic assumptions for the scenario analysis are:

- All monetary figures are of 2010; that is to say all costs and prices are converted to the values of the year 2010;
- Increases in fossil fuel prices are based on expected price developments as documented in IEA (2009) and IEA (2011) and own analyses for feedstock and wood prices as depicted in Figure 8-1; This Figure shows price developments of fuels (2010=1) excl. taxes historically (up to 2010) and assumptions till 2020. For all our scenarios we use price increases for fossil fuels of 3% per year up to 2050, of 2% per year for feedstocks (oil seeds, cereals) and 1% per year for wood-based resources (WRI, FWR…) see Figure 5-9;
- The introduction of CO_2 tax as of 2013, as described latter in detail in Chapter 6.1;
- The development of costs of alternative fuels is based on international learning rates for the corresponding investments as described in Section 5.4.

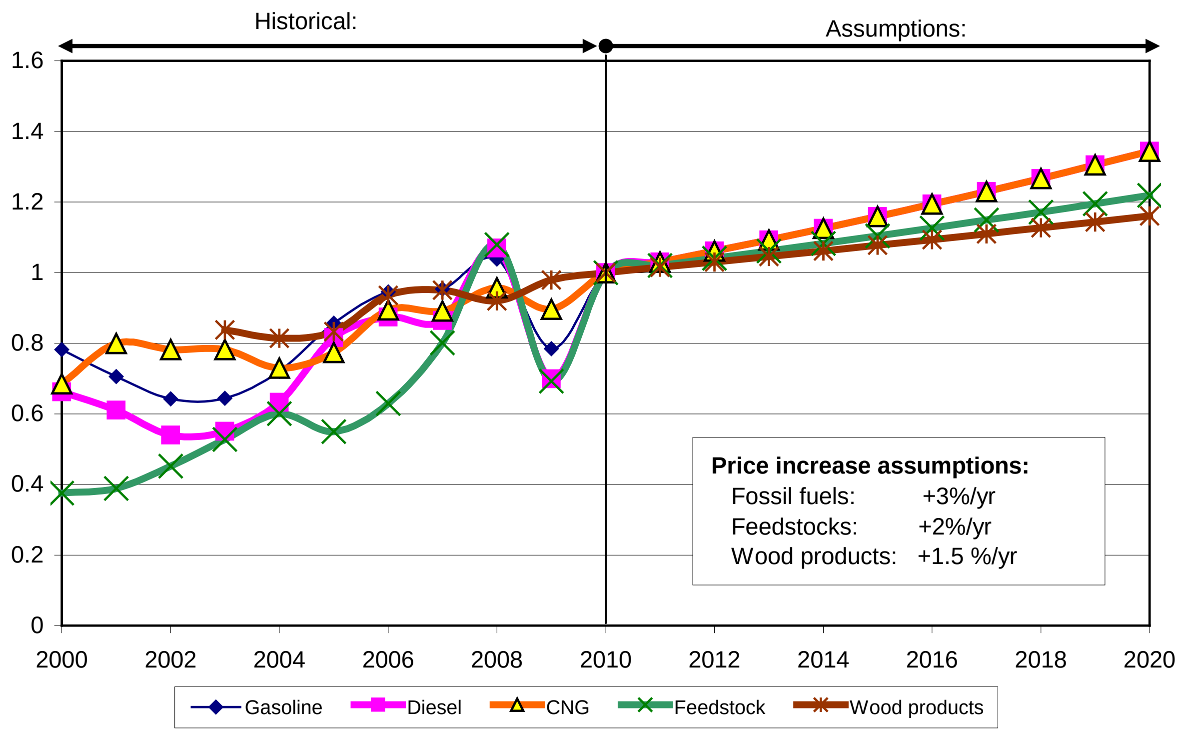

Figure 5-8 Price developments of fuels (2010=1) excl. taxes: Historical (up to 2020) and assumptions up to 2050

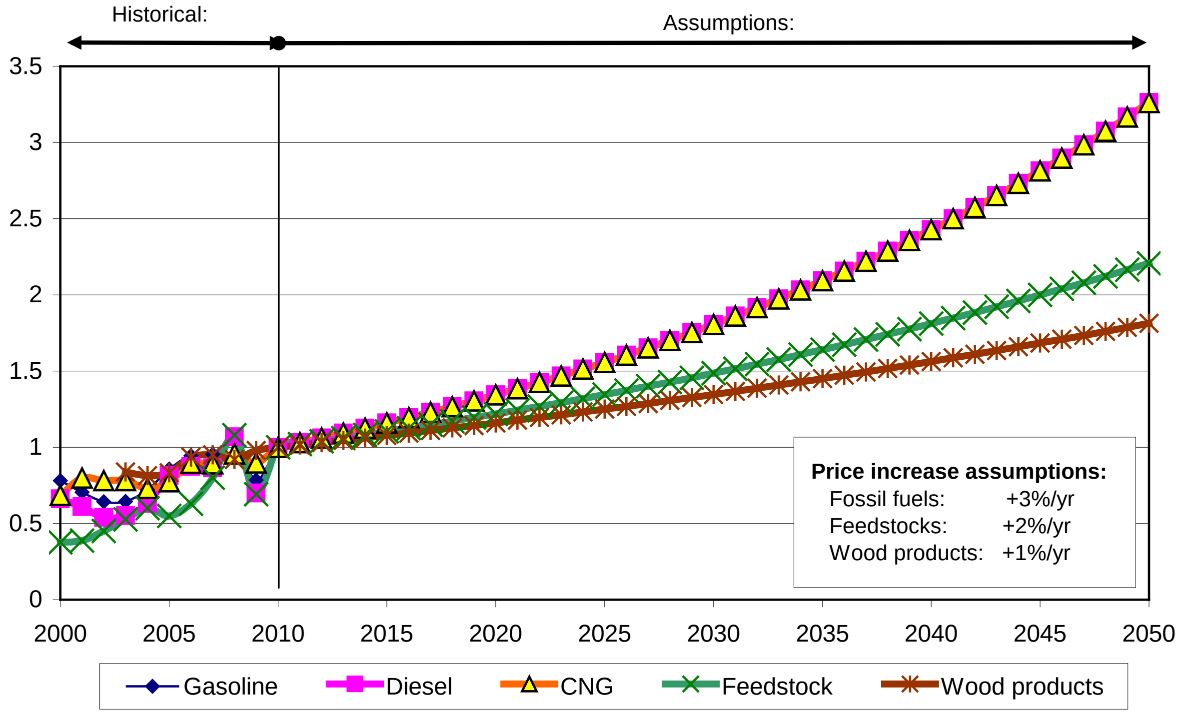

Figure 5-9 Price developments of fuels (2010=1) excl. taxes: Historical (up to 2050) and assumptions up to 2050

The resulting price developments of fossil fuels and AEC (in EUR/kWh) excl. taxes are depicted in Figure 5-10 historically (until 2010) and based on our assumptions till 2050.

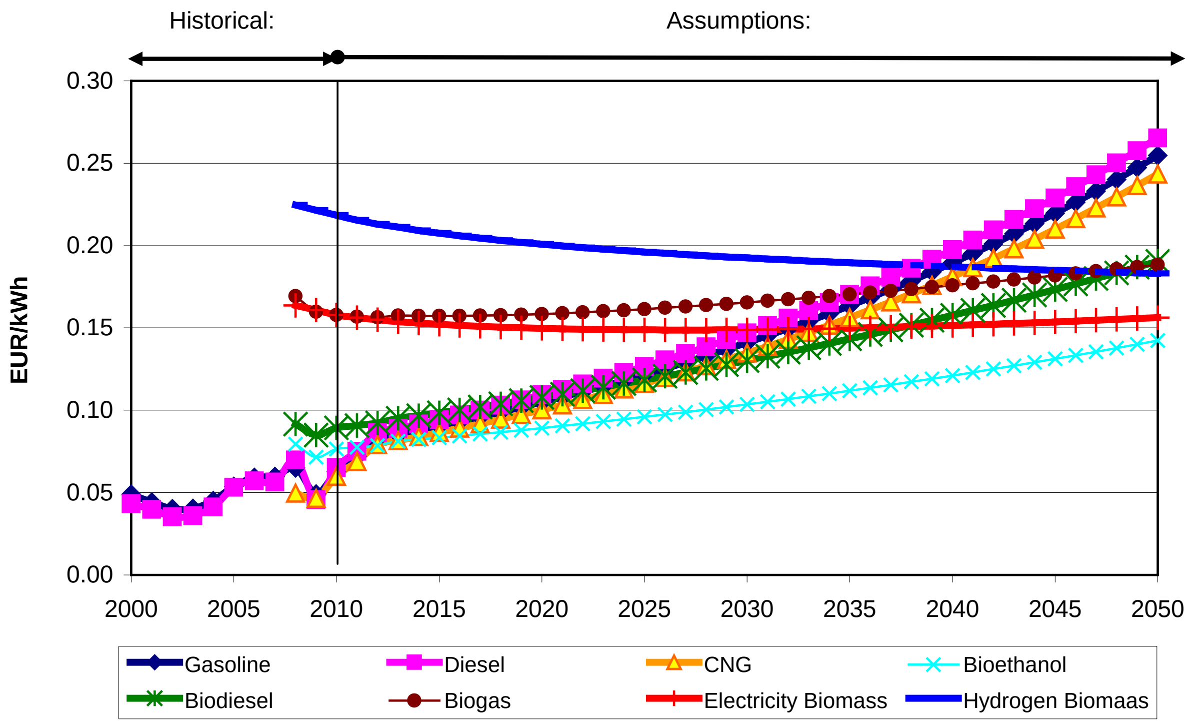

Figure 5-10 Price developments of fuels (in EUR/kWh) excl. taxes: Historical (up to 2050) and assumptions up to 2050

5.4 International assumptions for learning rates up to 2050

The dynamic cost analyses in this work are based on international quantities. The data used for this report – especially for the estimation of the effects on technological learning - are based mainly on studies of the IEA.

The major assumptions regarding technological learning effects used for the scenario analysis are:

- The development of alternative fuel costs is based on international learning rate of 25% and national learning rate of 15% regarding the investment costs of theses technologies;
- International learning corresponds to world-wide quantity developments in the Reference Scenario (RS) and the Alternative Policy Scenario (AS) in IEA (2009) up to 2030.

According to IEA (2009, 2011b) major increases in global biofuels production are seen in the 450 Scenario. In this scenario consumption in 2030 should be two times higher than in Reference Scenario, see Figure 5-11. Deployment of 2nd generation biofuels is expected around 2015 – five years earlier than in the Reference Scenario. As it can be seen in both scenarios 1st generation biofuels will be dominant till 2020. However, concerns about the effects of biofuels production on food prices, questions about the magnitude of the GHG emissions savings due to the switch to biofuels as well as doubt about their sustainability, have stoke many countries to rethink their biofuels blending targets. The last decade of the projection period sees a rapid increase in the production of the 2nd generation biofuels, accounting for all the incremental biofuels increase after 2020 [WEO, 2009].

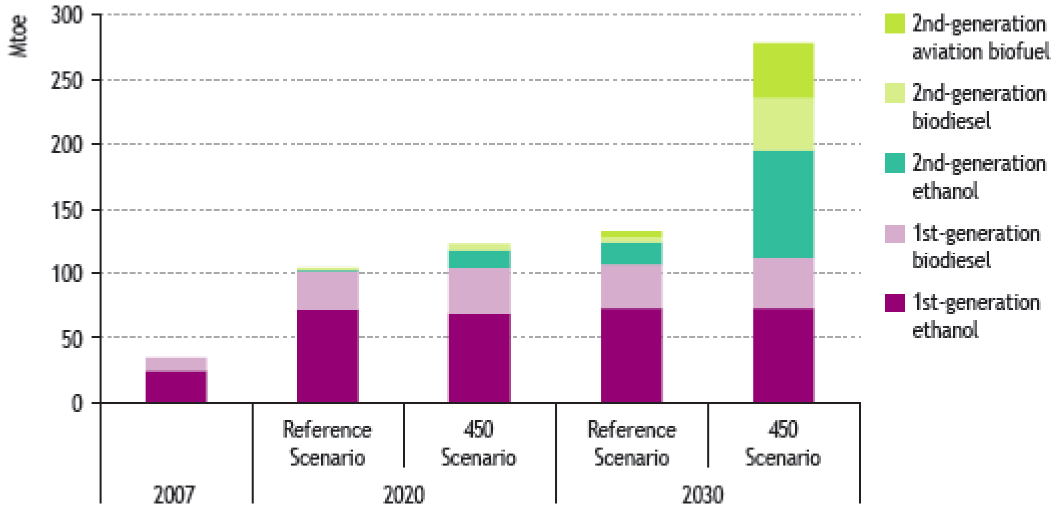

Figure 5-11 Biofuels demand by type and scenario in the WEO 2009

In Table 5-3 are shown production projections for 2nd generation biofuels up to 2050 for two different scenarios according to IEA. Total transport fuel demand by 2050 is projected to be 3270 Mtoe in ACT Map and 2656 in BLUE Map. On that basis, biofuels would provide approximately 15% in ACT Map and 23% in BLUE Map scenario [IEA, 2008].

Table 5-3 Second generation biofuels production projections (Mtoe) in the IEA Energy Technology perspectives 2008, [IEA, 2008]

	2010	2015	2030	2050
ACT Map				
LC ethanol	0.0	1.5	46	140
BtL biodiesel	0.0	0.3	49	333
BLUE Map				
LC ethanol	0.0	3.0	62	121
BtL biodiesel	0.0	0.2	102	491

In the BLUE Map scenario by 2050 about 160Mha of land would be needed to produce the projected volumes of biofuels. However, with the increasing biofuels production sustainability of biofuels production and land use is becoming a challenging issue. A solution could be increasing use of ligno-cellulosic feedstocks which are coming from crop and forest residues, or are cultivated on marginal or degraded land, thereby avoiding competition with food. Demand for biofuels and land requirements in the BLUE Map scenario are shown in Figure 5-12.

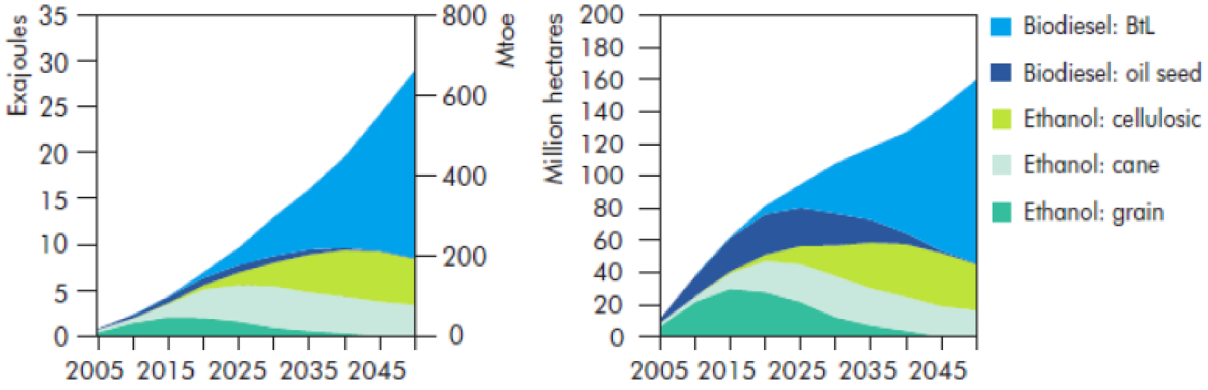

Figure 5-12 Demand for biofuels and land requirements in the BLUE Map scenario in the IEA Energy Technology perspectives 2008

6. A comparative dynamic economic assessment of alternative energy carriers

The core question is: To what extent can the available resources and derived potentials depicted in the former chapter be achieved in practice? This depends mainly on their economic performance and on policy interferences. This may also affect the aspect which AEC finally will be produced. In this chapter we provide a comparative dynamic analysis of the economic performance of AEC in comparison with fossil fuels (based on technological learning). This comparison is based on the results obtained for the single AEC (see Annex B) and the assumptions made for the price development of fossil fuels in Chapter 8. The method of approach for this economic analysis is described in Section 3.2.

6.1 Comparison of scenarios for costs of AEC vs. conventional fuels costs

First we provide a summary of the cost developments of the analysed AEC with and without taxes with special focus on the effect of CO_2 taxation. Figure 6-1 depicts the cost development without taxes and is corresponding to Figure 5-10. But it is presented in a different style for a better comparison with the following figures. In this case by about 2040 all AEC will be finally cheaper than fossil fuels.

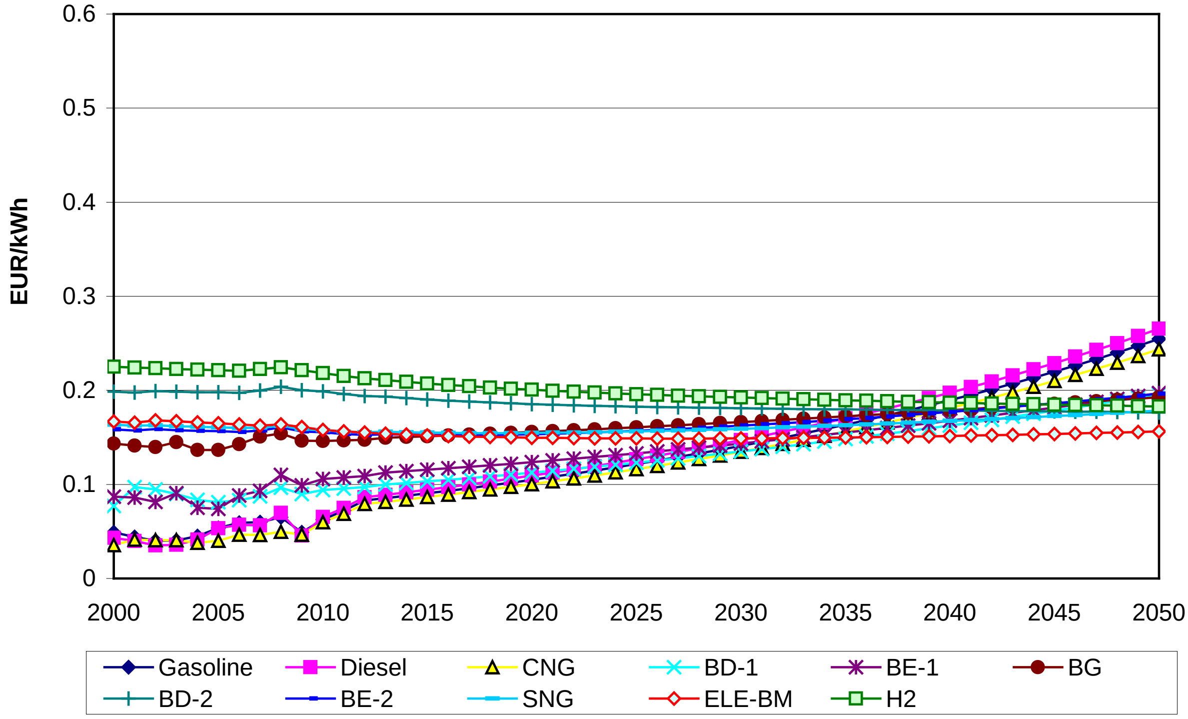

Figure 6-1 Development of costs of various AEC in comparison to conventional fuels (without taxes) up to 2050[2]

However, all analysed AEC have different CO_2 emission balances and could more or less contribute to the reduction of GHG emissions. In Figure 6-2 the CO_2 emissions of the analysed AEC in comparison to conventional fuels in 2050 on a WTW base are summarized.

[2] The scale in this figure corresponds to Figure 6-3 and Figure 6-4.

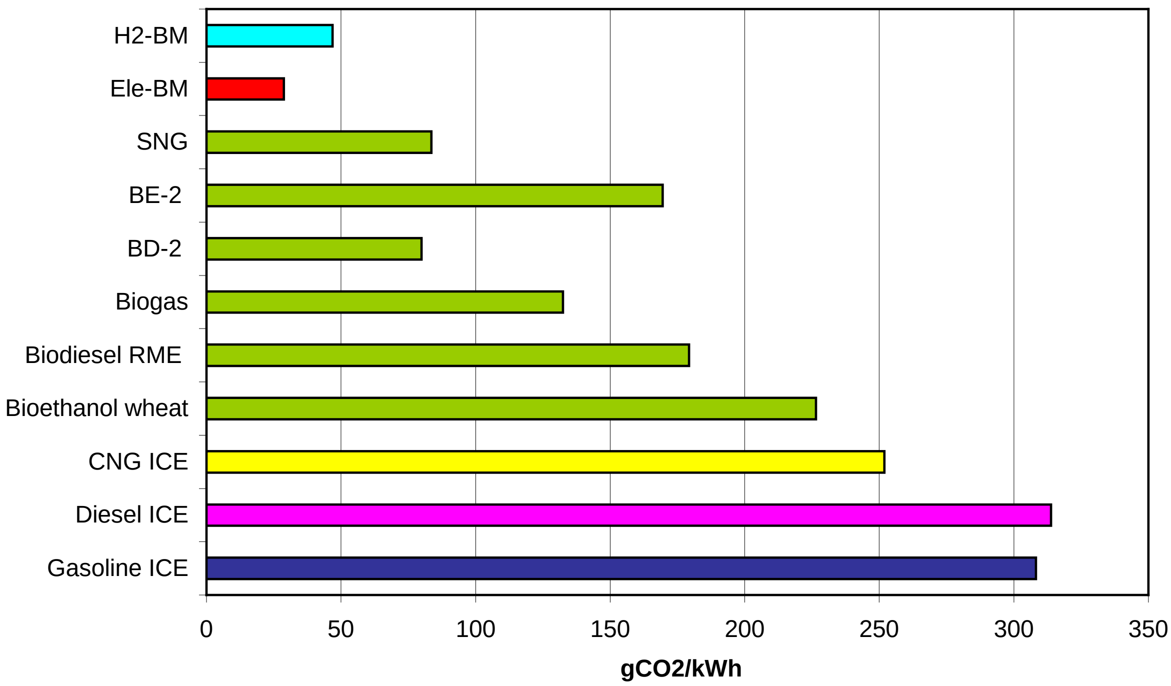

Figure 6-2 CO_2 emissions of various AEC in comparison to conventional fuels in 2050 on a WTW base

This figure shows that by 2050 the AEC with the lowest CO_2 emissions are electricity and hydrogen from biomass, FT-Diesel (BD-2) and SNG. With an appropriate CO_2 based tax these AEC could become more competitive on the market and highly attractive compared to fossil fuels.

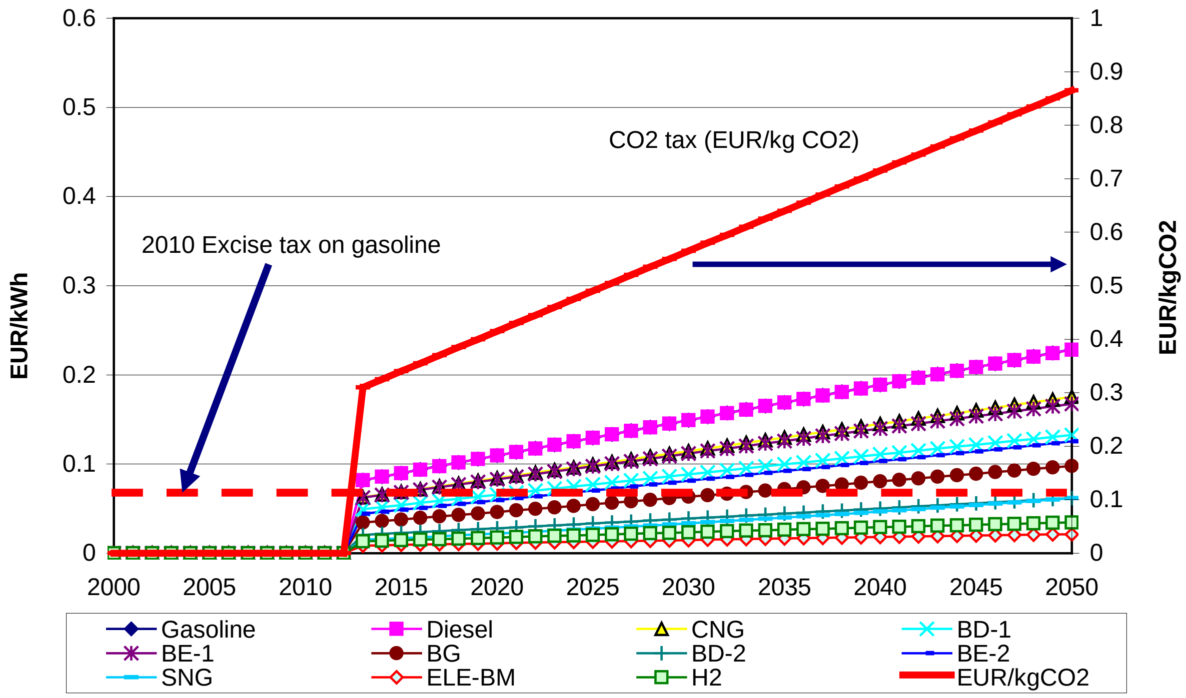

Figure 6-3 CO_2 tax developments of various AEC in comparison to conventional fuels up to 2050 and CO_2 tax per kg CO_2 (starting in 2013)

Such a policy is depicted in Figure 6-3 where the CO_2 tax developments of various AEC in comparison to conventional fuels up to 2050 and CO_2 tax per kg CO_2 (starting in 2013) are shown.

The idea of the suggested tax reform described in Figure 6-3 is as follows: The highest excise tax in 2010 – which was on gasoline – is converted in a CO_2 tax of the same magnitude. For all other fuels including diesel and CNG this tax is set relative to their WTW - CO_2 emissions – see Figure 6-2 – compared to gasoline. This tax starts in 2013 and is increased by 0.015 EUR/kgCO_2/yr up to 2050. It can be noticed that AEC with lowest CO_2 balances have lowest tax levels in 2050.

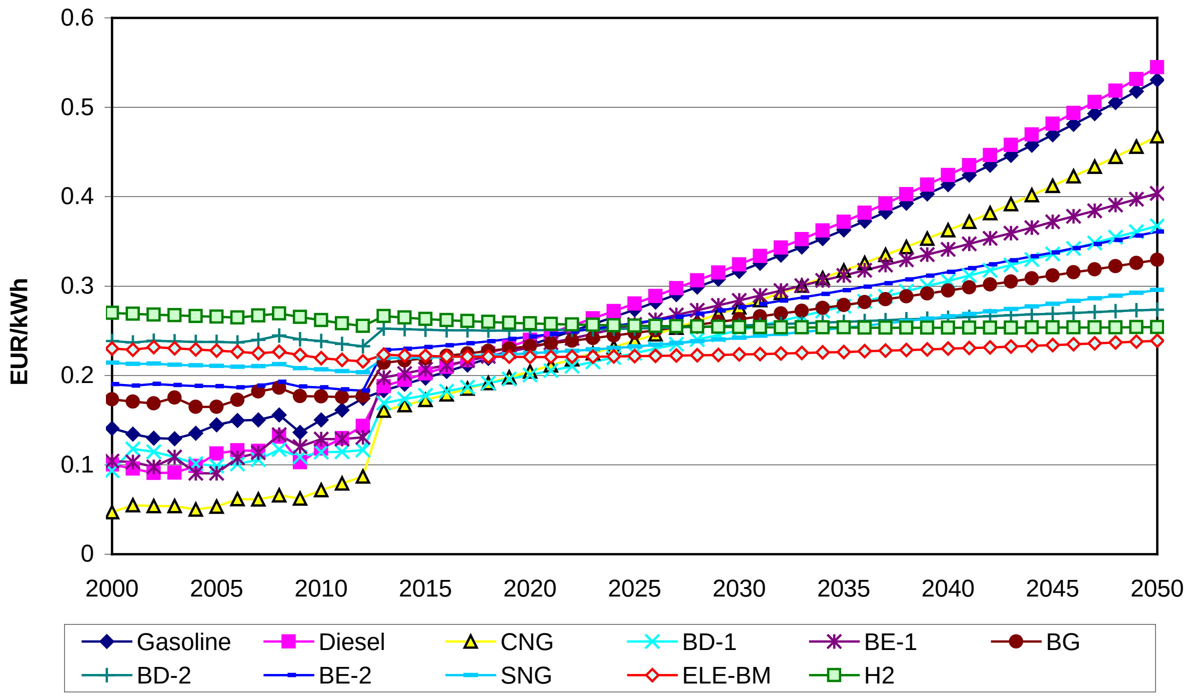

Figure 6-4 Development of costs of various AEC in comparison to conventional fuels including taxes up to 2050

Figure 6-4 depicts the development of costs of various AEC in comparison to conventional fuels including all taxes up to 2050. In contrast to Figure 6-1 the cost differences are much bigger. Moreover, the fuels with the lowest CO_2 taxes - electricity and hydrogen from biomass, biodiesel (BD-2) and SNG – are the cheapest ones by 2050. With CO_2 tax AEC could become competitive with fossil fuels starting from 2020. In contrast in Figure 6-5 the Development of costs of various AEC in comparison to conventional fuels with no switch to a CO_2 based tax system is presented. This strategy would be less favourable for most AEC than the CO_2 tax scenario. AEC would become competitive with fossil fuels about ten years latter than in Figure 6-4.

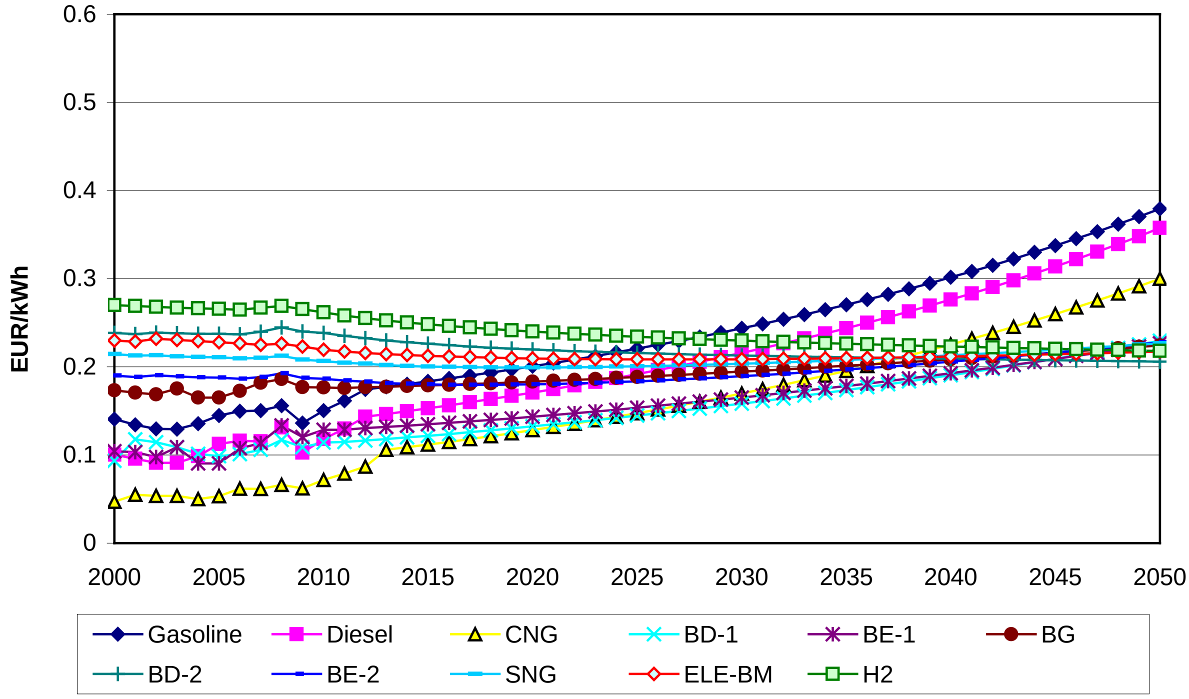

Figure 6-5 Development of costs of various AEC in comparison to conventional fuels with no switch to CO_2 based tax system

The following figures depict the development of production costs (exclusive tax) and prices of AEC (including CO_2 tax and VAT) in comparison with fossil fuels, inclusive and exclusive taxes.

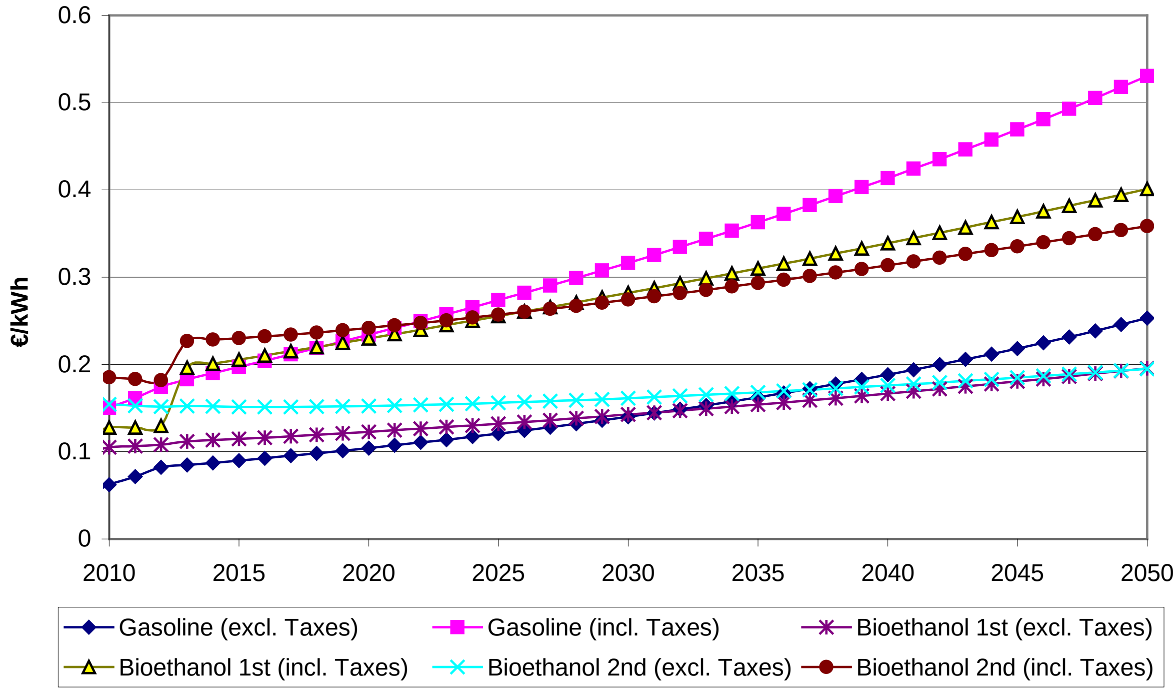

Figure 6-6 Price versus costs of gasoline and bioethanol 1st and 2nd generation

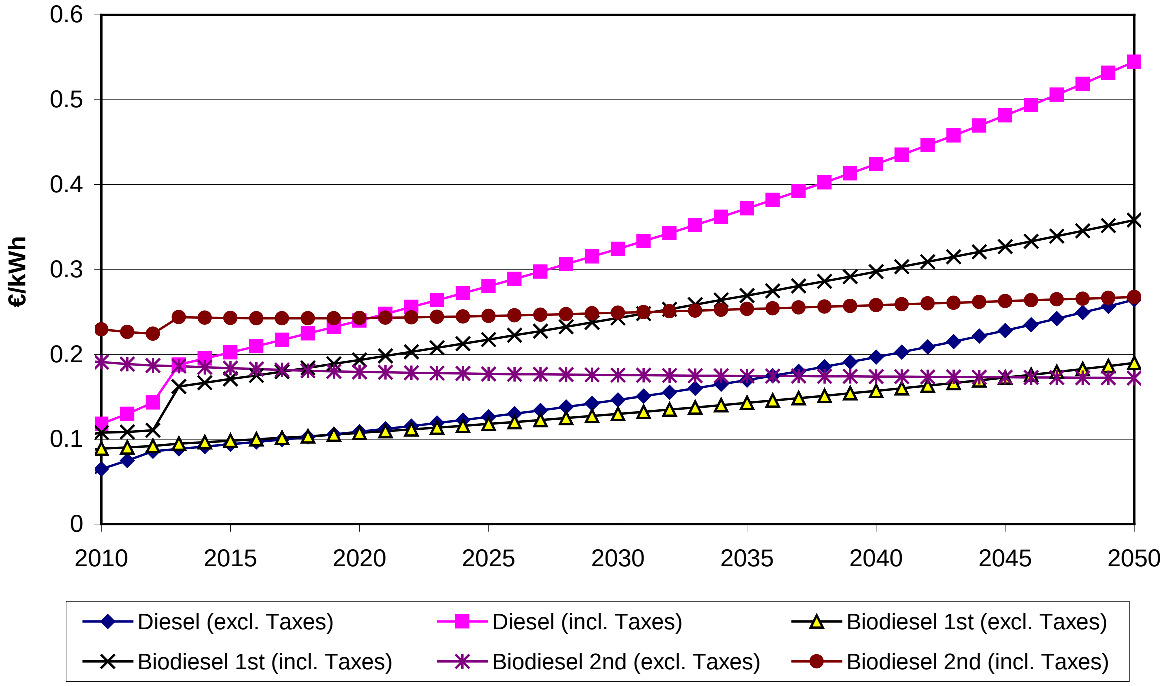

Figure 6-7 Price versus costs of diesel and biodiesel 1st and 2nd generation

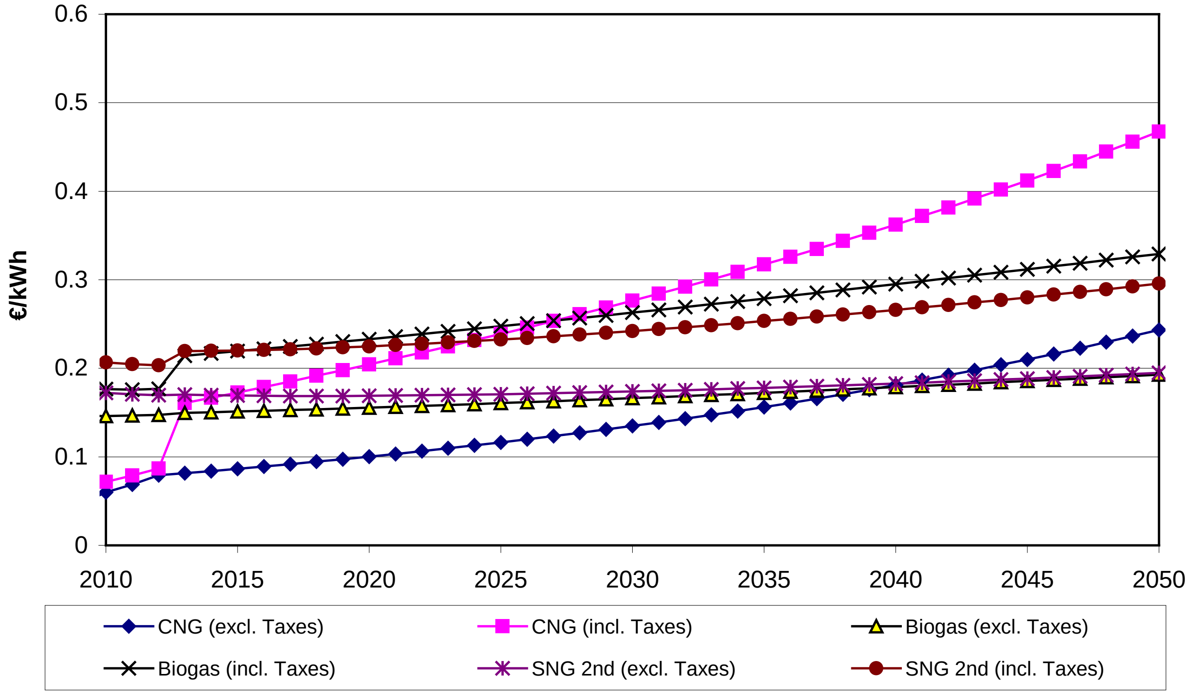

Figure 6-8 Price versus costs of CNG, biogas and SNG

As can be seen from Figure 6-6 and Figure 6-7 the costs of 1st generation bioethanol and biodiesel are slightly increasing mostly due to increasing feedstock prices. The major cost reduction of biofuels 2nd generation is caused by learning effects for capital costs. These learning effects are triggered mainly by international learning.

The major results of this analysis are: (i) 2nd generation bioethanol will become competitive including CO_2 tax by about 2020, see Figure 6-6; (ii) Biodiesel 2nd generation will compete with fossil diesel also shortly after 2020, see Figure 6-7; (iii) Biogas could become competitive with CNG already before 2015 and SNG about ten years later, see Figure 6-8 ; (iv) Yet, if no taxes are considered, competitiveness with fossil fuels could be reached in the next 25 to 30 years.

In Figure 6-9 the cost development of hydrogen and electricity from biomass is depicted with and without CO_2 taxes. We can see that electricity costs are slightly increasing. The reason is that only moderate technological learning is expected, while feedstock prices increase. A slight decrease of costs of hydrogen is expected due to international technological learning.

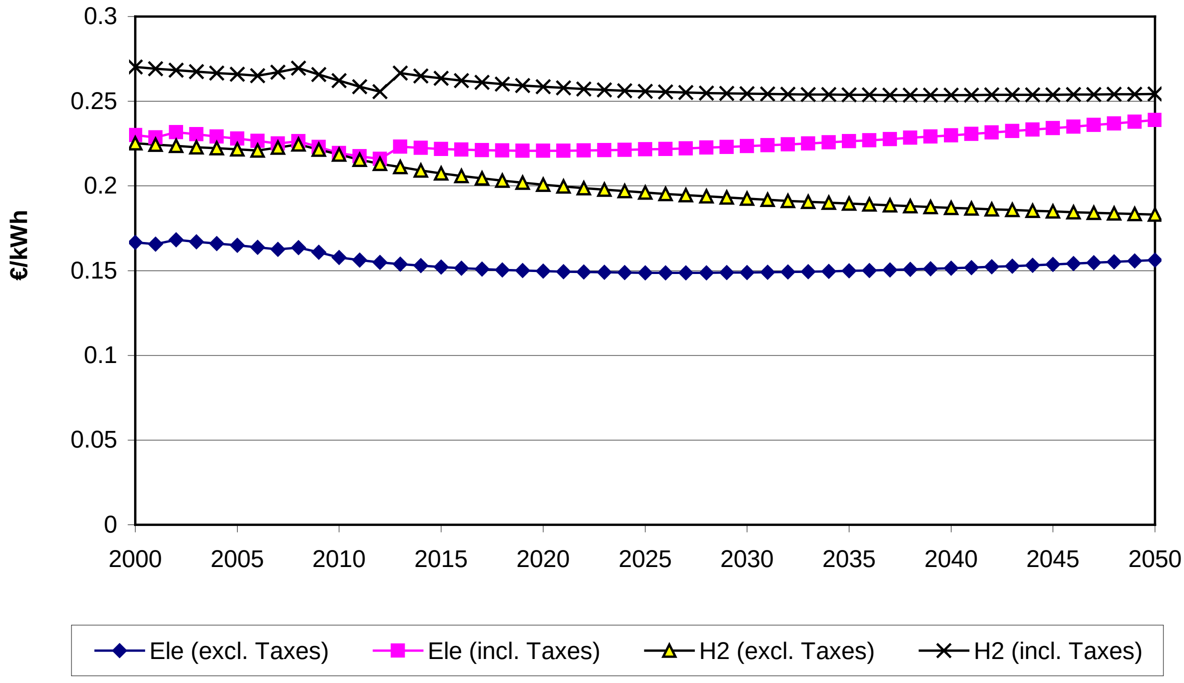

Figure 6-9 Costs of electricity and hydrogen from biomass

6.2 Survey on size categories and investment costs of AEC in 2010

In Table 6-1 we provide an overview on typical sizes for small and large plants for the production of AEC and corresponding investment and specific costs in 2010.

Table 6-1 Overview on typical sizes for small and large plants for the production of AEC and corresponding investment and specific costs in 2010

Small-scale				
	Capacity		***Investment costs***	
	convent. units	*MW_f*	*Total*	*Specific*
Biodiesel 1st gen.	50 000 t BD	65 MW_f	36 Mio EUR	715 EUR/t BD
Bioethanol 1st gen.	50 000 t BE	50 MW_f	35 Mio EUR	700 EUR/t BE
Biogas (raw)	4000 MWh/yr	0.5 MW_f	2.2 Mio EUR	4500 EUR/kW_f
Biodiesel 2nd gen.	50 000 t BD	65 MW_f	600 Mio EUR	12000 EUR/t BD
Bioethanol 2nd gen	50 000 t BE	50 MW_f	210 Mio EUR	4250 EUR/t BE
SNG	-	10 MW_f	160 Mio EUR	16000 EUR/kW_f
Electricity	-	3 MW_f	11 Mio EUR	3800 EUR/kW_{ele}
Hydrogen	10 000 tons H_2	42 MW_{H2}	315 Mio EUR	31500 EUR/t H_2

Large-scale				
	Capacity		***Investment costs***	
	convent. Units	*MW_f*	*Total*	*Specific*
Biodiesel 1st gen.	200 000 t BD	260 MW_f	110 Mio EUR	550 EUR/t BD
Bioethanol 1st gen.	200 000 t BE	200 MW_f	110 Mio EUR	500 EUR/t BE
Biogas	16000 MWh/yr	2.0 MW_f	51 Mio EUR	3200 EUR/kW_f
Biodiesel 2nd gen.	400 000 t BD	520 MW_f	2400 Mio EUR	6000 EUR/t BD
Bioethanol 2nd gen.	400 000 t BE	400 MW_f	1000 Mio EUR	2500 EUR/t BE
SNG	-	80 MW_f	640 Mio EUR	8000 EUR/kW_f
Electricity (from biomass)	-	30 MW_{ele}	75 Mio EUR	2500 EUR/kW_{ele}
Hydrogen (from biomass)	100 000 tons H_2	420 MW_{H2}	1850 Mio EUR	18500 EUR/t H_2

f….fuel

6.3 An analysis of cost structures in 2010 and perspectives for 2050

In the following figures we show the cost structures of AEC in Austria in comparison to the market prices of fossil fuels in 2010 and based on our analyses for 2050.

Figure 6-10 shows the production costs of biofuels (exclusive taxes in 2010) compared to fossil fuels. We can see that biofuels are considerably more expensive than fossil fuels. Therefore it is clear that their economic performance has to be improved.

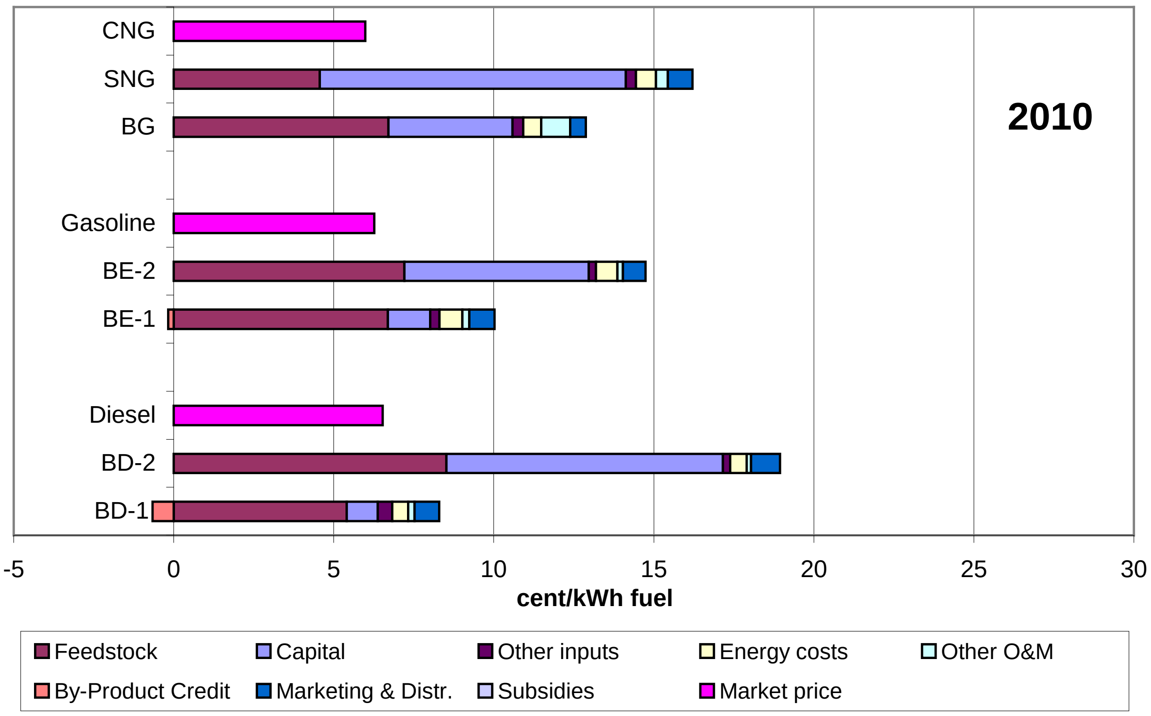

Figure 6-10 Production costs of biofuels vs. fossil fuels (exclusive taxes) in 2010

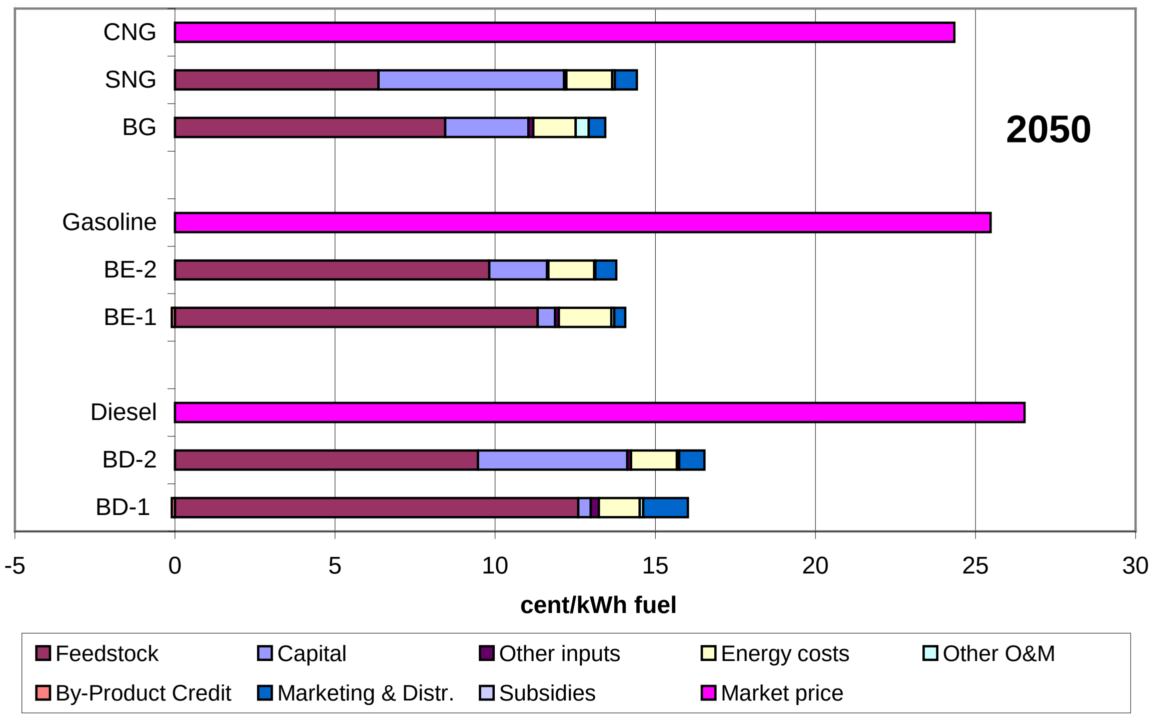

Figure 6-11 Production costs of biofuels vs. fossil fuels (exclusive taxes) in 2050

The major reason for the recent increasing market share of biofuels is that they were exempted from excise taxes so far.

In this context it is important to identify the shares of cost categories. As it can be seen clearly from Figure 6-10 by far largest cost share of BD-1 and BE-1 are feedstock costs. On the second place are capital costs. Capital costs are currently much higher by BF-2. However, due to technological learning and scaling effects these costs could be significantly reduced by 2050, see Figure 6-11.

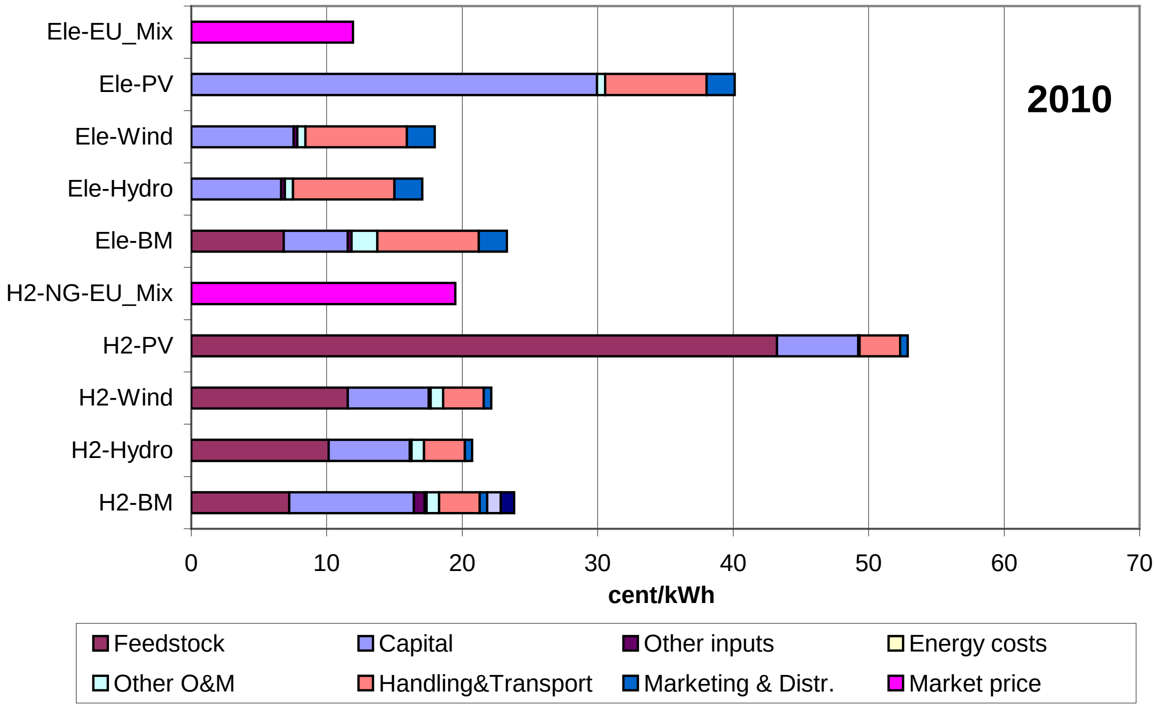

Figure 6-12 Production costs of electricity and hydrogen in 2010 (incl. grid costs, excl. taxes)

Electricity and hydrogen can be produced from different primary energy sources. As it can be seen from Figure 6-12 highest production costs are in the case of photovoltaic electricity production as well as hydrogen production by electrolysis with photovoltaic electricity. Production costs of electricity and hydrogen in energy chains with wind or hydro power are significantly lower.

Expected production costs of electricity and hydrogen in 2050 are shown in Figure 6-13. Market prices of electricity and hydrogen will be increasing over time, due to the increasing price of fossil energy. Cost of electricity from photovoltaic can be reduced significantly, but it will remain most expensive way to produce electricity as well as hydrogen.

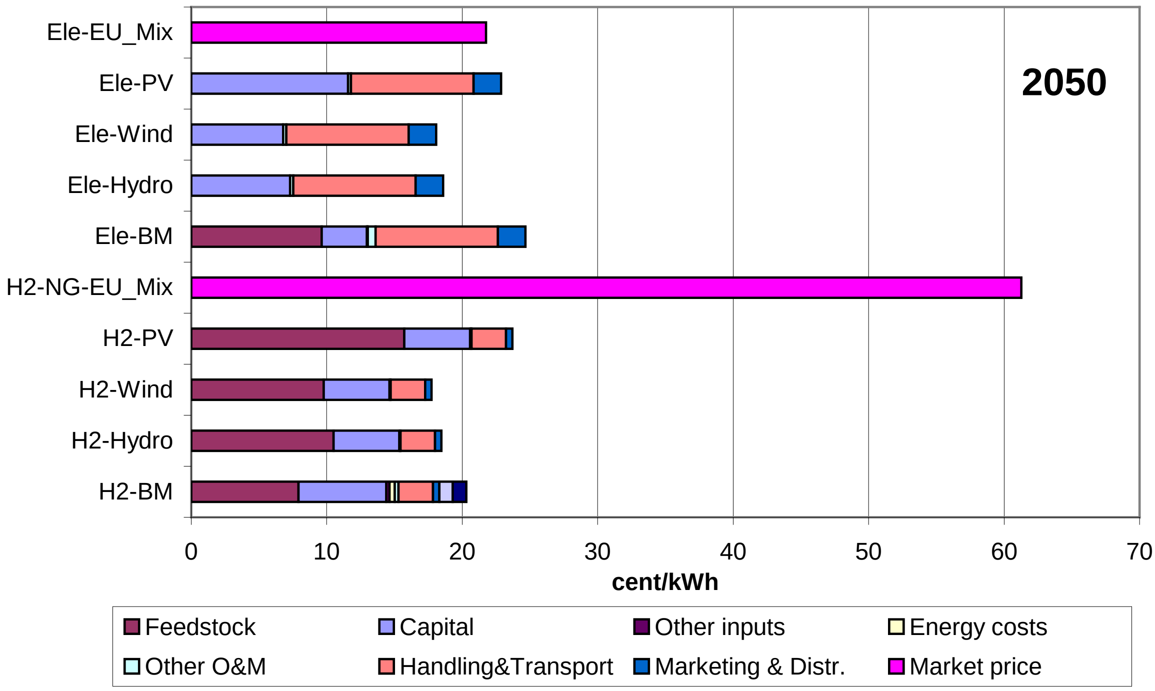

Figure 6-13 Production costs of electricity and hydrogen in 2050

Figure 6-14 depicts the costs of biofuels vs. fossil fuels (inclusive and exclusive taxes) in 2010 and 2050. We can see that due to the introduction of a CO_2 based tax – given the assumptions in Figure 6-3 – the economic attractiveness of all biofuel fractions increases.

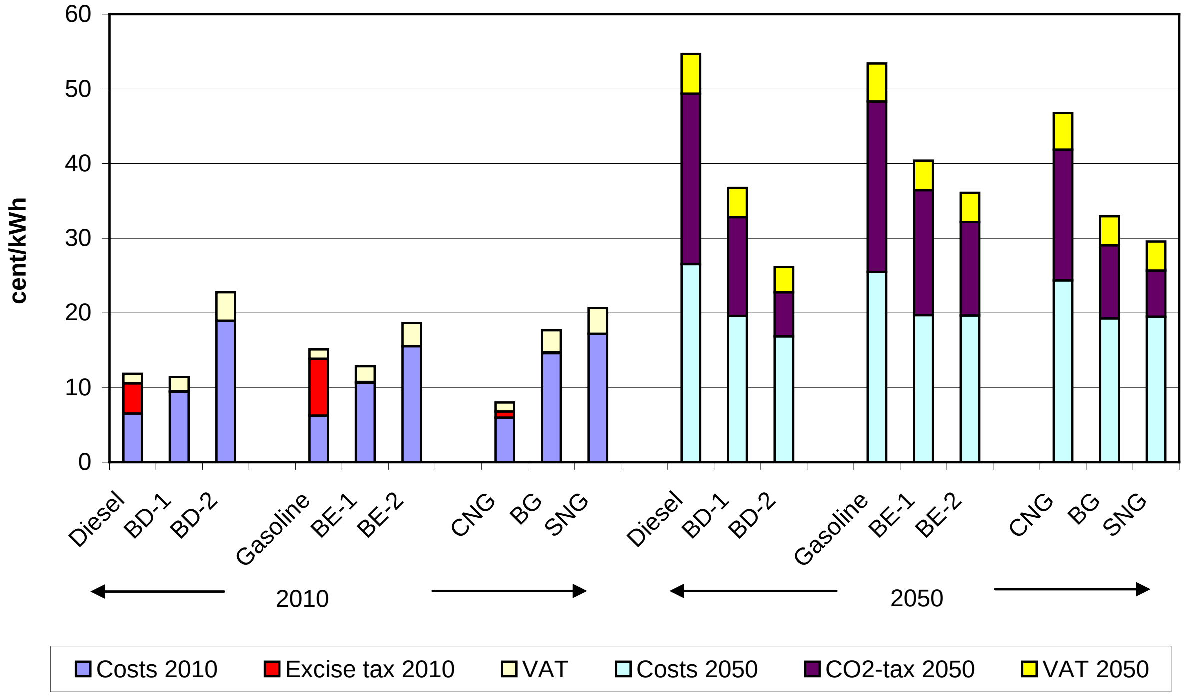

Figure 6-14 Cost of biofuels vs. fossil fuels incl. and excl. taxes in 2010 and 2050

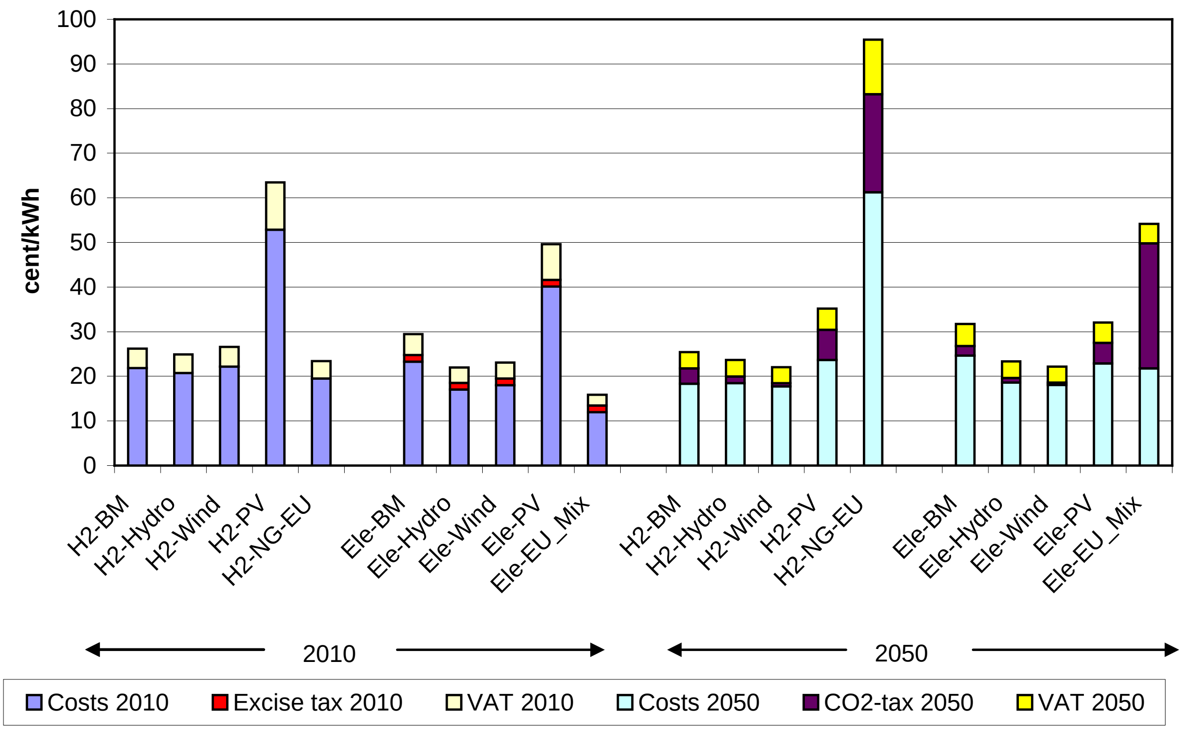

Figure 6-15 Cost of hydrogen and electricity incl. and excl. taxes in 2010 and 2050

Hydrogen and electricity costs (inclusive and exclusive taxes) in 2010 in comparison to expected costs in 2050 are shown in Figure 6-15. It can be seen that due to the introduction of a CO_2 based tax the economic attractiveness of electricity and hydrogen from RES increases significantly. With CO_2 based tax electricity as well as hydrogen from all investigated AEC could clearly become competitive.

7. The model

In this project the costs and the quantities of the defined categories of AEC are modelled in a dynamic framework. The model used is based on economic decision criteria and the impact of policies. The dynamics of costs is modelled as described in Chapter 3. The model is based on the principle that additional resources will be used if it is favourable due to economic criteria or other policy conditions (e.g. quotas). Vice versa, fewer resources (e.g. areas) will be used if a specific AEC becomes economically less favourable than another one. That is to say, additional feedstock resources and land areas are used for additional production of various AEC if these are (incl. all taxes, subsidies) cost-effective. Alternatively they will be used if a (not yet met) quota exists. For the maximum of resources available we use the potentials derived in Chapter 5.

Note that all modelling activities start after 2015 because the capacities to be built before are by and large already known today.

Learning (with respect to investment costs) as well as changes in feedstocks production and conversion into AEC are considered and modelled.

7.1 Maximum additionally usable areas

For every area category considered the maximum additional feedstock area per year (A_{FS_ADDt}) is calculated as:

$$A_{FS\_ADD\_t} = \varphi\ (A_{FS\_MAX\_t} - A_{FS\_t-1}) \qquad (7.1)$$

φ … maximum percentage to be added or reduced per year.

7.2 Basic conditions for additional areas used

Additional feedstock areas are used for AEC under the following conditions (also other conditions may apply):

$$A_{FS\_t} = A_{FS\_t-1} + A_{FS\_Addt} \;\Big|\; C_{AECt}(C_{FSt})[1+\tau_{AEC}] < p_{FFt}[1+\tau_{FF}] \qquad (7.2)$$

C_{AEC}…..total production costs of an AEC [€/kWh]

τ_{AEC}……tax on AEC [€/kWh]

τ_{FF}……..tax on fossil fuels [€/kWh]

p_{FF}…….price of fossil fuels (excl. tax) [€/kWh]

On contrary the area of feedstock j is reduced if

$$A_{FS\_t} = A_{FS\_t-1}(1-\varphi) \;\Big|\; C_{AEC_{VARt}}(C_{FSt})[1+\tau_{AEC}] > p_{FFt}[1+\tau_{FF}] \qquad (7.3)$$

or the specific area for growing special feedstocks will be reduced in any case if another way of producing biofuels in the same area using feedstock j is cheaper than the variable costs of using feedstock i:

$$A_{FS\_t} = A_{FS\_t-1}(1-\varphi) \mid C_{AECt}(C_{FSt\_i})[1+\tau_{AEC}] < C_{AEC_{VARt}}(C_{FS\_j}[1+\tau_{AEC}] \qquad (7.4)$$

C_{AEC_VAR}.....variable production costs of an AEC [€/kWh]

Note that a minimum of quantities of all feasible products in Austria are produced due to R&D (with increasing trends).

7.3 Assigning feedstock areas to AEC categories

Feedstocks as well as feedstocks areas may also be used for different AEC categories. E.g. some crop areas are suitable for oilseeds for 1st generation biodiesel (BD-1), for wheat for 1st generation bioethanol (BE-1) and for corn stover for 2nd generation bioethanol (BE-2). In this case the feedstocks and/or the feedstocks' area are dedicated to the biofuels category which leads to the cheapest production costs per kWh biofuel:

$$C_{AEC_t}(C_{FS_t}) = Min(C_{AEC_t\, FS_{j\_t}}; j = 1...m) \qquad (7.5)$$

m… number of possible biofuels categories.

Example (see also Figure 8-12): Currently a certain crop area is used for rapeseed for BD-1. As described in Figure 6-7 by about 2033 BD-2 might become cheaper than BD-1. In Figure 8-12 we can see that the area on which rapeseed is grown is phasing out and it is instead used for corn stover to produce BD-2.

7.4 Maximum potential of non-area dependent feedstocks

The maximum potential of non-area dependent feedstocks $C_{FS\_max\_BF}$ is modelled as follows:

$$Q_{FS_{\max BF\_t}} = Q_{FS_{\max_t}}(1-\delta)$$

δ… share of non-area dependent feedstock used for other applications

7.5 Policies modeled

We model the following policies in addition to Eq. (7.2) in Section 7.2:

- Introducing a quota:

$$A_{FS\_t} = A_{FS_{t-1}} + A_{FS_{Add_t}} \Big| q_{t-1_{Act}} < q_{t0} \qquad (7.6)$$

$$A_{FS\_t} = A_{FS_{t-1}} \Big| q_{t-1_{Act}} \geq q_{t0} \qquad (7.7)$$

q_{t0}…………… Quota to be fulfilled at t

q_{t-1Act}………..Actual quota fulfilled at t-1

7.6 Calculation of CO_2 savings and costs

CO_2 savings ΔCO_2 of a specific AEC are calculated as:

$$\Delta CO_2 = CO_{2\_fossil} - CO_{2\_AEC} \quad (7.8)$$

where CO_{2_fossil} are the corresponding CO_2 emissions of the relevance fossil energy carrier.

Costs of CO_2 savings $C_{\Delta CO2}$ are calculated as:

$$C_{\Delta CO2} = \frac{\Delta C}{\Delta CO_2} \quad (7.9)$$

ΔC………Difference in costs between a specific AEC and corresponding reference fossil fuels (e.g. between bioethanol and gasoline)

ΔCO_2…. Difference in specific CO_2 emissions between AEC and corresponding fossil fuels (e.g. between bioethanol and gasoline)

8. Scenarios for AEC in Austria up to 2050

In order to provide a sound assessment of the future prospects of alternative energy carriers, in the following we derive scenarios up to 2050 to show under which circumstances, to which extent and when specific alternative energy carriers could become economically competitive in Austria.

In order to be able to evaluate the long-term perspectives of AEC the following major influence parameters are considered in the scenarios:

- possible developments of fossil energy prices;
- global developments (particularly regarding technological learning effects), see Section 5 and Annex A);
- environmental and energy policies in Austria and at the EU level, mainly CO_2 taxes.

The scenarios for the development of energy prices incl. CO_2 taxes based on the assumptions made in Chapter 5 and the tax policy defined in Chapter 6 are summarized in Figure 8-1. It can be seen that after 2020 AEC start to become increasingly competitive. Depending on these price developments scenarios are developed, depicting which AEC are economically feasible on a long-term basis, until 2050 in Austria under different developments of the mentioned influence parameters. Most important is to identify which AEC can achieve a critical mass and relevant potential. The results in this chapter are mainly based on a “Policy Lead Scenario” (PLS) which corresponds to the assumptions of international deployments of biofuels and hydrogen according to IEA (IEA, 2006; IEA, 2008; IEA, 2009). In this scenario priority is given to the production of liquid biofuels over electricity. Based on this PLS further analyses of sensitivity are accomplished, in order to test the stability of the possible market entrance of the respective AEC regarding the changed parameters. From these analyses it is derived which market diffusion of the AEC is to be expected in a dynamic context and which AEC have a special relevance in Austria in the long-term.

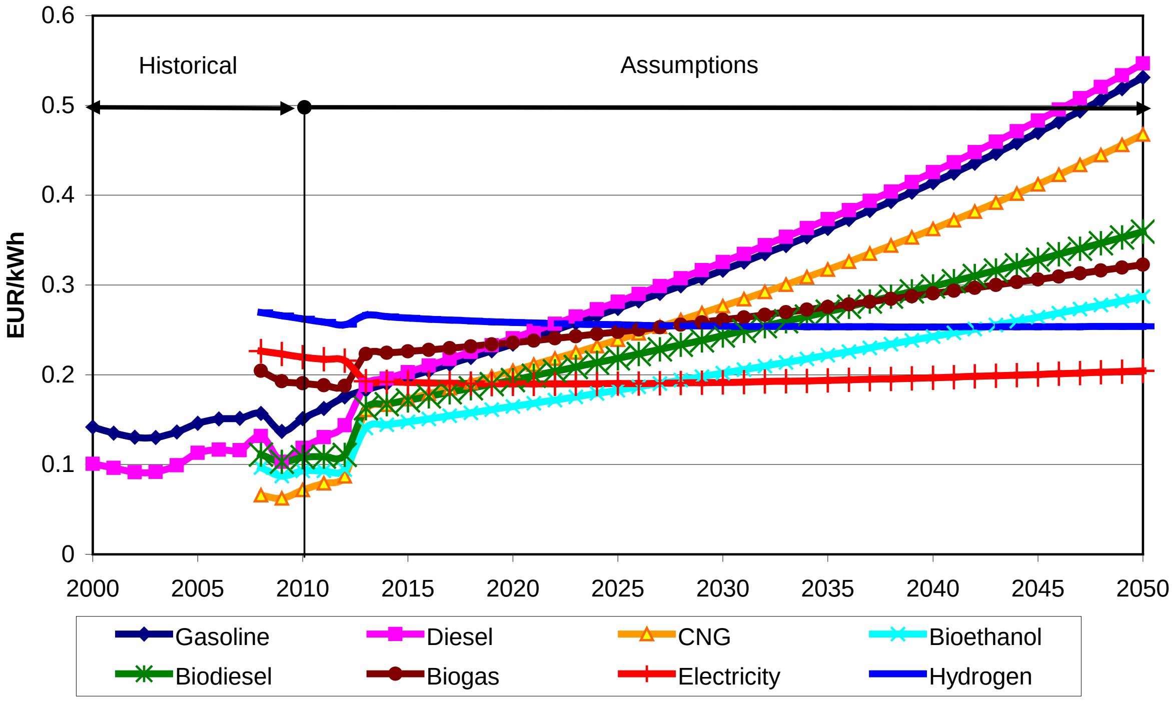

Figure 8-1 Fuel price developments including CO_2 tax up from 2013

In the following chapters we present the results of the corresponding quantities of AEC that can be possibly produced in Austria till 2050. A major focus is put on alternative energy carriers based on "new" biomass resources. An increasing use of biomass in the future in Austria could raise two issues: (i) the use of biomass requires large amounts of land which otherwise could be used for other purposes (e.g. food production); (ii) increasing biomass production might be in contradiction with sustainability issues.

8.1 Scenarios for AEC based on "new" biomass

In this chapter we conduct a comparison of AEC from "new" biomass (excl. pellets, wood chips, fuel wood) in the following scenarios:

1. Policy Scenario with arable land, with CO_2 tax
   - 1.A Policy Scenario with biofuels priority **(Policy Lead Scenario – PLS)**
   - 1.B Policy Scenario with hydrogen priority
   - 1.C Policy Scenario with no priority
2. Policy Scenario without arable land, with CO_2 tax
   - 2.A Policy Scenario with biofuels priority
   - 2.B Policy Scenario with hydrogen priority
   - 2.C Policy Scenario with no priority
3. No Policy Scenario: No arable land, no policies, no priorities – a Business-as-usual (BAU)-scenario

In the following the major results of these scenarios are depicted.

The Scenario 1.A is our major scenario, our **Policy Lead Scenario (PLS)**. The reason is that – as will be seen later – it finally produces the largest energy quantities up to 2050. Figure 8-2 depicts the energy production in this scenario. As can be seen in this scenario by 2050 finally more than 130 PJ of AEC will be produced. This is about four times more than in 2010. After about 2023, due to technology maturity, a significant and continuously increasing share of the 2nd generation bioethanol can be noticed. The share of 2nd generation biodiesel is increasing starting from 2032. Finally, most BD-2 are produced from corn stover (whole plant used) from arable land. In this scenario with biofuels priority SNG provide significant contribution to energy production starting from 2017. Yet, this takes place only if it can be managed that these technologies – BTL, FT-Diesel, SNG – become mature and if significant learning effects are achieved. Due to the finally better energetic and economic performance of BD-2 it also substitutes BE-2 production after 2040. However, it must be noticed that energetic as well as economic developments of the different categories of BF-2 are of course not known in detail today. Due to these uncertainties other fractions of BF-2 could also "win". What can be stated today is that – given that the economic performance of any BF-2 leads to cost-effectiveness under the suggested CO_2-tax policy – there is a significant potential for BF-2 after 2030 regardless which one will succeed.

A note on biogas: There is a temporarily slight decrease of biogas, because its production from maize silage will phase out. But on the other hand gradually more biogas will be produced from grass and cover crops.

Electricity will due to the priority for biofuels in scenario 1.A be produced only from those feedstocks which are not usable for biofuels production such as waste wood.

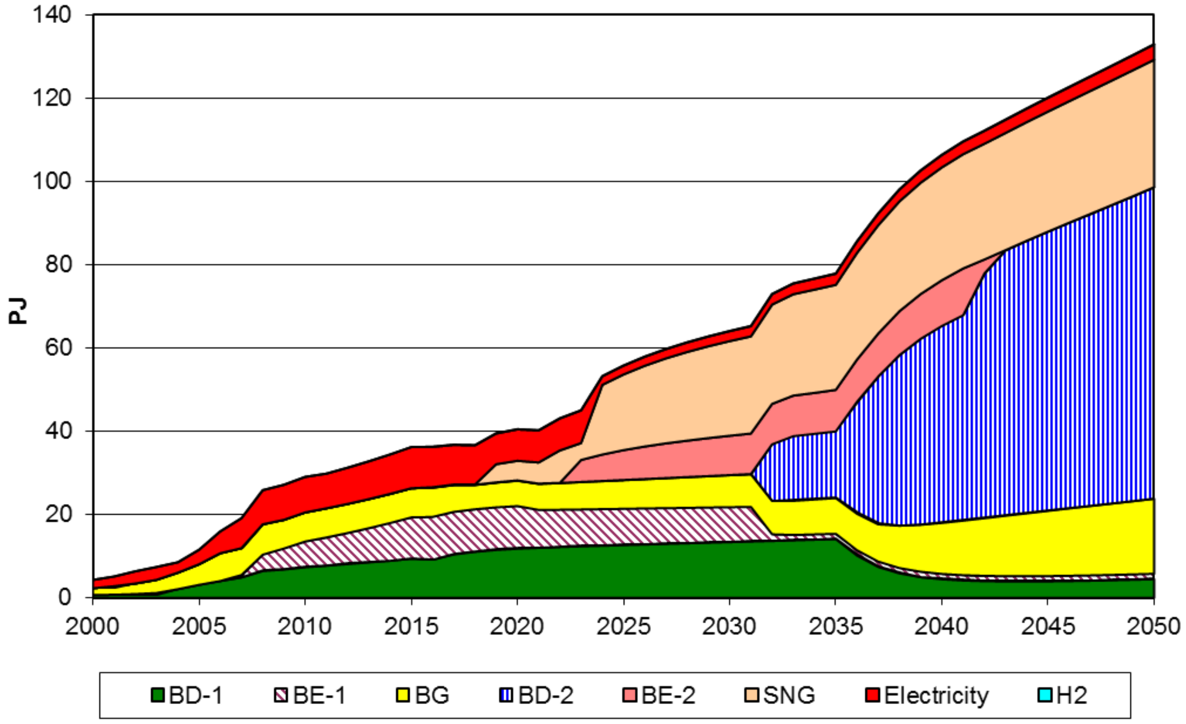

Figure 8-2 Energy production (final energy) in the Policy Lead Scenario 1.A (With max. 30% arable land in 2010, with CO_2 tax, and with priority for biofuels)

The major reasons why in Figure 8-2 BD-2 and SNG reach so high amounts are:

- they have highest energy efficiency and hence lowest feedstock costs;
- they have lowest CO_2-emissions and hence lowest CO_2-taxes.

As an alternative to biofuels hydrogen might serve as another option for an AEC. We present in Scenario 1.B the future development if a priority is given to hydrogen. That means that regardless of the economic preference hydrogen is produced from WIR and SRC with priority. Biofuels enter the market only if they are cheaper than electricity and if they are produced from the mentioned feedstocks. The result is presented in Figure 8-3. The total energy produced by 2050 is slightly lower than in Scenario 1.A.

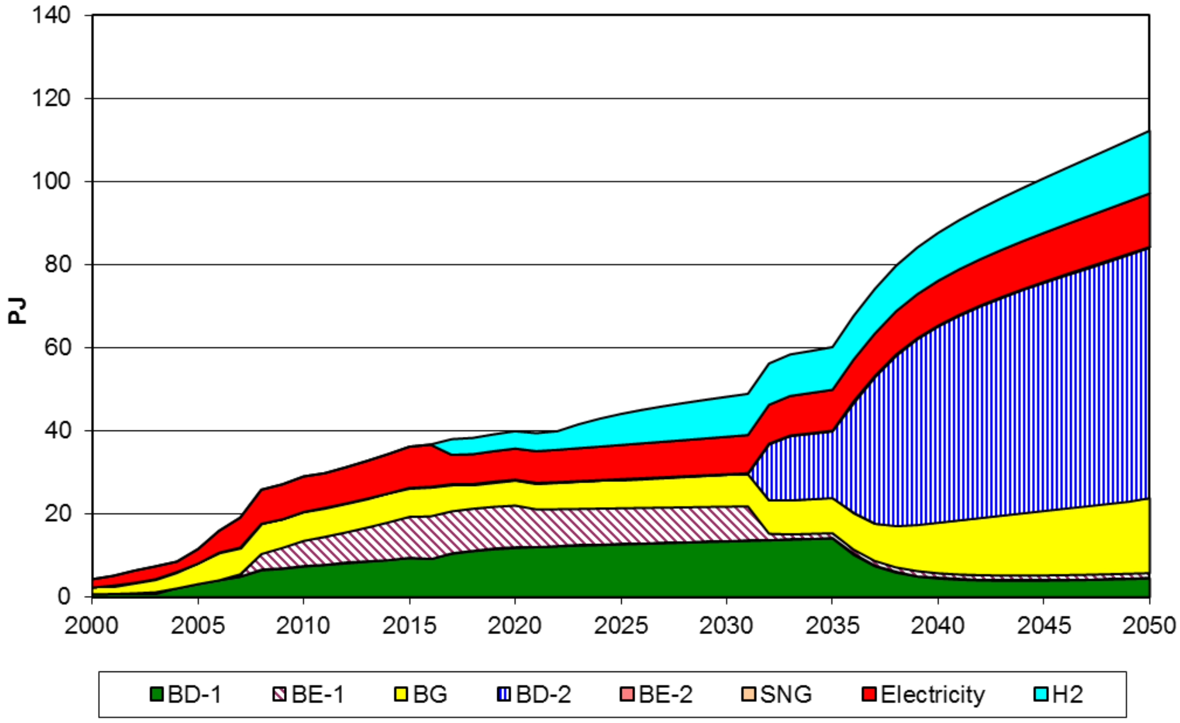

Figure 8-3 Energy production in the Scenario 1.B with priority for hydrogen (With max. 30% arable land in 2010, with CO_2 tax)

Energy production in the Scenario 1.C with no priority for biofuels or hydrogen is shown in Figure 8-4. The total quantity produced is about the same as in Scenario 1.B. In this scenario electricity plays a more important role than in the former scenarios, yet it is nonetheless not overruling BD-2.

Next we look at scenarios without the use of additional arable land up to 2050. Because the basic relations between the three different scenarios are the same as for the scenarios with arable land we only present Scenario 2.A, the scenario with priority for biofuels. The comparison of the results of all investigated scenarios is presented in Chapter 9 in Figure 9-1 and Figure 9-2.

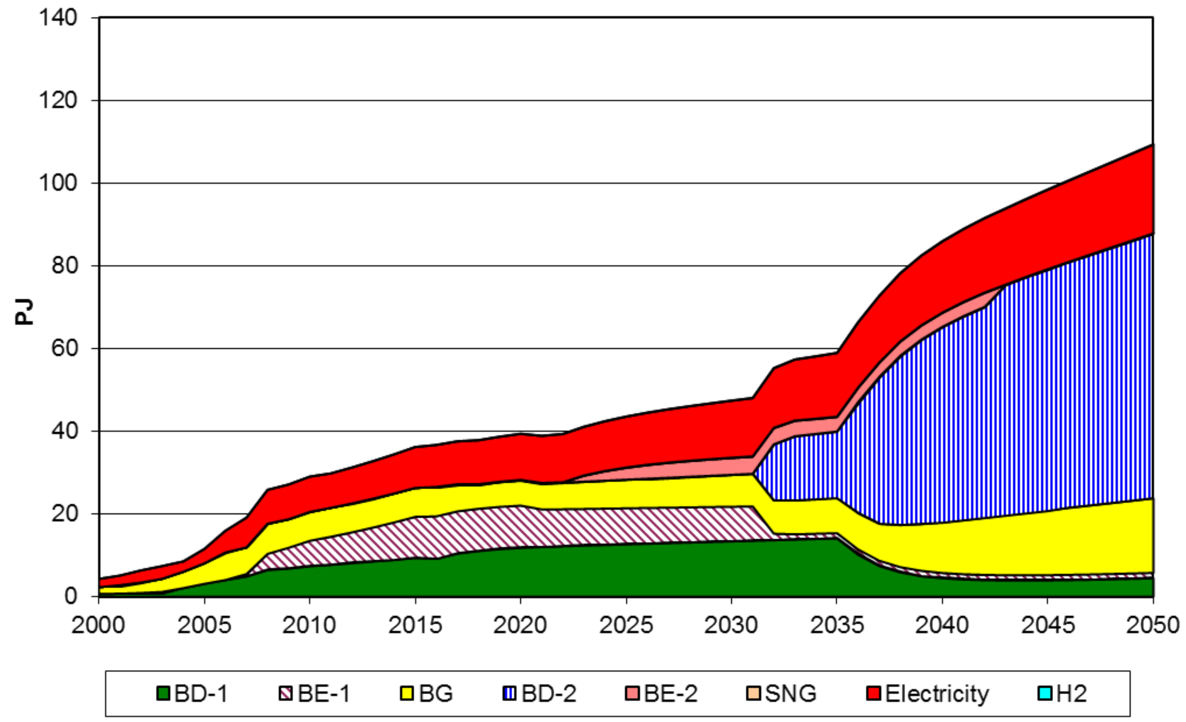

Figure 8-4 Energy production in the Scenario 1.C with no priority for any AEC (With max. 30% arable land in 2010, with CO_2 tax)

Figure 8-5 depicts the energy production in the Scenario 2.A – with CO_2 tax, priority for biofuels but without additional arable land. We can see that in this case the overall potential level is much lower – about 60 PJ less than in Scenario 1.A.

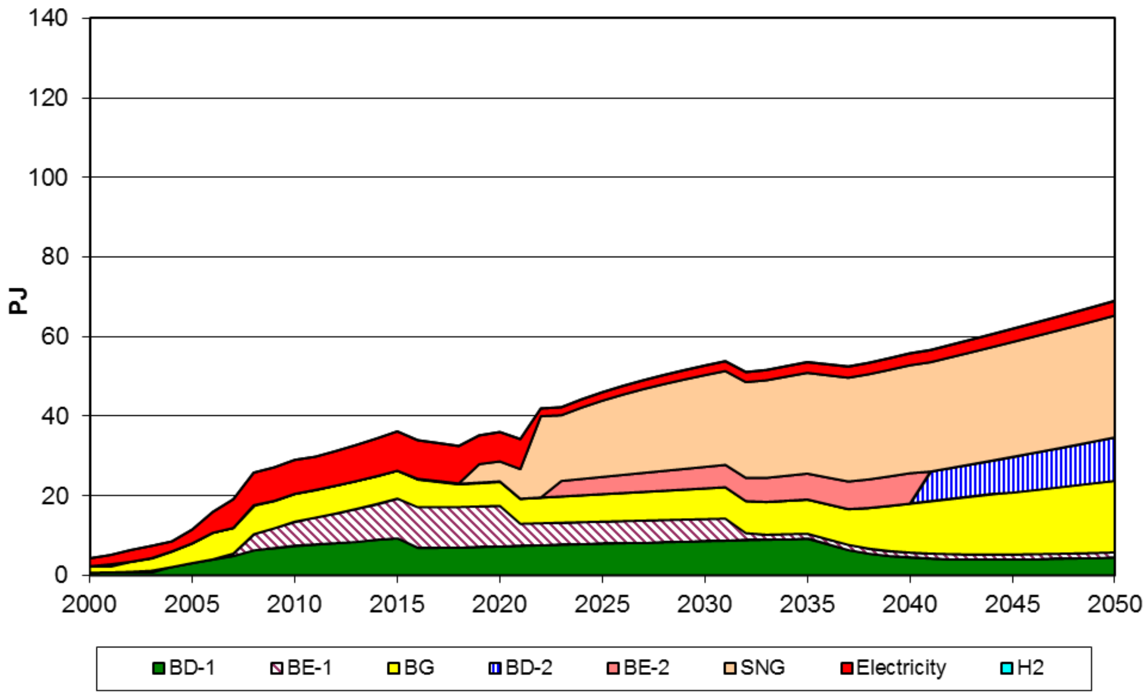

Figure 8-5 Energy production in the Scenario 2.A (No additional arable land, with CO_2 tax and with priority for biofuels)

Finally we depict the development without any new policies, without arable land and without any priorities for a specific brand of AEC. This scenario can also be considered as BAU-scenario and is depicted in Figure 8-6. In this scenario with no tax changes biofuels 1st generation remain in the market till 2050 and electricity retains a remarkable share. It is also important to note that there is virtually no difference in total energy output compared to Figure 8-5 but the fuel mix is different.

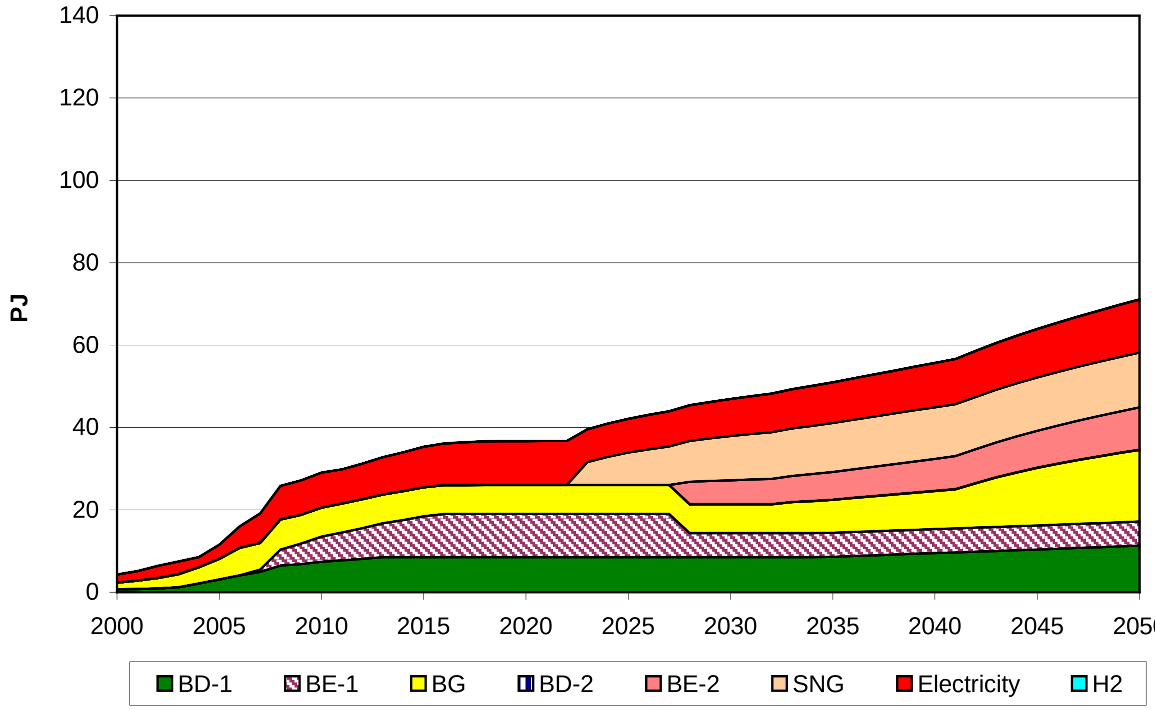

Figure 8-6 Energy production in the Scenario 3 (No additional arable land, no CO_2 tax, no priority for any fuels)

8.2 Scenarios for all AEC in Policy Lead Scenario

The next two figures compare the major results for energy production in the Policy Lead Scenario in addition to Figure 8-2 (which was for AEC from “new” biomass resources only, without pellets, fuel wood and wood chips and without electricity and hydrogen from non-biomass renewables e.g. wind, PV, hydro).

Figure 8-7 depicts total energy from AEC from biomass only - without electricity and hydrogen from non-biomass renewables (wind, PV, hydro).

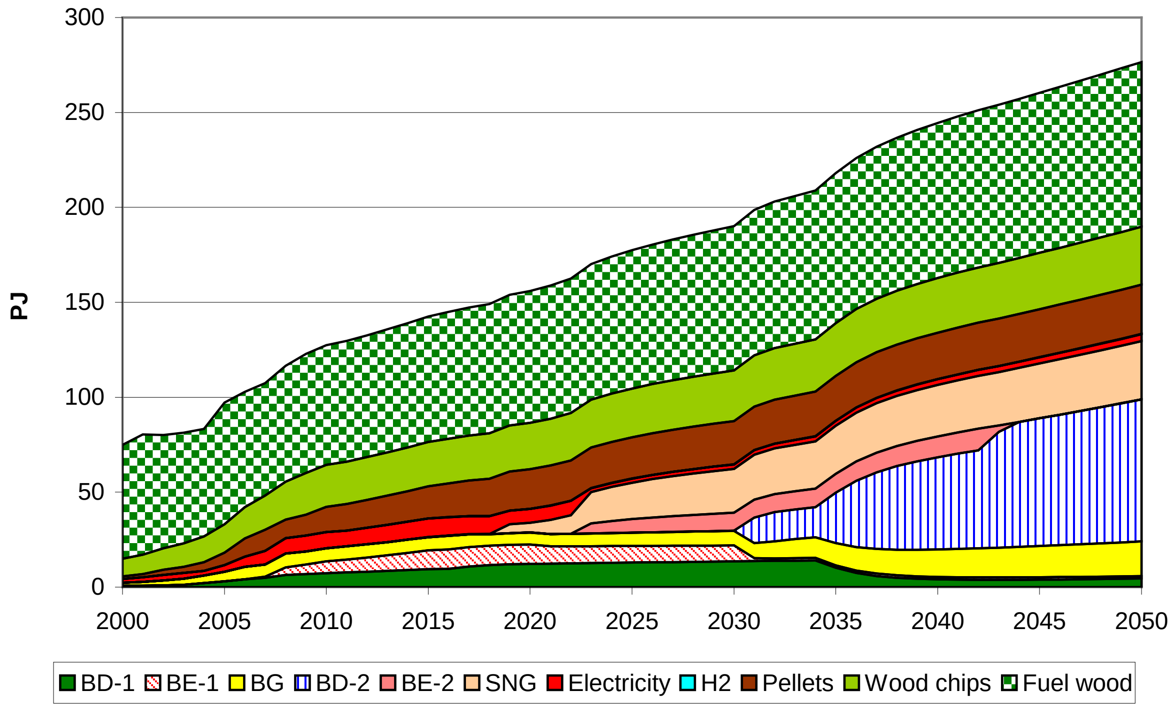

Figure 8-7 Total energy from AEC from biomass only in PLS

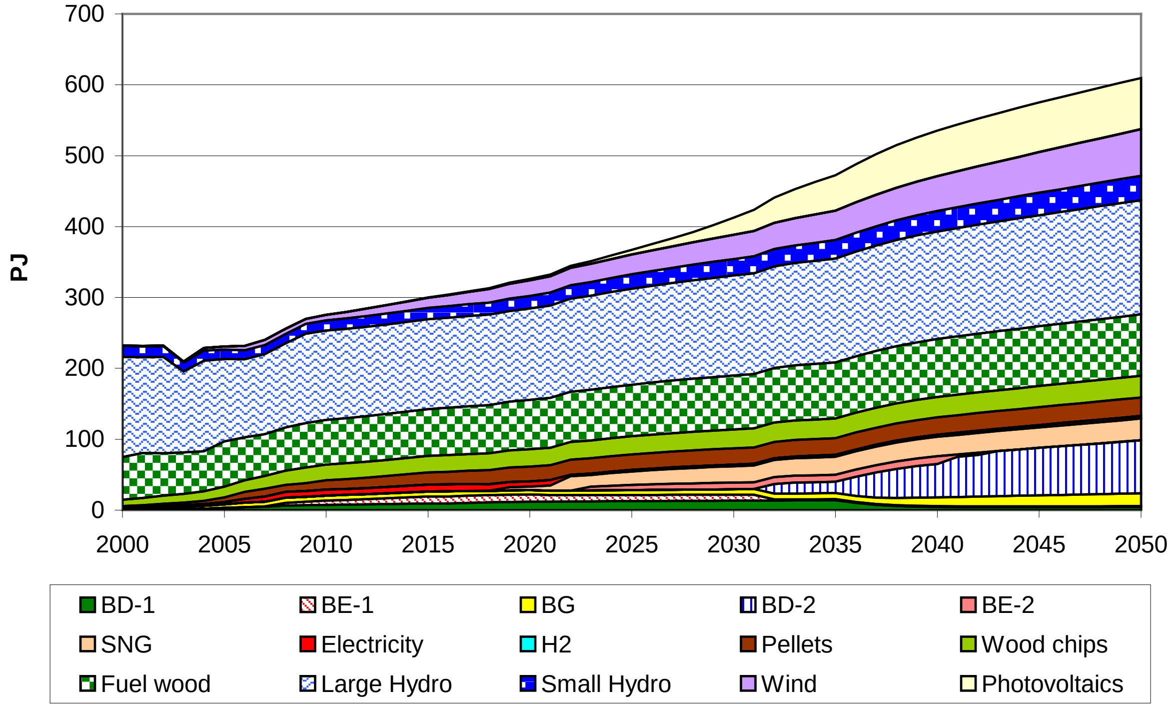

Figure 8-8 Total energy from AEC by AEC category 2010-2050 in PLS

Figure 8-8 shows the potential of AEC based on all available RES (incl. fuel wood and electricity from large hydro plants, wind and PV) till 2050.

These potentials for non-biomass based RES are based on Auer (2011), BMWFJ (2010), WIFO (2009), Streicher et al (2010). A summary table is provided in Annex F.

It can clearly be seen that hydro power, wind and photovoltaics can deliver significantly higher contribution than biomass-based energy carriers. In total the potential for 2050 – ca. 600 PJ (165 TWh) – would meet about 60% of the Austrian final energy consumption of the year 2009. In general view of all AEC we consider to be relevant by 2050, those which are based on new biogene resources (excl. fuel wood, pellets and wood chips), will in 2050 contribute to about 18%.

8.3 Effects of the Policy Lead Scenario on land areas and resources

The following figures depict the effects of the Policy Lead Scenario on land areas, use of resources and other details.

The increasing production of AEC based on domestically produced feedstock will occupy additionally land use, see Figure 8-9. (However, for 2nd generation biofuels mainly non- crop area dependent resources will be used).

This figure also depicts the change in the use of arable land. With growing economic attractiveness of BF-2 the arable land area is more and more used for whole plants like corn stover while BD-1 and BE-1 are phasing out. Moreover, we see from about 2037 an increase of biogas which is produced from grass, see also increase in used grass area, Figure 8-10.

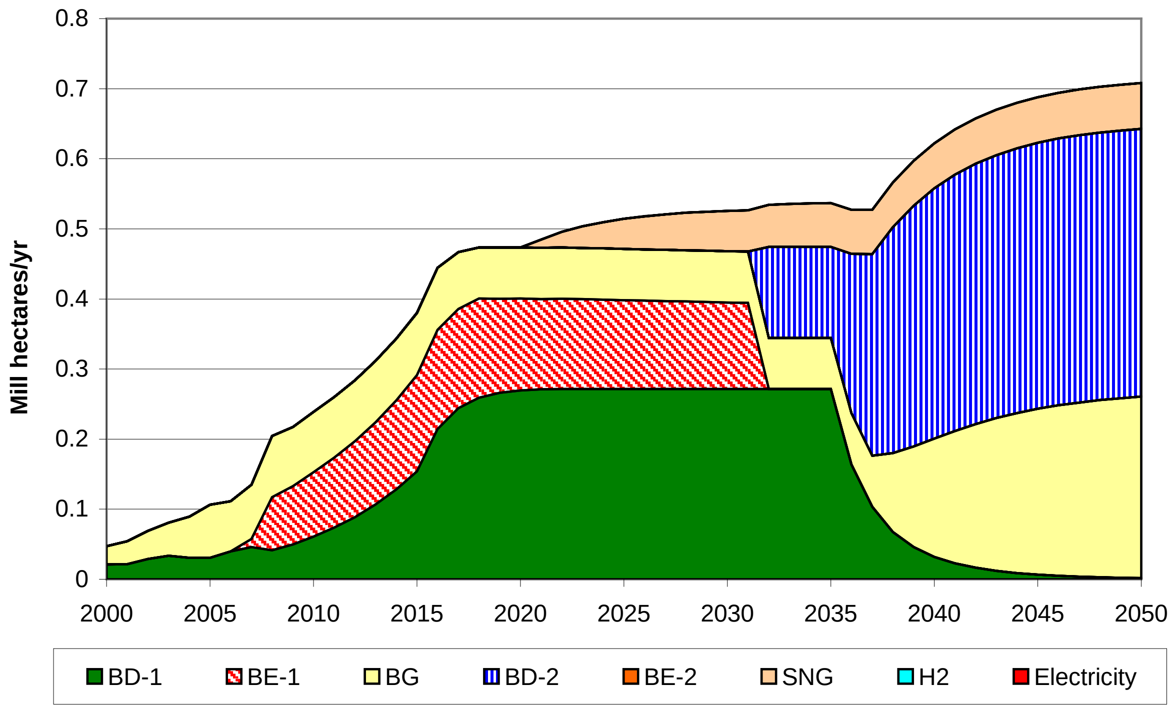

Figure 8-9 Total area for AEC by AEC category (excl. forest) 2010-2050, PLS

Due to the switch to the 2nd generation biofuels after 2020 also significant poplar areas could be used for feedstock production, see Figure 8-10. Total land area for biofuels production by 2050 will be about 0.7 Mill. hectares. Also the grass areas used for BG-1 production could increases finally up to about 200 000 ha. Note, that there is no competition with BF-2 for grass area.

Figure 8-11 depicts energy from AEC by type of feedstock. In this figure most impressing is that the share of corn stover for BF-2 increases considerably after 2035.

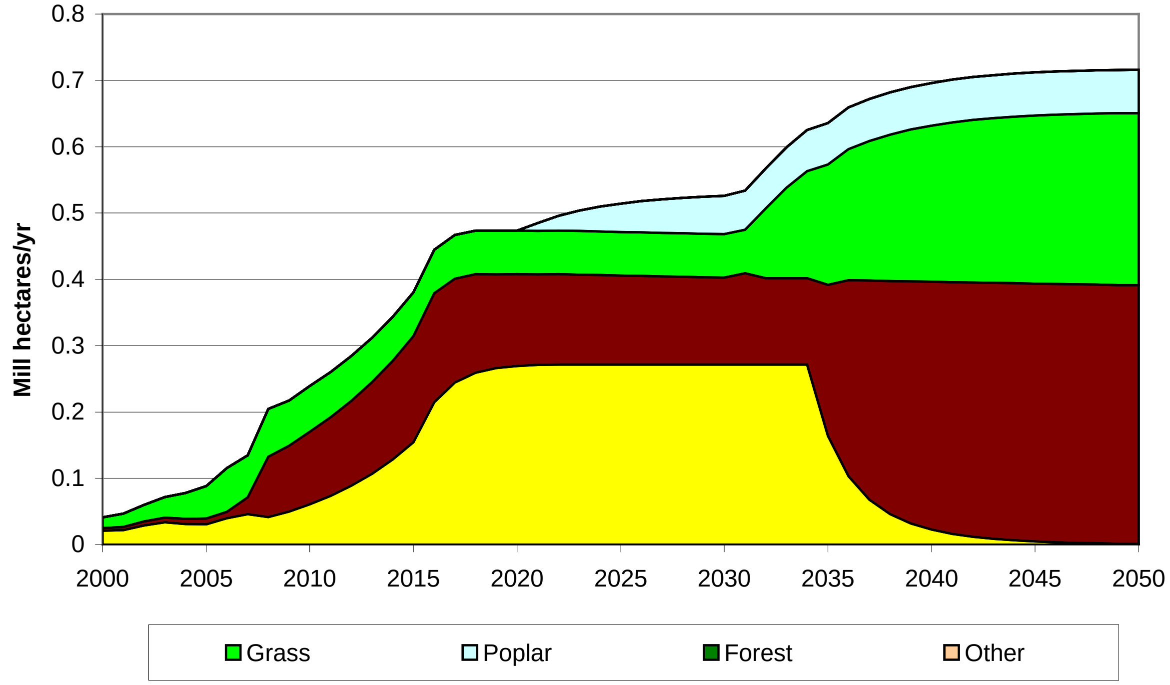

Figure 8-10 Areas for biofuels by area type, 2000-2050, in the PLS (excl. forest area)

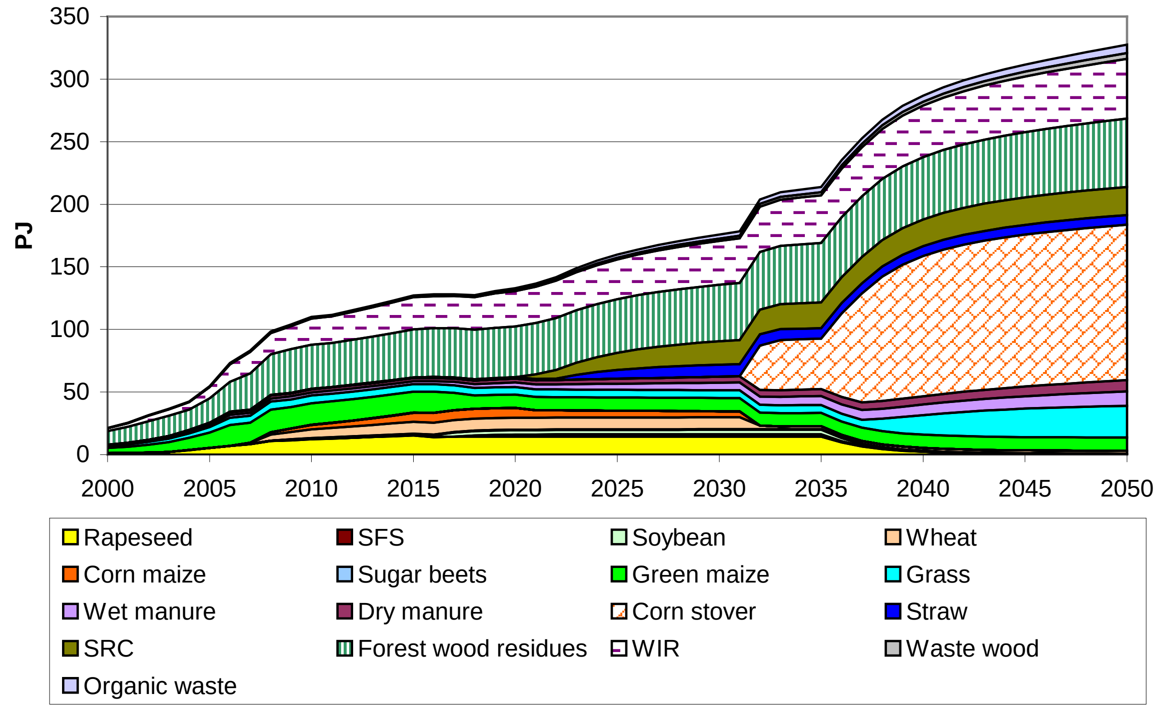

Figure 8-11 Energy from AEC from non-conventional biomass resources by type of feedstock, 2000-2050

Total crop area used for AEC by category of AEC is shown in Figure 8-13. We can see the mentioned switch from BF-1 to BF-2.

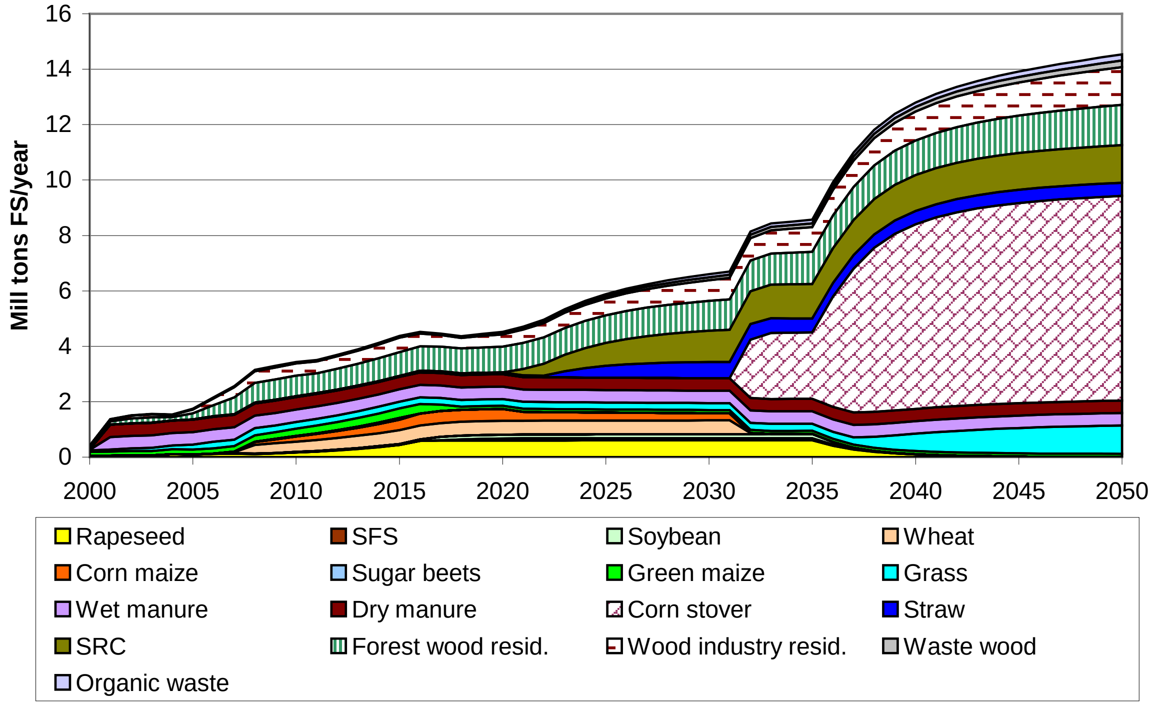

Figure 8-12 Tons of feedstock used for the production of AEC by type, 2010 – 2050

Figure 8-12 shows the corresponding tons of feedstock used for the production of AEC by type of feedstock.

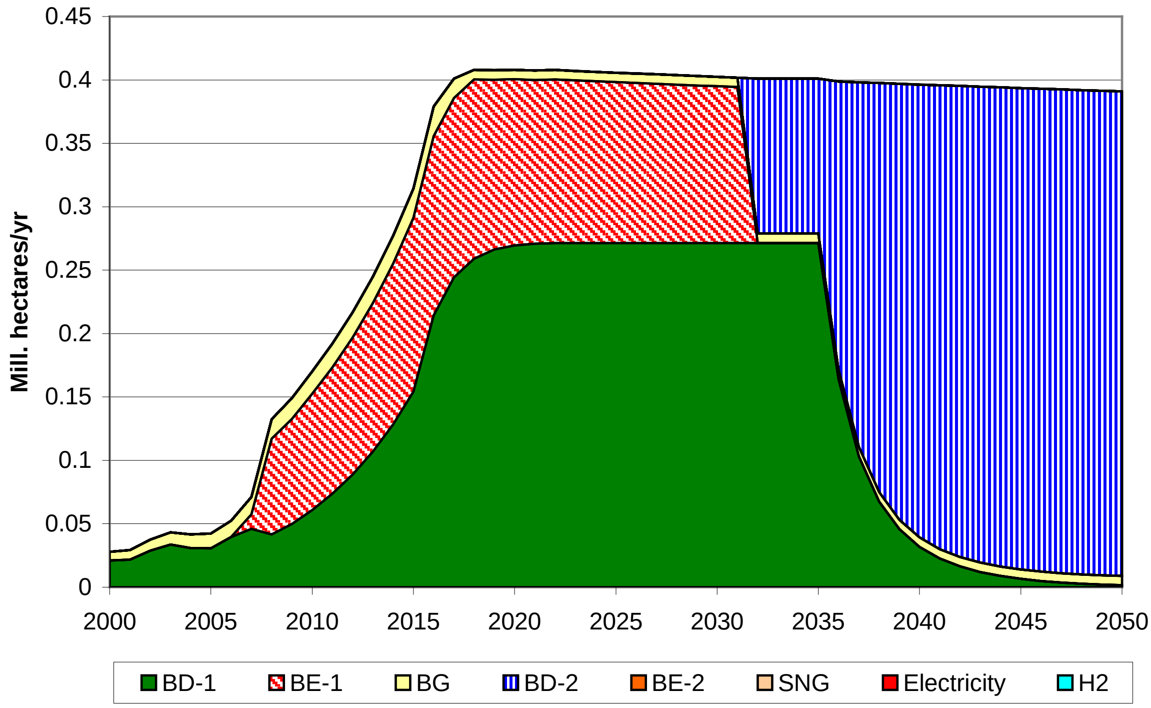

Figure 8-13 Total crop area used for AEC by category of AEC, 2010 – 2050

Of specific interest is finally how much energy can be harvested per hectare. Figure 8-14 depicts the energy output per hectare by type of feedstock. It can be seen that the steepest increase is possible for forest wood residues.

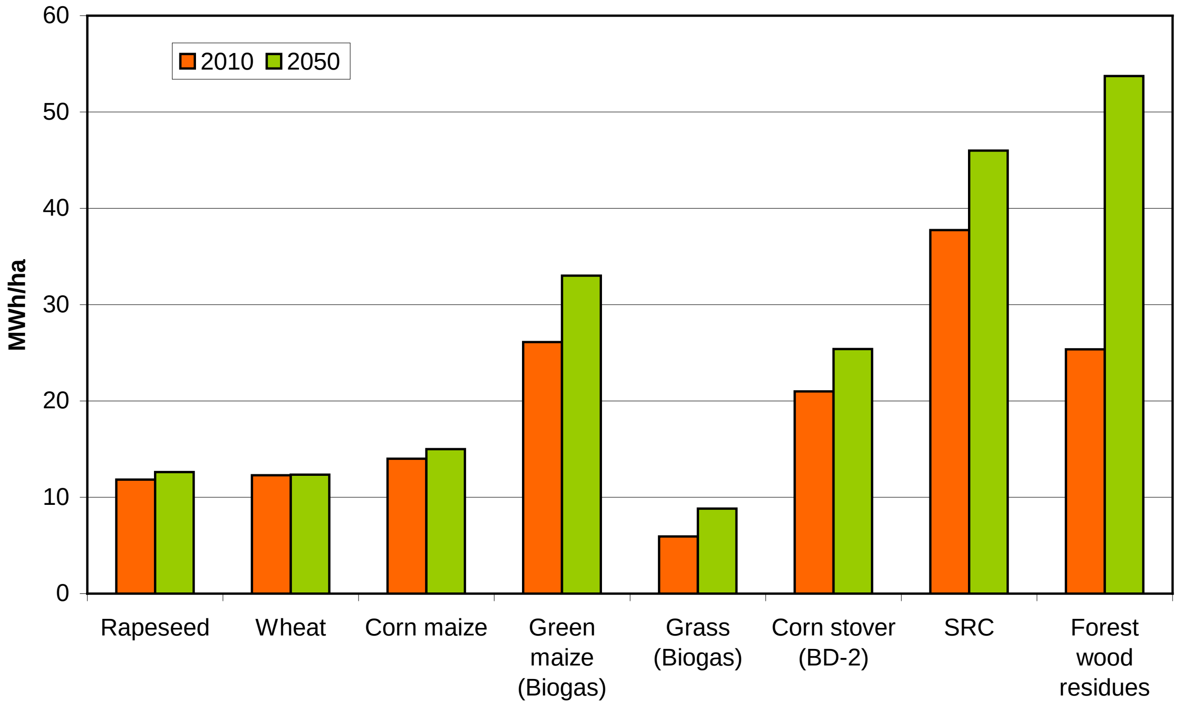

Figure 8-14 Energy output per ha by type of feedstock, 2010 – 2050

8.4 Effects on CO_2 emissions

One of the major reasons for a forced introduction of AEC is that they are expected to reduce GHG emissions significantly. The following figures depict for the Policy Lead Scenario, (Figure 8-2) the effects on CO_2 emissions in Austria.

In Figure 8-15 the costs of CO_{2eq} savings per GJ output of AEC in 2010 vs. 2050 in Austria are described. Hydrogen, electricity and BD-2 as well as SNG are from this point the most favourable AEC.

Aside from the emission savings also their costs are relevant. The costs of CO_{2eq} savings by type of AEC are depicted in Figure 8-16 over the period 2010 – 2050 in Austria in the Policy Lead Scenario. This figure shows very impressive that due to the increases in the prices of fossil energy carriers up from about 2020 the CO_{2eq} savings show negative costs. That is to say that after this period of time it is even profitable to use these AEC.

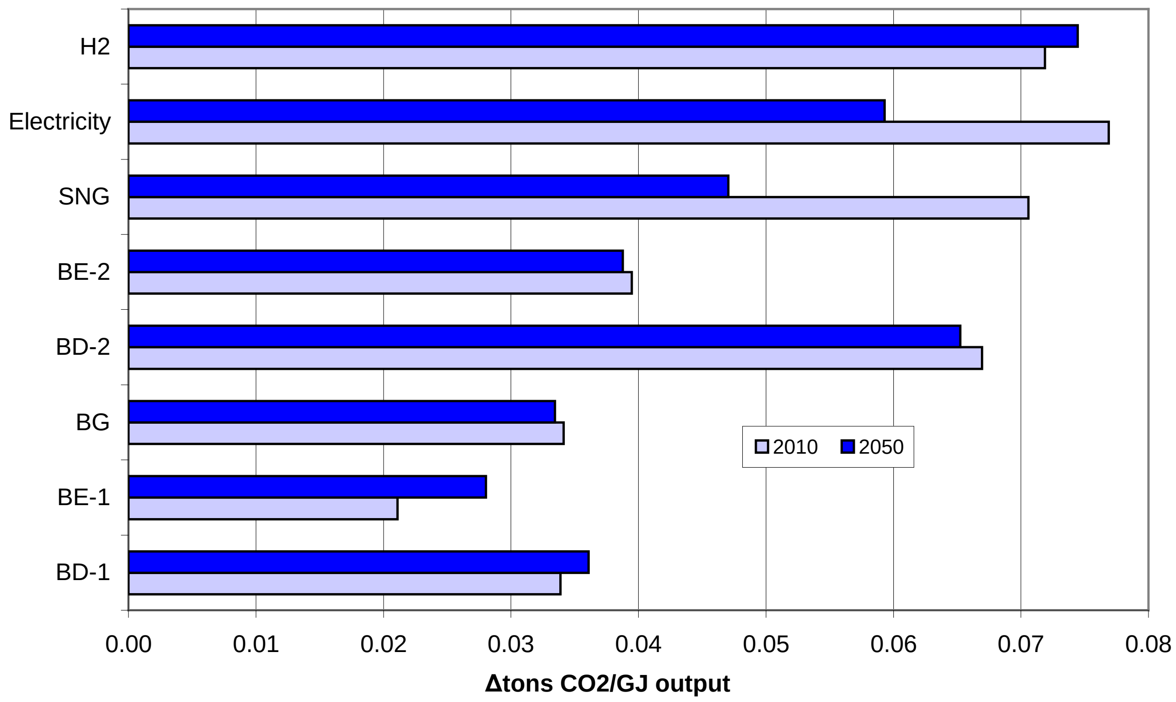

Figure 8-15 CO_{2eq} savings per GJ output of AEC, 2010 – 2050 in Austria

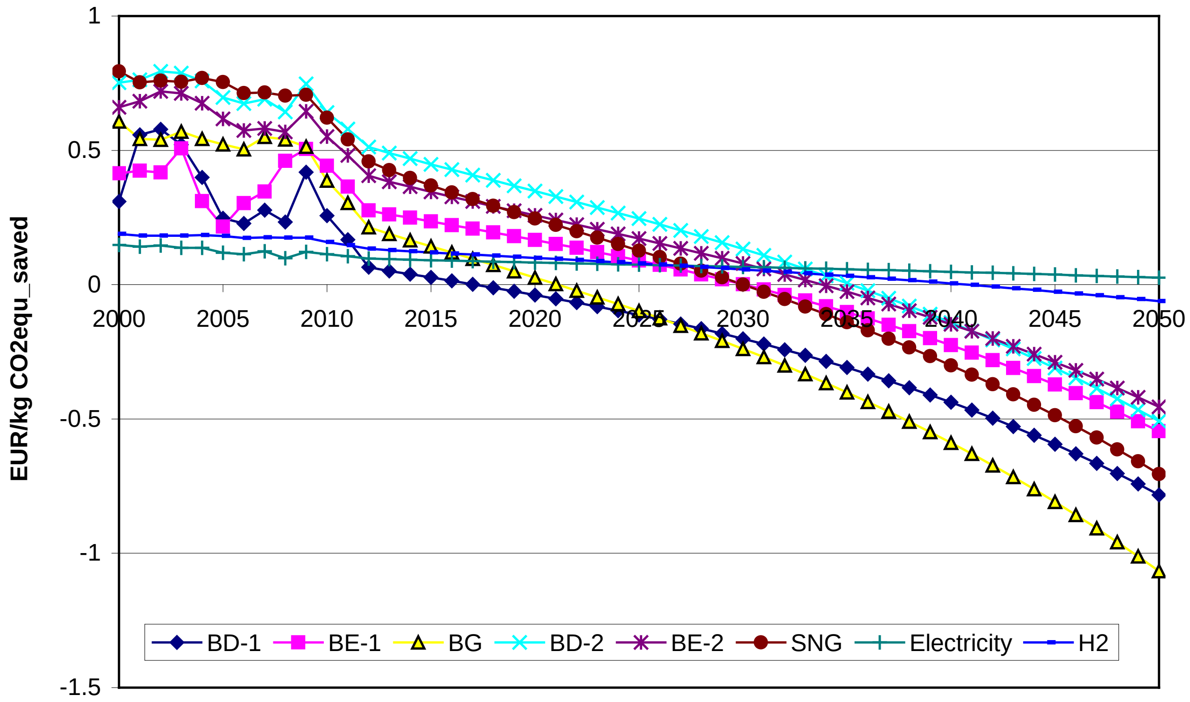

Figure 8-16 Costs of CO_{2eq} savings by type of AEC, 2010 – 2050 in Austria in the Policy Lead Scenario

The total CO_2 emission savings compared to fossil fuels are shown in Figure 8-17 (bioethanol compared to gasoline, biodiesel compared to diesel, biogas compared to gasoline and electricity and hydrogen compared to conventional production). It can be seen that with increasing shares of BF-2 the CO_2 savings increase. Finally, the largest shares of savings are achieved by the use of BD-2 and SNG. The remaining CO_2 emissions from AEC are depicted in Figure 8-18. Yet, most interesting is how the difference of savings vs. remaining emissions evolves. This effect is shown in Figure 8-19.

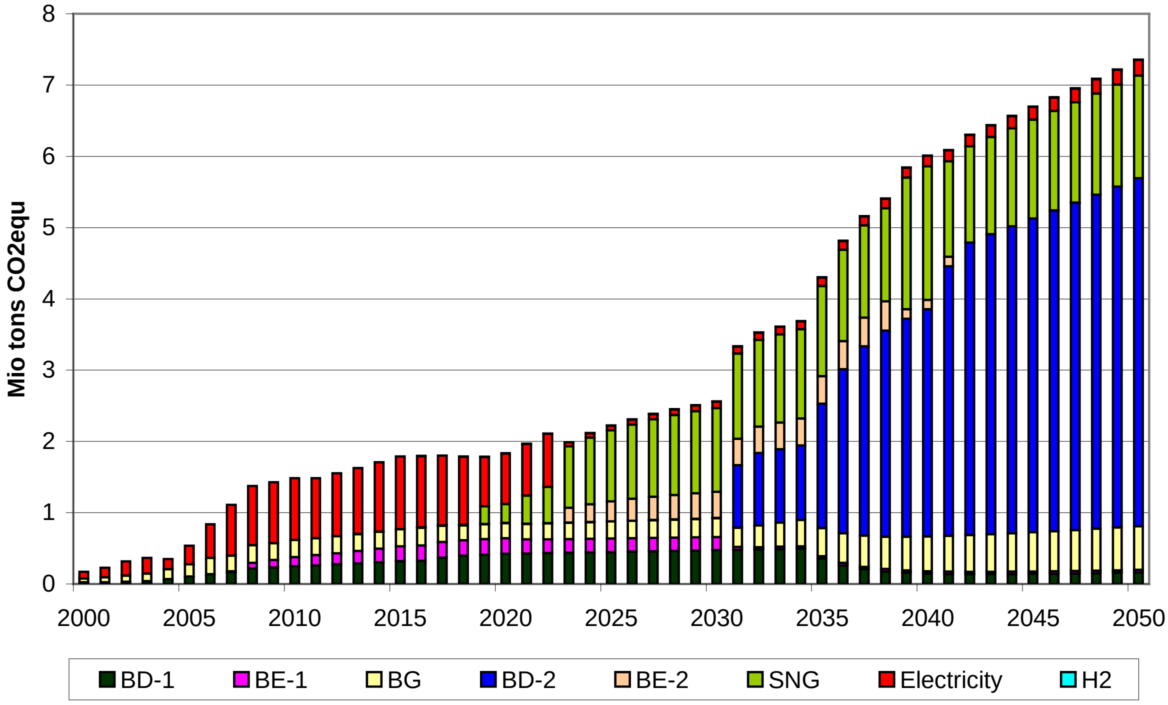

Figure 8-17 CO_2 emissions savings due to biomass-based AEC in Austria from 2000 to 2050 in the Policy Lead Scenario

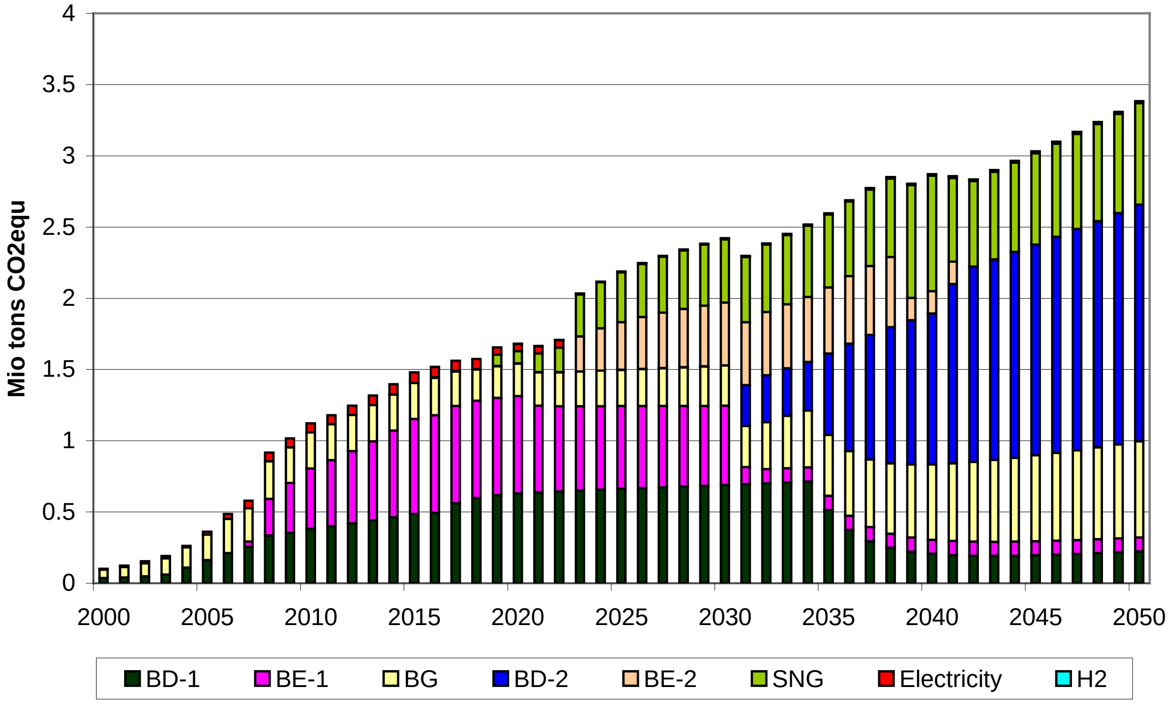

Figure 8-18 Remaining CO_2 emissions from biomass-based AEC in Austria from 2000 to 2050 in the Policy Lead Scenario

Figure 8-19 depicts the total CO_2 emissions from biomass-based AEC in Austria from 2000 to 2050 in the Policy Lead Scenario in comparison to total CO_2 emissions without the use of AEC. We can see that by 2050 the CO_2 emissions will be reduced finally by more than half.

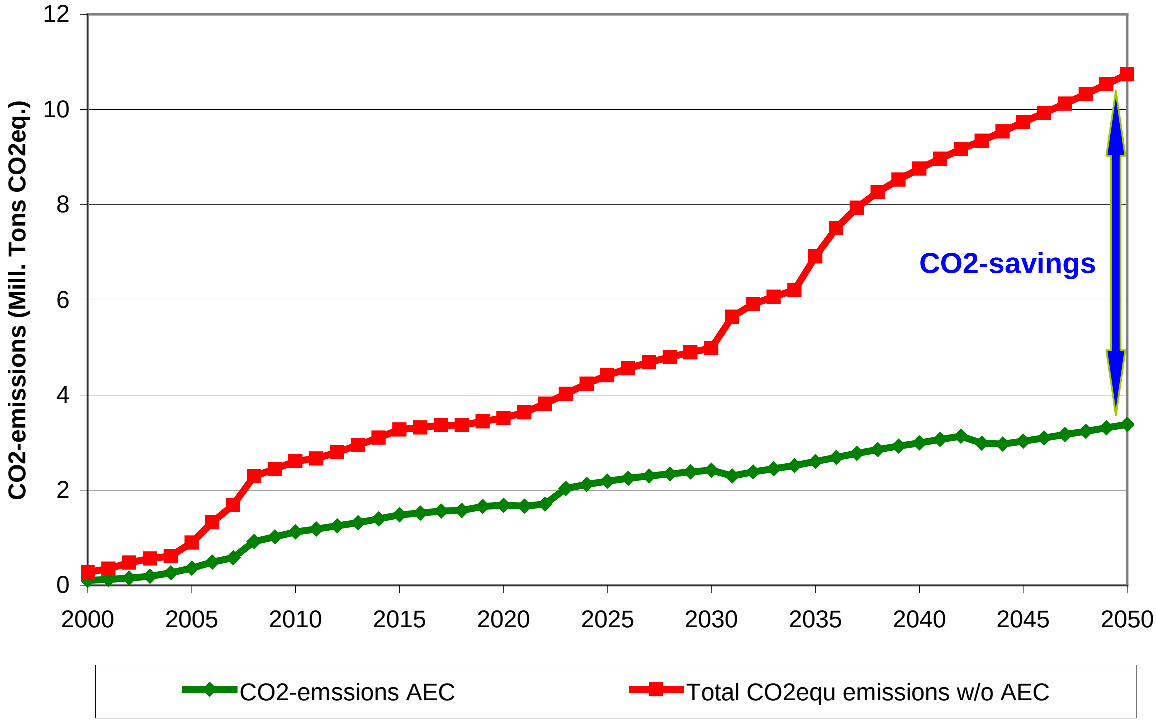

Figure 8-19 Total CO_2 emissions from biomass-based AEC in Austria from 2000 to 2050 in the Policy Lead Scenario in comparison to total CO_2 emissions without the use of AEC

9. Designing an Action plan

The most important result of this project is a concrete action plan for policy makers for a dynamic development of these potentials in form of strategies with the necessary accompanying energy-political instruments. These strategies are based on the scenarios depicted in Chapter 8. In this chapter recommendations for future priority-setting of technology research and development in the field of sustainable AEC in Austria are derived.

First, we compare the results of the scenario analysis conducted in Chapter 8. Figure 9-1and Figure 9-2 provide a comparison of energy outputs of different scenarios in 2050 with total energy consumption in Austria in 2010. The major perceptions of this Figure are: (i) Scenarios without the use of arable land show overall outputs which are about 60 PJ lower; (ii) Scenarios with biofuel priority have slightly better performance regarding overall energy output than those with no priority or with priority for hydrogen; The reason for that is mainly because biofuels 2nd generation (mainly FT-Diesel and SNG) have a better energetic conversion efficiency than other AEC; (iii) In the scenarios with no priority electricity has higher shares than biofuels and hydrogen mainly due to the lower cost and more mature technology.

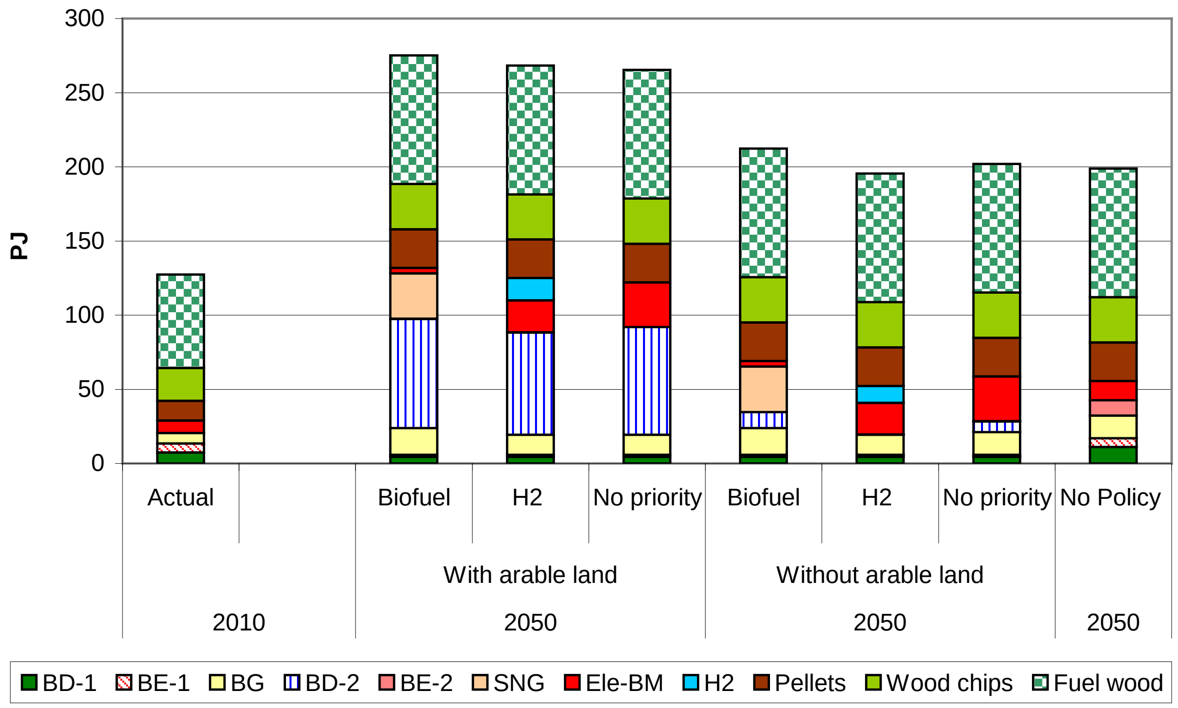

Figure 9-1 Energy outputs of different scenarios in 2050 from biomass-based AEC in comparison to 2010

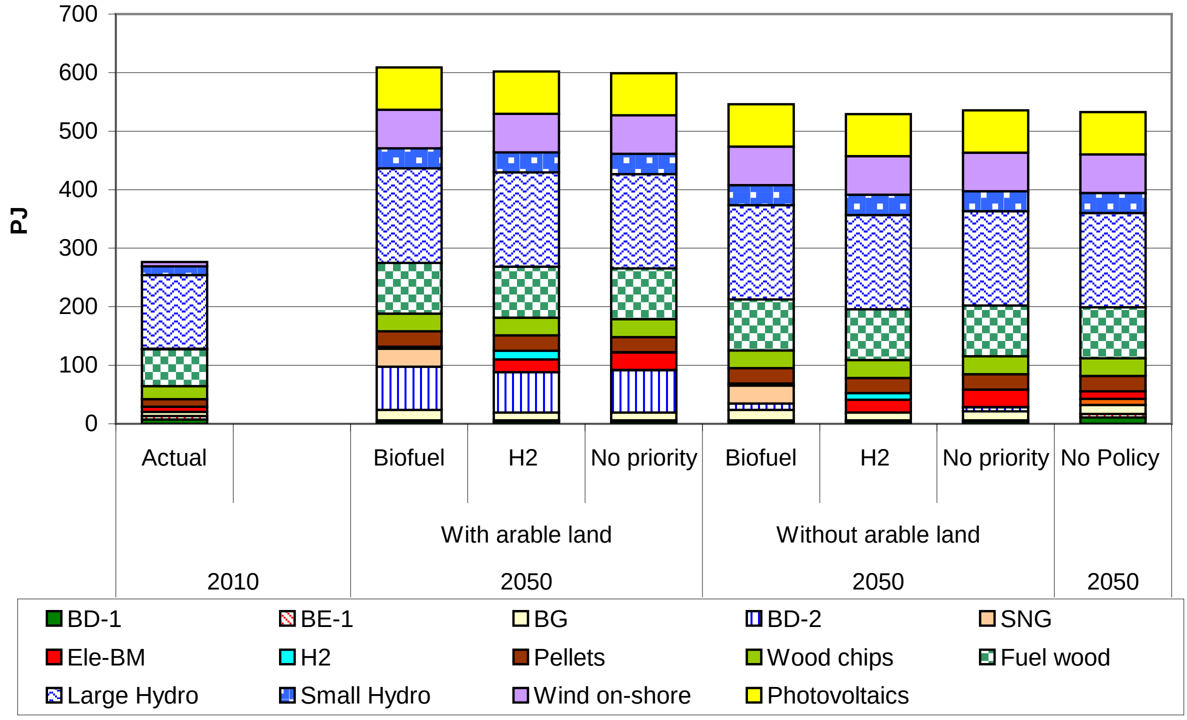

Figure 9-2 Energy outputs of different scenarios in 2050 from all AEC in comparison to 2010

Next, we try to find out which contribution these AEC can deliver to total final energy consumption. Figure 9-3 documents a comparison of energy outputs of different scenarios in 2050 with total energy consumption in Austria in 2010 (left side). The major perception is that based on 2010, with final energy consumption of about 1000 PJ, this contribution will be about 60% if arable land is also used for energy production, and about 55% if not.

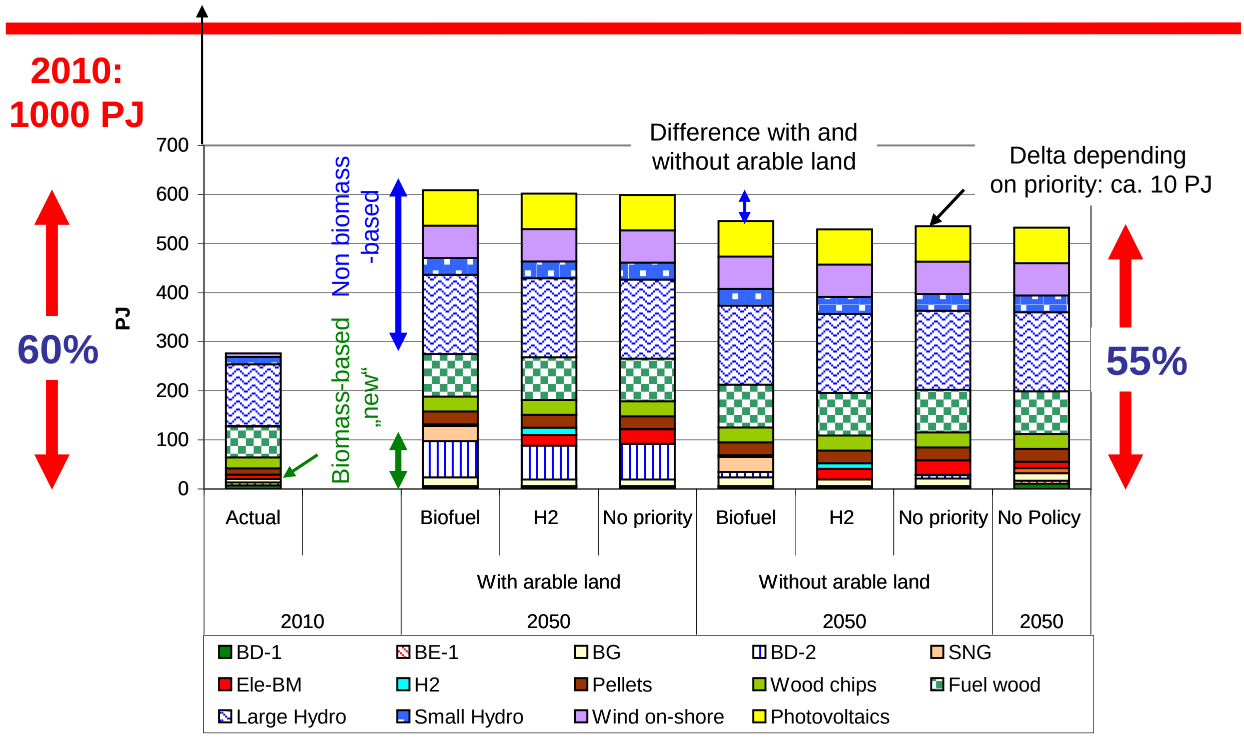

Figure 9-3 Comparison of energy outputs of different scenarios in 2050 with total energy consumption in Austria in 2010

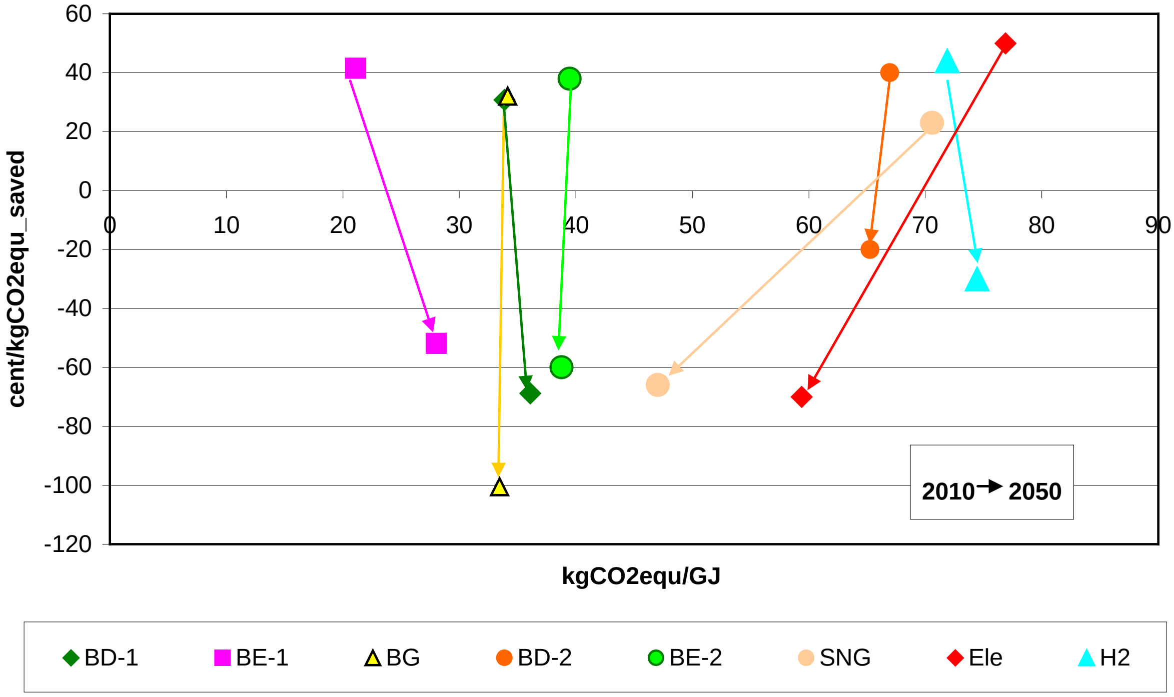

Figure 9-4 A comparison of the costs per kgCO2equ saved and the overall savings of CO2equ per GJ in 2050 in comparison to 2010

A comparison of the costs saved per $kgCO_{2eq}$ and the overall savings of CO_{2eq} per GJ in 2010 and 2050 is shown in Figure 9-4. The major perception is that up to 2050 costs of all investigated AEC will turn into profits. With CO_2 tax these AEC will earlier become profitable.

In a concise action plan the major steps towards harvesting an optimal portfolio of AEC in Austria up to 2050 are:

1. Introduction of a CO_2 based tax: This tax ensures that, depending on the dynamic ecological performance of different AEC, they will enter the market;
2. A rigorous tightening of the standards regarding CO_2 emissions of these AEC: It should be made sure that , e.g. by means of a strict and continuous certification and monitoring programme, the ecological balance mainly of BF-1 but also of the emerging new BF-2 is improved gradually.
3. A focussed R&D programme for 2nd generation biomass and for fuel cell with an accompanied performance evaluation from energetic and environmental point of view.

10. Conclusions

The major conclusions of this analysis are (see also survey in Table 10-1):

- While the economic prospects for the 1st generation biofuels are rather promising – cost-effectiveness under current tax policies exists already – their potentials are very restricted especially due to limited crops areas. Moreover, the environmental performance of 1st generation biofuels is currently rather modest; Up to 2050 the ecological and energetic life-cycle performance of BF-1 may slightly improve but this aspect has to be forced by policy, e.g. by means of introducing monitoring and certification shames;

- 2nd generation biofuels will – in a favourable case – enter the market between 2020 and 2030. However, their full potentials will be achieved only after 2030. The major advantage of the 2nd generation biofuels is that they can be produced also from resources such as lignocellulose based wood residues, waste wood or short-rotation copies, which are not dependent on food production-sensitive crop areas. From the ecological and energetic life-cycle performance BF-2 can bring about a significant improvement;

- Within the different brands of BF-2 it is not clear which one will be preferable or whether there will be a mix. We think that up to 2050 one specific category will turn out to be most cost-effective and from today`s point of view this will be Fischer-Tropsch diesel (BD-2) yet in stron competition with SNG;

- Since the 1st generation biofuels will be cheaper than 2nd generation biofuels till 2030 they will remain in the market at least until 2030;

- Hydrogen will not become competitive before 2050 and currently no reliable maximum future potentials can be estimated reliably;

- From our analysis regarding the energetic output we have found that for the use of biomass-based resources biofuels are slightly preferable to the production of electricity and hydrogen;

- An issue that especially influences biofuels are land-use changes. However, while we are convinced that they will play an important role in future in a world-wide dimension it is neglectable in Austria (see Figure 5-2);

- With respect to economics electricity production is and will over the next decades remain cheapest. It is the most mature technology and, especially because of the additional use of heat, it will retain its economic preference.

- Finally, Table 10-1 summarizes the major performance parameters of AEC. It is important to emphasize theirs core current weaknesses.

- Regarding BF-1 the major problems are still high CO_2 emissions due to rather large amounts of fossil fuels use. For BF-2 immature production processes and corresponding high production costs are the major impediment.

• With respect to electricity the problem of storage is still prevailing. And finally, the major barrier for a broader use of hydrogen is lack of mature technology – fuel cells that work at reasonable prices – to convert it into energy services.

Table 10-1 Survey on major problems related to the broader use of AEC as of 2012

	Production	***Storage***	***Conversion into services***	***CO_2 emissions***
BD-1 and BE-1	Minor problems	No problem	No problem	Problem of still large shares of fossil inputs
Biogas	Problem of high investment costs & low scaling and learning effects	No problem	No problem	No problem
BD-2, BE-2 and SNG	Problem of high investment costs. Problem, that the technology is so far not mature.	No problem	No problem	No problem
Electricity	No problem	Storage is still a costly problem	No problem	Depends on source of production (no problem with RES)
H2	No problem	No problem	A proper reliable and affordable conversion technology (fuel cells) is not yet available	Depends on source of production (no problem with RES)

The final major conclusion is that only if the portfolio of actions described above – CO_2 tax, ecological monitoring system, and a focussed R&D programme for BF-2 and fuel cells – is implemented in a tuned mix it will be possible to exploit the potential of AEC up to 2050 in Austria in an optimal way for society.

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Annex A

A. Technological Learning effects

Technological Learning (TL) is one of the major impact parameters on the future economic performance of AEC. For TL the learning rate (LR) is of key relevance. To obtain sound LR for the further analysis we have conducted a detailed investigation of this parameter.

A.1. Calculation of learning curves

The basic assumption of learning curve is that the production costs of goods in a competitive market progressively decline according to production volume.

Based on empirical data sampled from different technologies there is a fixed ratio between the doubling of the total volume produced and the decrease of production costs. This progress ratio is product specific and will not change, even if there is a doubling of the production output several times in succession. Instead of using product costs learning curves are often based on product prices as well. This is because historical data often refers to prices and less regularly to costs. Learning curves can be determined by price data, but additional effects, which needs additional interpretation, may occur.

The experience curve is described by the following mathematical expression (IEA, 2000):

$$C_t(x) = P_0 \cdot x^{-E}$$

C is price at year t, P_0 is a constant equal to the price at one unit of cumulative production or sales. X is cumulative production or sales in year t. E is the (positive) experience parameter, which characterises the inclination of the curve. HIgh values of E indicate a steep curve with a high learning rate.

The relation between the progress ratio (PR) and the experience parameter is:

$$PR = \frac{P_0(2X)^{-E}}{P_0 X^{-E}} = 2^{-E}$$

A learning curve is usually represented by total units produced against costs per unit.

In a logarithmic scale this produces a straight line (Figure A-1).

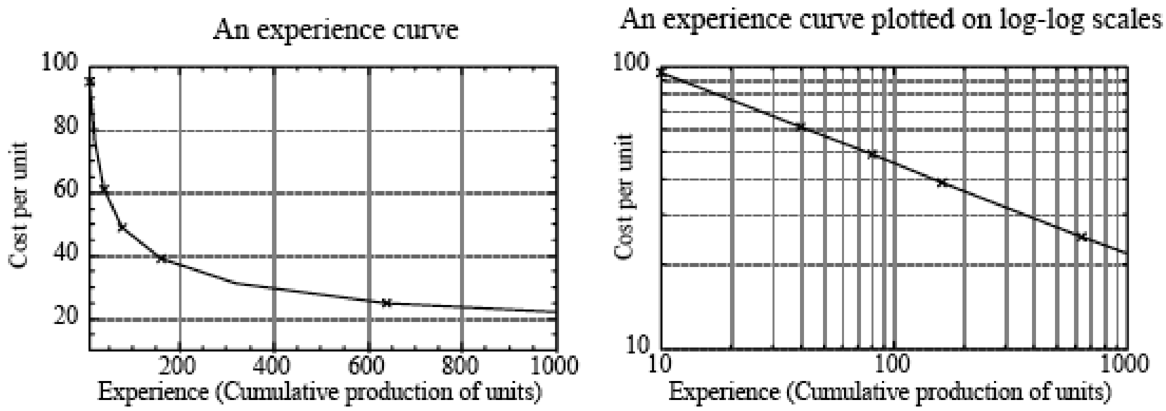

Figure A-1 Example learning curve with a progress ratio of 80% ((Needs 2006))

In interpreting experience curves it is important to ensure that the doubling of the produced units is measured by number and not over time. The time needed to achieve adequate production doubling has no effect on the learning rate. Therefore using learning curves in future scenarios always requires production volume scenarios.

A.2. Limitations in learning curve theory

Learning curves are tool to project production costs in the future. However, the use of learning curves is subject to certain limitations.

- The effect of rising material costs is not included in the short-term view. This applies also for geographical restrictions. The product costs may increase due to these factors, although the cost curve actually falls. An example of this is the production of solar cells, where a supply shortfall of silicium resulted in rising product costs for the manufacturers. This effect disappeared after enough silicium production capacity was built. The geographical potential restriction can for example be seen in the limited availability of arable land for cultivation of biomass substrates.
- Learning curves can be used to describe future production cost reductions but they can not predict price trends. Other influences may be crucial, such as political support for certain technologies or lack of raw materials. Therefore, when using learning curves for the development of scenarios these restrictions need to be considered additionally.
- Learning curves can describe cost development better than simple price assumptions over time. In long-term scenarios small variation of learning rates could lead to very different results in particular. Therefore, a bandwidth or framework assumptions are necessary.
- Learning curves can describe cost development for rising market penetration, but they give no indication whether this penetration will take place or not. Whether a product can succeed in the market depends not solely on the production costs. Therefore, the assumption of market penetration in external scenarios has to be set and cannot be done solely by learning curves.

- Political support may shorten the period in which doubling of production takes place. An acceleration of the learning rate is, however, not observed (Junginger et al. 2008)
- If there is no cost data available price data has to be used. Thereby additional uncertainties are brought into the calculation, which must be taken into account. A closer look at the account of price data in learning curves is to be found in Junginger et al. 2008.
- Through promotion of certain technologies a strong product demand may occur, resulting in rising prices. This effect cannot be shown in a learning curve. Rising prices may also have other causes such as commodity shortages, rising capital costs of reference technologies and changing exchange rates. This does not mean that the costs are reduced, but that the falling costs are not reflected in prices.

A.3. Learning curves

A.3.1. Learning curve of fossil fuelled power plants

Combined cycle gas power plants

The first combined gas and steam turbine power plants were built in the 70s and since that time continuously developed. They are among the most efficient clean electricity generation technologies with efficiency up to 60%. Typically they are operated with natural gas. For this technology a progress ratio of 90% is provided in literature (Junginger et al. 2008; Neij 2008; Needs 2006).

Coal-fired power plants

Coal power plants are an established technology for which there are few studies on learning curves (Neij 2008). A learning curve from Rubin (Rubin et al. 2007) shows a progress ratio of 95%. The creation of learning curves for coal-fired power plants is complicated because new technology components were added during the years. For these components internal learning curves can be created, which add to the whole cost development. This is true for desulphurization components (Rubin et al. 2007) (progress ratio 89%) and in the future maybe for carbon capture equipment (Fischedick et al. 2008).

A.3.2. Learning curves of renewable energy technology

Learning curves are often used to describe the possible future development of future renewable energy technology. This was necessary because the political targets for the renewable energies usually cover long time periods.

A.3.2.1. Photovoltaics

Photovoltaics is one of the technologies with the highest percentage growth increases in recent years and is thoroughly reviewed for learning curve effects. In the years 2003 to 2010, the annual increase in production was on average 50% (Figure A-2).

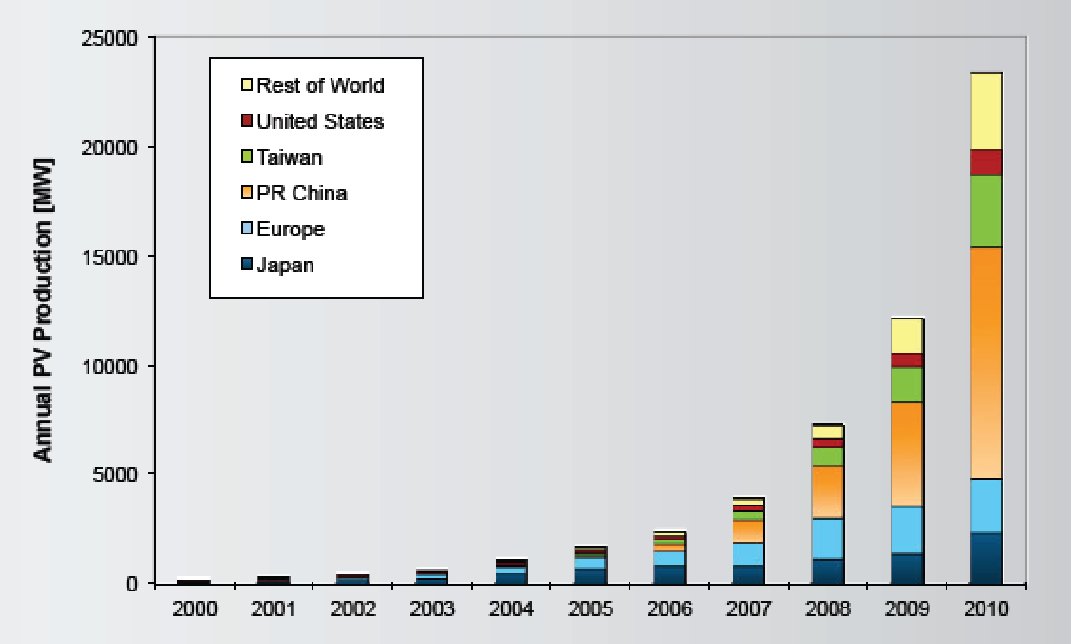

Figure A-2 Development of PV modules produced each year from 2000 to 2010 (Jäger-Waldau, 2011)

There are a number of studies about photovoltaic systems with significantly different results for the learning curve. The results differ between 53% and 90%. This is caused by covering very different regions, different technologies and different time periods (Table A-1). On average the progress ratio of PV modules is 77 to 82 (Needs 2006).

Table A-1. Learning curves for photovoltaic systems (Needs 2006)

PV system	Geographical area	Time period	PR	Source
PV modules (crystalline silicon)	Japan	1979-1988	79%	(Tsuchiya, 1992)
PV modules	USA	1976-1988	78%	(Cody and Tiedje, 1997)
PV modules	USA	1976- 1992	82%	(Williams and Terzian, 1993)
PV modules		1981-2000	77%	(Parente et al., 2002) (data source unknown)
PV modules		1968-1998	80%	(Harmon, C. 2000) (several different data source)
PV modules (crystalline silicon)		1976-1996	84%, 53%,79%	(OECD/IEA, 2000)(based on the EU atlas project and Nitsch 1998)
PV modules	Germany		app. 90%	(Schaeffer et al., 2004)
PV modules	the Netherlands		app. 90%	(Schaeffer et al., 2004)
PV modules	Globally*	1976-2001	75-80%	(Schaeffer et al., 2004)
PV BOS	Germany	1992-2001	78%	(Schaeffer et al., 2004)
PV BOS	The Netherlands	1992-2001	81%	(Schaeffer et al., 2004)
			74%	Maycock, 2002, referred to in Nemet, 2006
PV modules		1976-2001 1987-2001	80% 77%	Strategies Unlimited, referred to in Schaeffer et al., 2004

* The Photex study (Schaeffer et al., 2004) is based on 3600 units and 26 MW installed capacity in Europe over a 10 years period. List prices are used.

Estimates of the average global growth rate till 2012 is according to BTM (BTM Consult ApS 2008) 20.7% per year and between 2013 and 2017 15.4%.

A.3.2.2. Wind Energy

Wind energy is one of the oldest forms of renewable energy used. Since late 70s the main technology to harvest electricity from wind is an electricity generator with the typical three bladed rotors. From the first plants with a generating capacity of a few kWh the technology has developed to 5 MW units. The installed capacity has been increasing strongly since the mid-90s (for example Germany in Figure A-3)

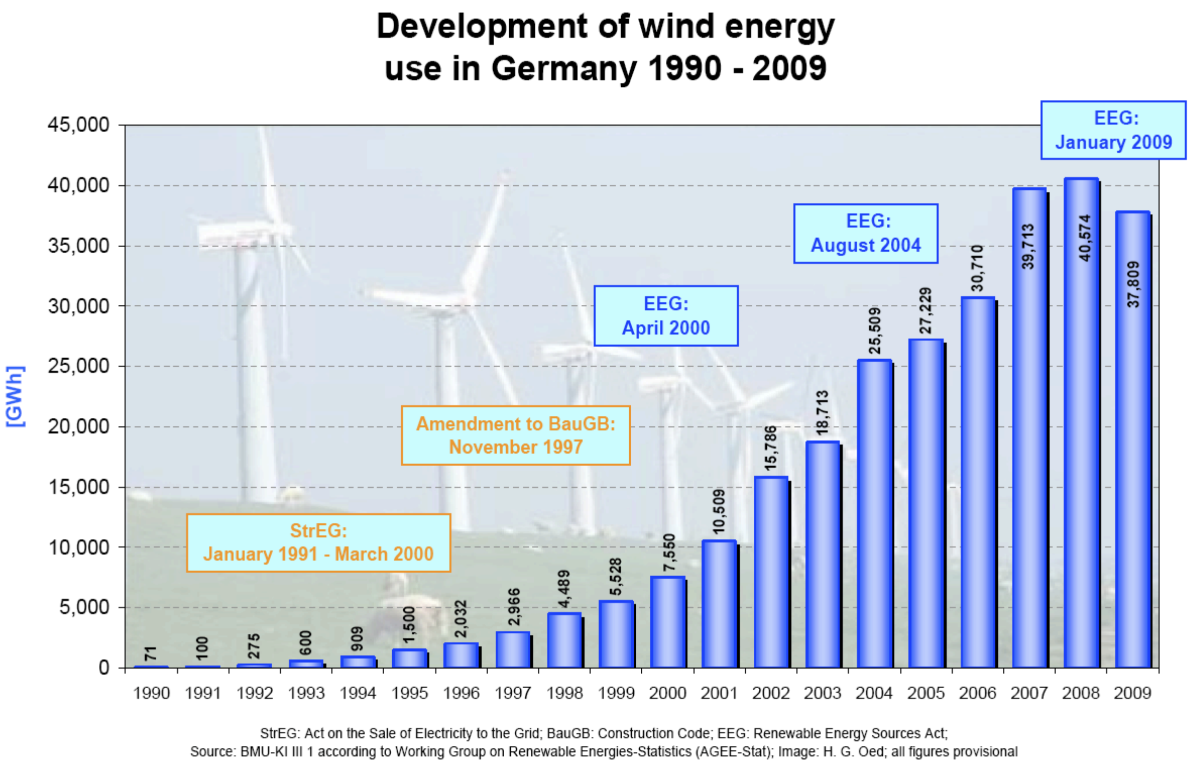

Figure A-3 Development of wind Energy use in Germany (BMU 2010)

There are a variety of learning curves for wind energy with a wide variation of cost development (Table A-2). This is partly because of the different areas and timeframes, which are examined. Combining all these variations there is a progress ratio from 91 to 94 % for Germany, Denmark and Spain (Junginger et al. 2008).

The production costs of wind turbines have been reduced significantly. The key technological drivers of this development were the increase of the turbine size.

Table A-2. Literature review of learning curve for onshore wind (Junginger et al. 2008)

Author	PR	Time frame	Region	n	R^2	Data qual.	Notes
Capacity of turbines / wind farms							
Mackay and Probert, 1998	85.7%	1981-1996	US	6.5	0.945	II	
(Durstewitz and Hoppe-Kilpper, 1999	92%	1990-1998	Germany	5.6	0.949	I/II	
(Neij, 1999	92%	1982-1997	Denmark	n.a.	n.a.	I/II	Danish-produced wind turbines
Seebregts et al., 1998	87% / 90%	n.a.	Denmark	n.a.	n.a.	II/III	
Lund, 1995	85%	n.a.	Denmark	n.a.	n.a.	II	
Neij et al., 2003	92-94%	1981-2000	4 countries[c]	n.a.	n.a.		Turbines *produced* per country
Milborrow, 2002	84.7%	n.a.	Danish manufacturers	7.1.	n.a.	II	
Neij et al., 2003	92-94%	.	Several WT manufacturers	varying	0.74-0.99	I	Produced wind turbines in Denmark and Germany
Neij et al., 2003	89-96%	1981-2000	4 countries[c]	varying	0.85-0.94	I/II	Turbines installed in a country
Junginger et al. 2005	81-85%	1990-2001	Global	3.3/3.6	0.875-0.978	II	Price data from the UK and Spain combined with global installed capacity
Junginger et al. 2005	91-101%	1991-2001	Germany	7.3	0.80-0.995	I/II	Turbine prices / wind farm prices, two clear phases: 1991-1995 (PR 91%) and 1996-2001 (PR 101%)
Taylor et al., 2006	85%	1982-2000	Global	n.a.	n.a.	II	Price data from California combined with global installed capacity
Cost of electricity							
Neij et al., 2003	86-88%	1981-2000	4 countries	n.a.	0.87-0.97	I	specific electr. production by a country, x-axis measures cum cap. (MW) installed
Neij et al., 2003	83%	1981-2000	Denmark	n.a.	0.97	I	levelized electr. production by a country, x-axis measures cum cap. (MW) installed
Taylor et al. 2006	85.5%	1981-2002	California	n.a.	0.88	II	

± Data estimated from a figure, as exact numbers were not given.
n Number of doublings of cumulative production on x-axis.
R^2 Correlation coefficient.
n.a. Data not available.
I cost/price data provided (and/or confirmed) by the producers covered
II cost/ price data collected from various sources (price lists, books, journals, press releases, interviews)
III cost/price data (or progress ratio) being assumed by authors, i.e. not based on empirical data

The situation for the offshore wind energy is a different one. According to the very different conditions between onshore and offshore there has to be different learning curves. Offshore facilities are built on the seabed, which requires a different technology for the anchoring of the tower compared to onshore technology. In addition, the cost components for the grid connection and for maintenance are much higher. Offshore plants have been built since 90s, today there are only a few plants in operation. Most energy scenarios predict a significant increase in proportion of offshore wind energy (Nitsch und Wenzel 2009). The progress ratio from these studies is between 92 to 97% for the total investment costs (**Table A-3**).

Table A-3. Literature review of learning curve for offshore wind (Junginger et al. 2008)

Source	Progress Ratio		Period	n[a]	R^2	Data quality	Notes
Lako, 2002	Rotor and nacelle	Balance of plant	1991-2007 (?)	~ 6.9 (NS[b]) - ~ 10 (OS[b])	N/A	III	PRs for on- and offshore Reference case wind are assumed in the range of ~ 90 - 96%
'Reference'	90%	95-97.5%				III	
'Low'	90%	92.5-95%				III	Case *low* analyses sensitivity to lower PR values
Junginger, 2005	Offshore turbine	81-85%	1991-2007 (?)	~ 7.8	N/A	II	Based on learning Cost reduction of 1-2% per year for steel: 15-20% cost reduction for foundations until 2020 observed for onshore wind
	Foundation	See text		N/A	N/A	III	
	Grid connection	62-71%		N/A	0.966-0.583	I	PR for HVDC cables 62%, PR for HVDC converter stations 71%
	Installation	77-95%		N/A	0.967	I	Marginal turbine installation time PR 77%
Isles, 2006	One-phase case (see note)	97%	1991-2007	~ 8.0	0.0578	I	Initially, Isles determined a Progress Ratio for the total period (one stage) of 97%
	Two-phase case (see note)	90-113% ('price umbrella')	1991-2007	~ 8.0	0.623-0.172	I	Learning (PR 90%) ends at approx. 300 MW cumulative capacity, after which prices increase (PR 113%)

a n = number of doublings of cumulative capacity.
b NS = Near Shore, defined as wind farms near the shore of Baltic Sea (Denmark and Sweden), and IJsselmeer (Netherlands); OS = Off Shore, defined as the balance, viz. the North Sea, Irish Sea, etc. (Lako, 2002)
I Data based on prices of offshore wind farms.
II Data based on scarce prices of offshore wind farms.
III Data based on scarce evidence or assumption.
Sources: Lako, 2002; Junginger, 2005; Isles, 2006.

The key reasons for the reduction in the cost of offshore wind energy in recent years are the increasing capacity of wind turbines, the larger capacity of wind farms and reduced cost of installation structures (vessels and port facilities).

A.3.2.3. Biomass

The data on learning curves for bio-energy plants is significantly narrower than for wind power and photovoltaic. One of the reasons is certainly that it is more difficult to show learning curves for biogas plants. There are different literature sources for individual biomass technologies, but few sources of biomass systems. Biomass systems (Junginger et al. 2008) consist of three modules, each subject to different learning curves: plant design and plant use, the crop biomass and the actual conversion technology (Figure A-4).

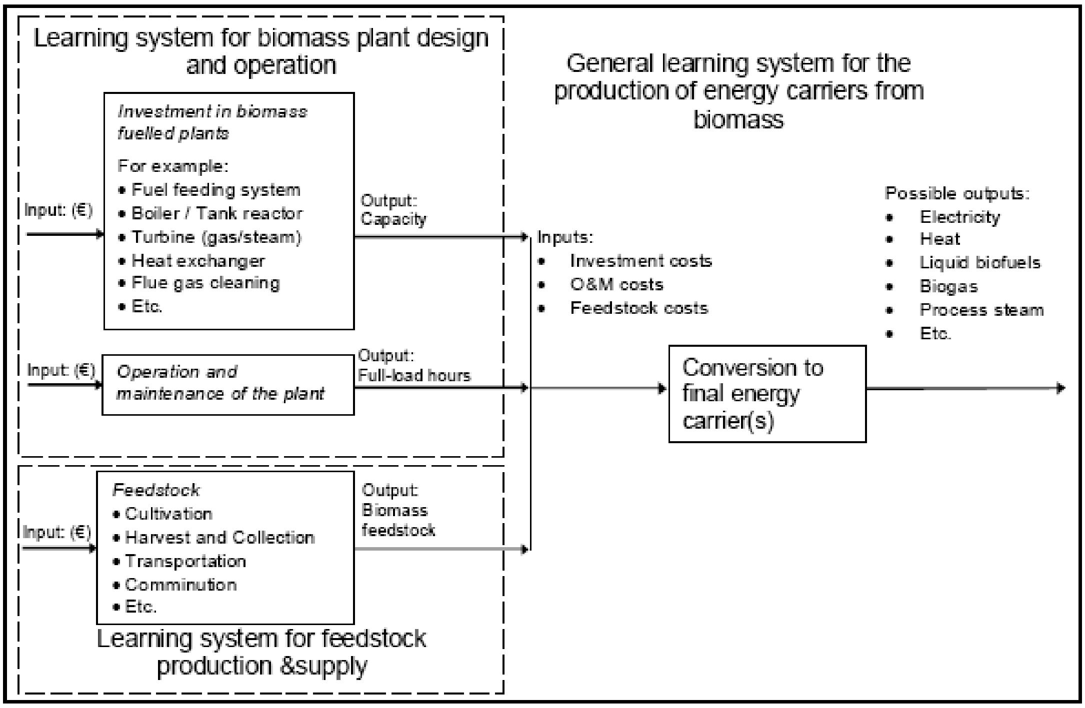

Figure A-4 General structure of learning systems for biomass (Junginger et al. 2008)

The variability of these three interrelated learning systems complicates the consideration of the overall learning curve of biomass technologies. There is a huge variety of combinations between conversion technology and deployed Biomass available, therefore the comparison of different studies is difficult. For consideration of special technology and biomass paths comparative analysis is often necessary.

For future developments both lower as higher cost reductions are proposed, depending on age and level of development of individual technologies and biomass systems. Needs (Needs 2006) shows for the production of fuels from biomass (wood chips, etc.) a progress ratio of 85% (+/- 5%). For the conversion technology a progress ratio of 95% was adopted, based on the progress ratio of advanced fossil fuel technologies.

Table A-4: Learning curves of the components for biomass systems (Junginger et al. 2008)

Learning system	PR (%)	Time frame	Region	n	R^2	Data qual.	Comment
Feedstock production							
Sugarcane (tonnes sugarcane) Van den Wall Bake et al.; 2008	68±3	1975-2003	Brazil	2.9	0.81	II	
Corn (tonnes corn) Hettinga, 2007	55±0.02	1975-2005	USA	1.6	0.87	II	
Logistic chains							
Forest wood chips (Sweden) Junginger et al., 2005	85-88	1975-2003	Sweden / Finland	9	0.87-0.93	II	
Investment & O&M costs							
CHP plants (€/kW_e) Junginger et al., 2005	75-91	1983-2002	Sweden	2.3	0.17-0.18	II	
Biogas plants (€/m^3 biogas/day) Junginger et al., 2005	88	1984-1998		6	0.69	II	
Ethanol production from sugarcane Van den Wall Bake et al.; 2008	81±2	1975-2003	Brazil	4.6	0.80	II	(annual capital charges & O&M cost combined)
Ethanol production from corn (only O&M costs) Hettinga, 2007	87±1	1983-2005	USA	6.4	0.88	II	
Final energy carriers							
Ethanol from sugarcane Goldemberg et al., 2004	93 / 71	1980-1985	Brazil	~6.1	n.a.	II	
Ethanol from sugarcane Van den Wall Bake et al.; 2008	80±2	1975-2003	Brazil	4.6	0.84	II	
Ethanol from corn Hettinga et al, 2007	82±1	1983-2005	USA	6.4	0.96	II	
Electricity from biomass CHP Junginger et al., 2005	91-92	1990-2002	Sweden	~9	0.85-0.88	II	
Electricity from biomass OECD/IEA (2000)	85	Unknown	EU (?)	n.a.	n.a.	n.a.	
Biogas Junginger et al., 2005	85- 100	1984-2001	Denmark	~10	0.97	II	

n Number of doublings of cumulative production on x-axis.
I cost/price data provided (and/or confirmed) by the producers covered
II cost/ price data collected from various sources (books, journals, press releases, interviews)
III cost/price data (or progress ratio) being assumed by authors, i.e. not based on empirical data

A.3.3. Learning curves for hydrogen and fuel cells

Because of the long-term view of the project ALTETRÄ it is necessary to look at hydrogen and fuel cells. Hydrogen is a secondary energy, today primarily based on natural gas and to a lesser extent by electrolysis. In the future hydrogen could gain importance as energy carrier, but also as a storage medium for integration of renewable energies in the energy system.

There are current studies on learning curves for the investment in hydrogen production technologies such as steam reforming, electrolysis and coal gasification (Schoots et al. 2008). Only for the investment costs of steam reforming (11% (+ / - 6)) and electrolysis (18% (+ / -13%)) a learning curve is available.

The reason for this low cost digression is not clear. Schoots et al. 2008 proposes three reasons as a possible cause. First, the increasing demand on the utilization of resources; secondly, increased demand on health, safety and environmental standards; and, third quality requirements for the end product hydrogen.

There is no learning effect in the hydrogen production. A reduction of investment costs per amount of hydrogen produced in the three technologies could not be established. This may be due to the heavy reliance on commodity prices, which possibly overlaps the cost reductions. For the projection of the production and investment costs this means that in the future only low cost reductions are to be expected.

The key technology for the use of hydrogen is the fuel cell. There is almost no historical cost data available for this technology (Neij 2008), so it is hardly possible to develop robust learning curves. But there remains the possibility of using other modular technologies to derive learning rates, and so gain at least an approximation to a learning curve (Neij 2008). Based on learning curves for modular systems from 15 - 30% (Neij 1999), a learning curve for fuel cells by 20% + - 5% can be assumed.

A.4. Learning curves for project-specific technologies

The technology paths considered in the project ALTETRÄ are associated with the known learning curves. It must be noted that the data quality of the learning curve is very different. For some technologies there are learning curves, which consist of a detailed and extensive data series and allow a realistic view of the development costs of the considered technologies. With other technologies, the learning curves are based on price data where other effects can override the cost effects. Finally, in some studies learning curves are assumed but not based on real data. These studies were used only if there are no better data available and the assumptions are sound. The selection of the progress ratio is based on relevance, applicability to the case investigated and data quality of the study.

Table A-5 Learning curves for technologies considered in the scope of project ALTETRÄ

Feedstocks	Conversion technology	Output	Progress ratio	Given period	Data quality	Source
Wood from forestry						
Wood	Gasification + FT-Synthesis 200.000 to/a	FT-Fuel	98		Estimated	(Deurwaarder et al. 2007)
Wood	Gasification + Polygeneration (Small plant, ca. 40.000 to/a)	FT Treibstoff +Electricity +Heat	95		Estimated, based on little data	(Needs 2006)
Wood	Pelletizing	wood pellets	93; 95; 97	2000-2010; 2010-2020; 2020-2030	Estimated	(Fritsche et al. 2004)
Wood	Chipping installations + drying	wood chips	85 (+/-5)			(Needs 2006)
Wood	Chipping installations + drying + Cogeneration (big: IGCC ca. 400 MWel)	Electricity + Heat	91-92	1990 - 2002	actual cost data	(Junginger et al. 2005)
Wood	Chipping installations + drying + Cogeneration (medium: steam turbine ca. 50 MWel)	Electricity + Heat	91-92	1990 - 2002	actual cost data	(Junginger et al. 2005)
Wood	Chipping installations + drying + Cogeneration (small: ORC, Stirling ca. 1 MWel)	Electricity + Heat	90; 93;95	2000-2010; 2010-2020; 2020-2030	Estimated	(Fritsche et al. 2004)
Oil crops						
Rape seed	Biodiesel-Plant 150.000 to/a	Biodiesel	97	1971 - 2006	actual historic data	(Berghout 2008)
Sugar crops						
sugar beet	Bioethanol-Plant 150.000 to/a	Bioethanol	80	1975 - 2004	Based on historic cost data	(Van den Wall Bake 2006)
Starch crops						

Maize	Bioethanol-Plant 150.000 to/a	Bioethanol	85	1983 – 2005	Based on historic cost data	(Junginger et al. 2005)
Maize (seed, silage)	BiogasPlant (Plant ca. 2 MW)	Biogas	90;93;95	2000-2010; 2010-2020; 2020-2030	Estimated	(Fritsche et al. 2004)
Wheat	Bioethanol-Plant 150.000 to/a	Bioethanol	80	1975 - 2004	Based on historic cost data	(Van den Wall Bake 2006)
Lignocellulos crops						
short rotation forestry	Gasification + FT-Synthesis 40.000 to/a	FT-Fuel	98		Estimated	(Deurwaarder et al. 2007)
short rotation forestry	Pelletizing	wood pellets	93; 95; 97	2000-2010; 2010-2020; 2020-2030	Estimated	(Fritsche et al. 2004)
short rotation forestry	Chipping installations + drying	wood chips	85 (+/-5)			(Needs 2006)
short rotation forestry	Chipping installations + drying + Cogeneration (big: IGCC ca. 400 MWel)	Electricity + Heat	91-92	1990 - 2002	actual cost data	(Martin Junginger u. a. 2005)
short rotation forestry	Chipping installations + drying + Cogeneration (medium: steam turbine ca. 50 MWel)	Electricity + Heat	91-92	1990 - 2002	actual cost data	(Martin Junginger u. a. 2005)
Agriculture residues						
Liquid manure	BiogasPlant (Plant ca. 2 MW)	Biogas	90;93;95	2000-2010; 2010-2020; 2020-2030	Estimated	(Fritsche u. a. 2004)
from commerce, industry and households						
waste wood	Chipping installations	wood chips	85 (+/-5)			(Needs 2006)
waste wood	Chipping installations + drying + Cogeneration (big: IGCC ca. 400 MWel)	Electricity + Heat	91-92	1990 - 2002	actual cost data	(Martin Junginger u. a. 2005)
waste wood	Chipping installations + drying + Cogeneration (medium: steam turbine ca. 50 MWel)	Electricity + Heat	91-92	1990 - 2002	actual cost data	(Martin Junginger u. a. 2005)
waste wood	Chipping installations + drying + Cogeneration (small: ORC, Stirling ca. 1 MWel)	Electricity + Heat	90; 93;95	2000-2010; 2010-2020; 2020-2030	Estimated	(Fritsche u. a. 2004)
sawing by-products	Gasification + FT-Synthesis (Plant ca. 200MW)	FT-Fuel	98		Estimated	(Deurwaarder et al. 2007)
sawing by-products	Gasification + Methaneisierung (PSI Proces - Plant ca. 100 MW)	SNG	98		Estimated	(Deurwaarder et al. 2007)
sawing by-products	Bioethanol-Plant (Plant ca. 400 MW)	Bioethanol	81	1977 - 2003	available	(Van den Wall Bake et al. 2009)
old foodoil and animal fat	Biodiesel-Plant (Plant ca. 200 MW)	Biodiesel	97	1971 – 2006	historic data	(Berghout 2008)
organic waste	BiogasPlant (Plant ca. 2 MW)	Biogas	90;93;95	2000-2010; 2010-2020; 2020-2030	Estimated	(Fritsche et al. 2004)
Waste liquor from paper industry	Gasification + FT-Synthesis (Choren process - Plant ca. 450 MW)	FT-Fuel	98		Estimated	(Deurwaarder et al. 2007)
RES						
Sun	Electrolysis+Compression	GH2	82	1960 -		(Schoots et al.

	450bar			2003		2008)
Sun	Electrolysis + Liquefaction	LH2	82	1960 - 2003		(Schoots et al. 2008)
Sun	PV	Electricity	80 (+-5)	Systematic review up to 2006	actual cost data	(Neij 2008)
Wind	Electrolysis + Compression 450bar	GH2	82 (+/- 11)	1940 - 2004	actual cost data	(Schoots et al. 2008)
Wind	Electrolysis + Liquefaction	LH2	82 (+/- 11)	1940 - 2004	actual cost data	(Schoots et al. 2008)
Wind	WindPlant	Electricity	91 - 94	1980 - 2005	actual cost data	(Junginger et al. 2008)
Hydropower	Electrolysis + Compression 450bar	GH2	82 (+/- 11)	1940 - 2004	actual cost data	(Schoots et al. 2008)
FOSSIL						
natural gas	Methanol-Plant (Plant ca. 600 MW)	Methanol	89		Based on historic cost data	(Schoots et al. 2008)
natural gas	steam reforming + CCS	GH2	89	no historic data available	Estimated	(Fischedick et al. 2007)
natural gas	combined gas/steam turbin e power plant + CCS	Electricity	90;93;95	2000-2010; 2010-2020; 2020-2030	Estimated	(Fritsche et al. 2004)
natural gas	combined gas/steam turbine power plant + CCS	Electricity + Heat	90 (+/-5)		Estimated	(Needs 2006)
Coal	Plant	Electricity	95 (+/- 2)	from 1970	Estimation based on scattered data	(Needs 2006)
Coal	Thermal power station	Electricity + Heat	95 (+/- 2)	from 1970	Estimation based on scattered data	(Needs 2006)

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Annex B

B. Assessment of single AEC up to 2050

In this Annex we conduct analysis of energetic, ecological and economic performance of all the AEC chosen in Chapter 2.

B.1. Biodiesel 1st generation

Biodiesel is a fuel produced from vegetable oil- or animal fat-based feedstocks. Biodiesel is usually produced by transesterification of oils with short-chain alcohols or by the esterification of fatty acids. The transesterification reaction consists of transforming triglycerides into fatty acid alkyl esters, in the presence of alcohol, such as methanol or ethanol, and a catalyst, such as alkali or acid, with glycerol as a byproduct (Palligarnai et al, 2008). Biodiesel shows similar properties as fossil diesel and can be used pure or blended with diesel in conventional internal combustion engines (ICE) without major modifications. The largest part of biodiesel is produced in EU countries mostly due to European biofuel targets and supporting policy measures such as subsidies or tax exemption. Most important feedstocks for biodiesel production in EU are rapeseed and sunflowers.

The energetic life-cycle balance of biodiesel from rapeseed (RME) in 2010 and 2050 are depicted in Figure B-1 and Figure B-2. It is, moreover, split up into renewable, fossil and other energy inputs.

A life-cycle assessment of GHG emissions in kg CO_2-equivalents is depicted in Figure B-3 and Figure B-4.

Economic assessment is presented in Section B.1.3. As shown in Figure B-5 the largest part of biodiesel costs are feedstock costs and these are largely dependent on prices on agricultural markets. Feedstock costs differ by the type of crop used, harvesting technologies and agricultural subsidies for crops and regions and they are currently very volatile. Capital costs have also a significant impact on the total biodiesel costs, as well as economics of scale. By large scale (LS) production plants biodiesel production costs are for about 4% lower than by small scale (SS) production.

In Figure B-6 the cost structure of biodiesel 1st generation from oil seeds is depicted for 2010 vs. 2050. Till 2050 biodiesel costs could be significantly higher mostly due to higher feedstocks prices and due to the CO_2 based tax, see Chapter 6. Capital costs could be in the future slightly lower due to the technological learning. However, the most important impact parameters on costs are the feedstock prices and tax.

Development of most important impact parameters on biodiesel cost are shown in Figure B-7. As it can be seen the slight energetic improvement cannot by far compensate the expected increase in feedstock prices.

B.1.1. Cumulated primary energy demand

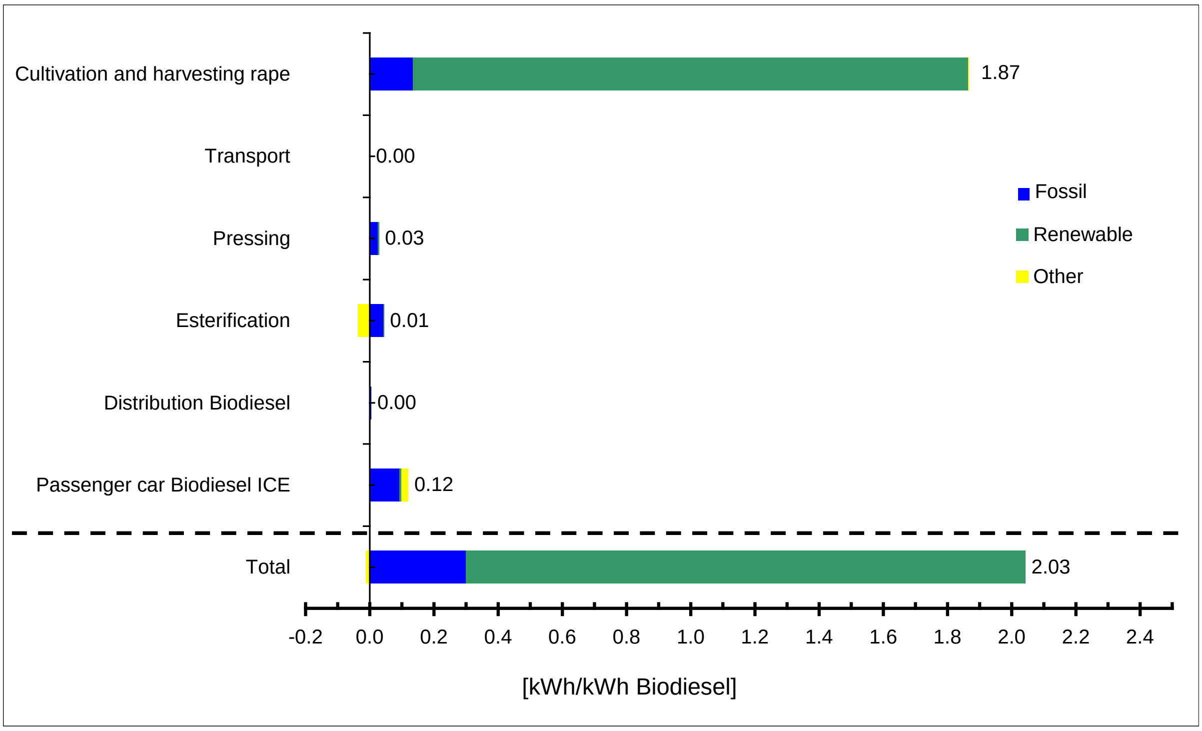

Figure B-1 WTW – Cumulated primary energy demand of biodiesel from rapeseed (2010)

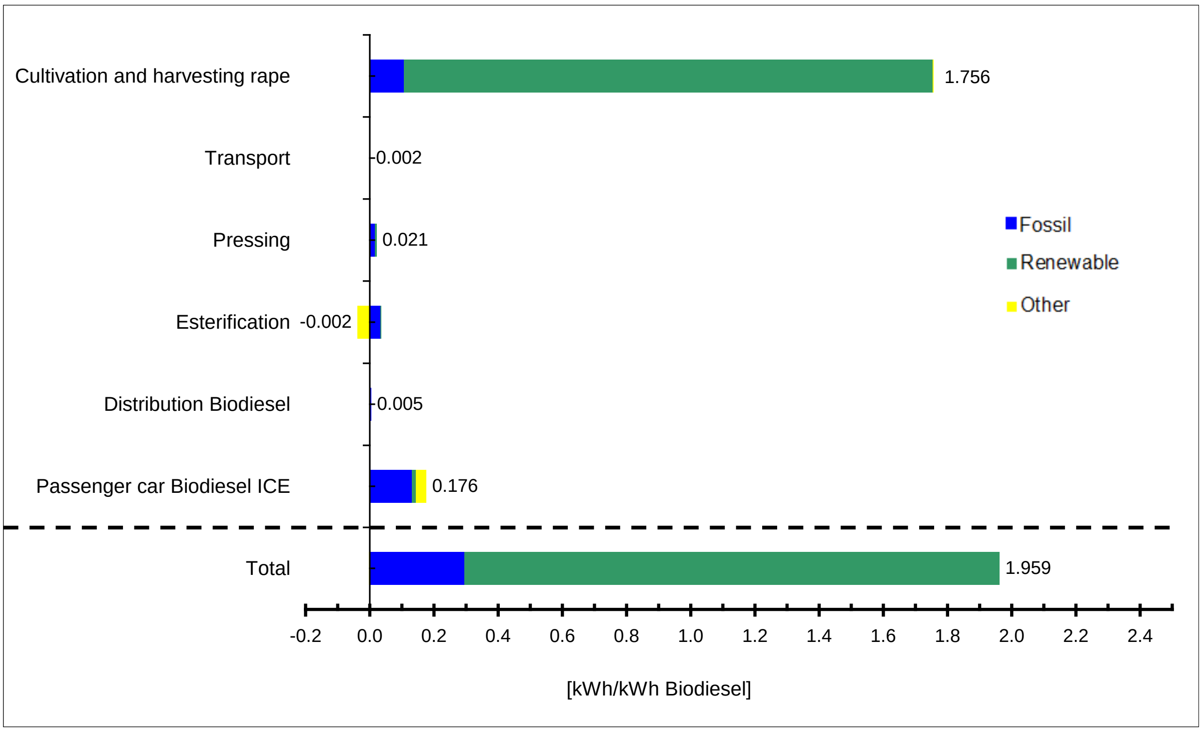

Figure B-2 WTW – Cumulated primary energy demand of biodiesel from rapeseed (2050)

B.1.2. Greenhouse gas emissions

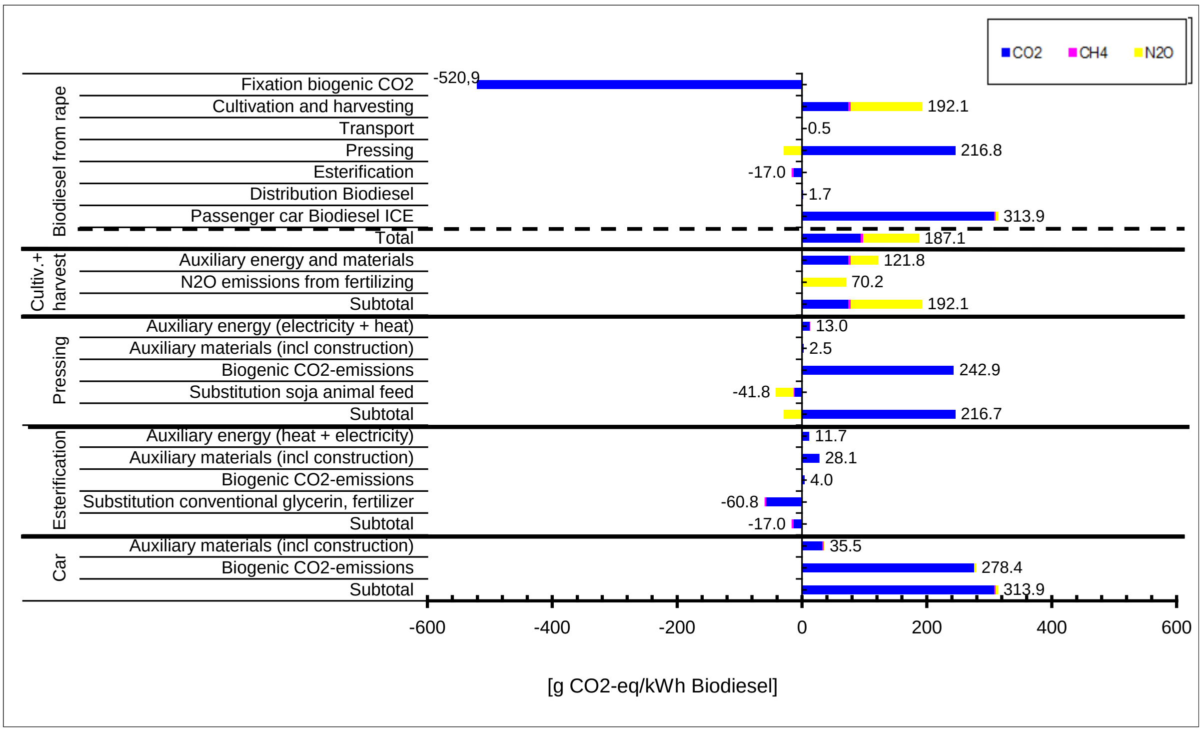

Figure B-3 WTW – GHG emissions of biodiesel from rapeseed (2010)

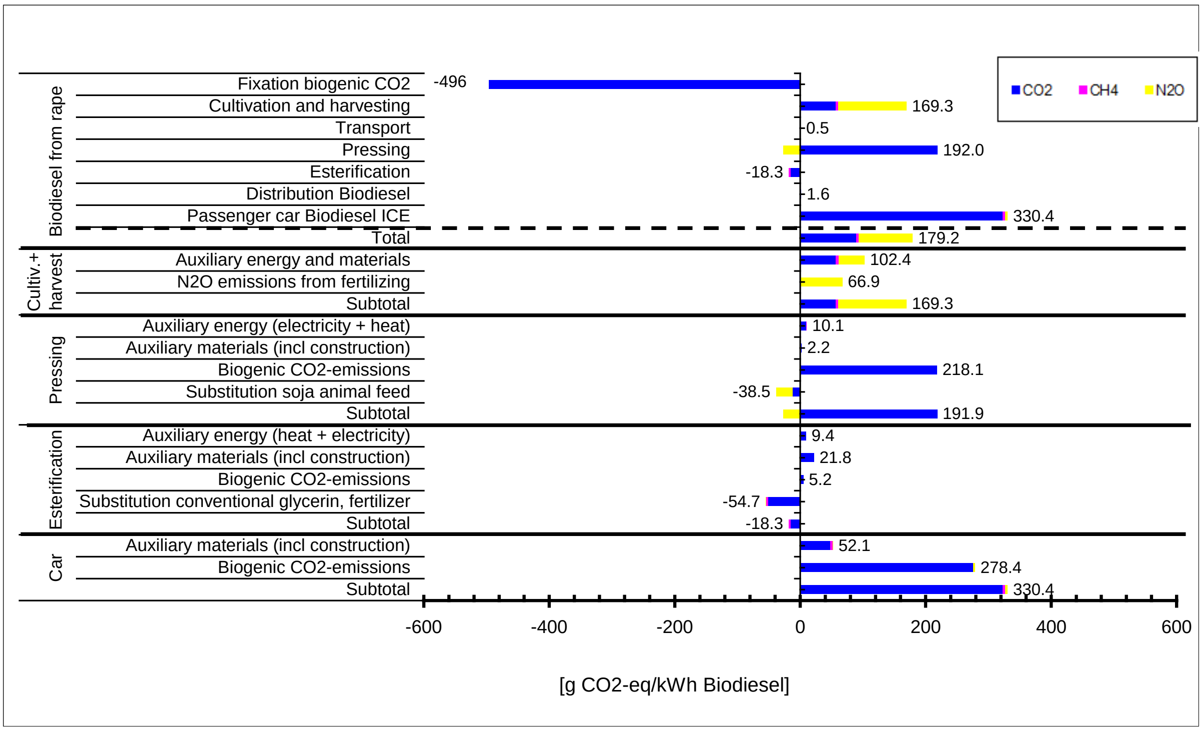

Figure B-4 WTW – GHG emissions of biodiesel from rapeseed (2050)

B.1.3. Economic assessment

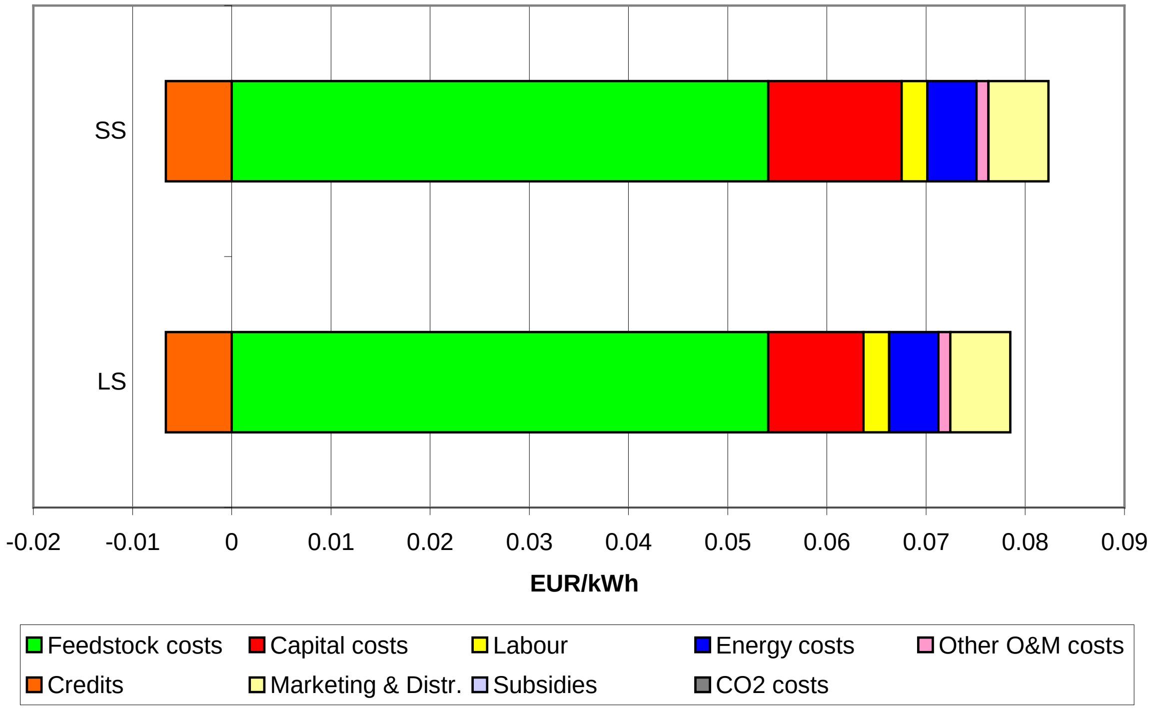

Figure B-5 Cost structure of biodiesel 1st generation in 2010

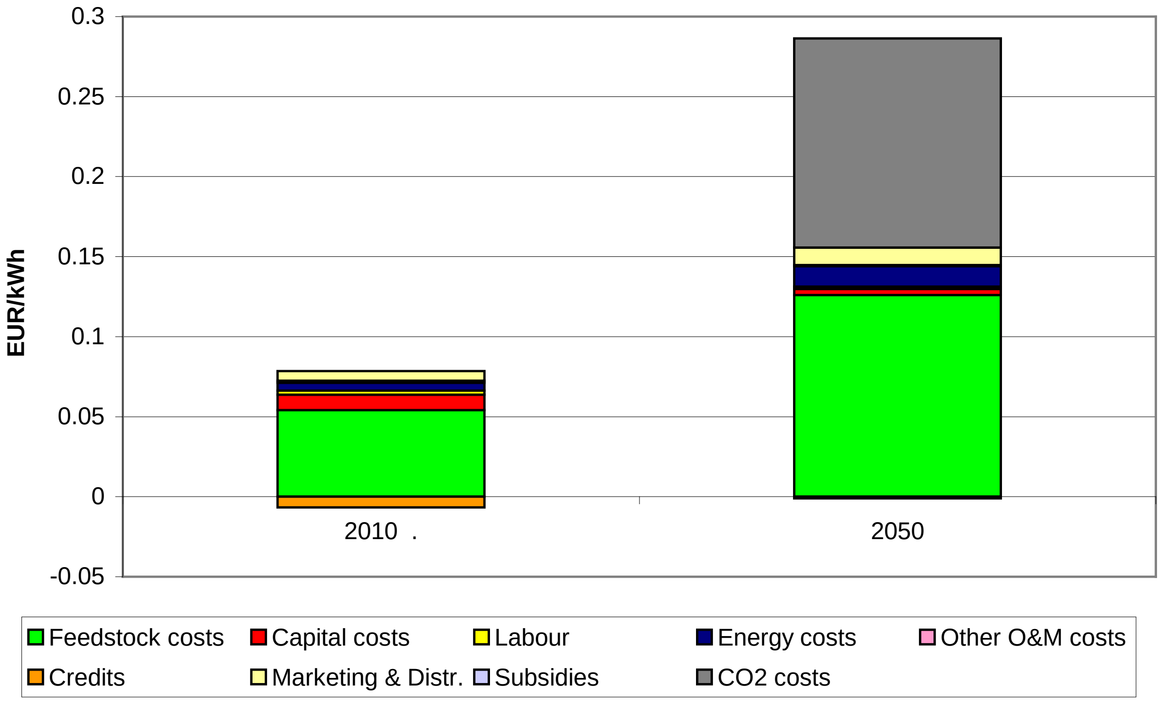

Figure B-6 Cost structure of biodiesel 1st generation in 2010 vs 2050

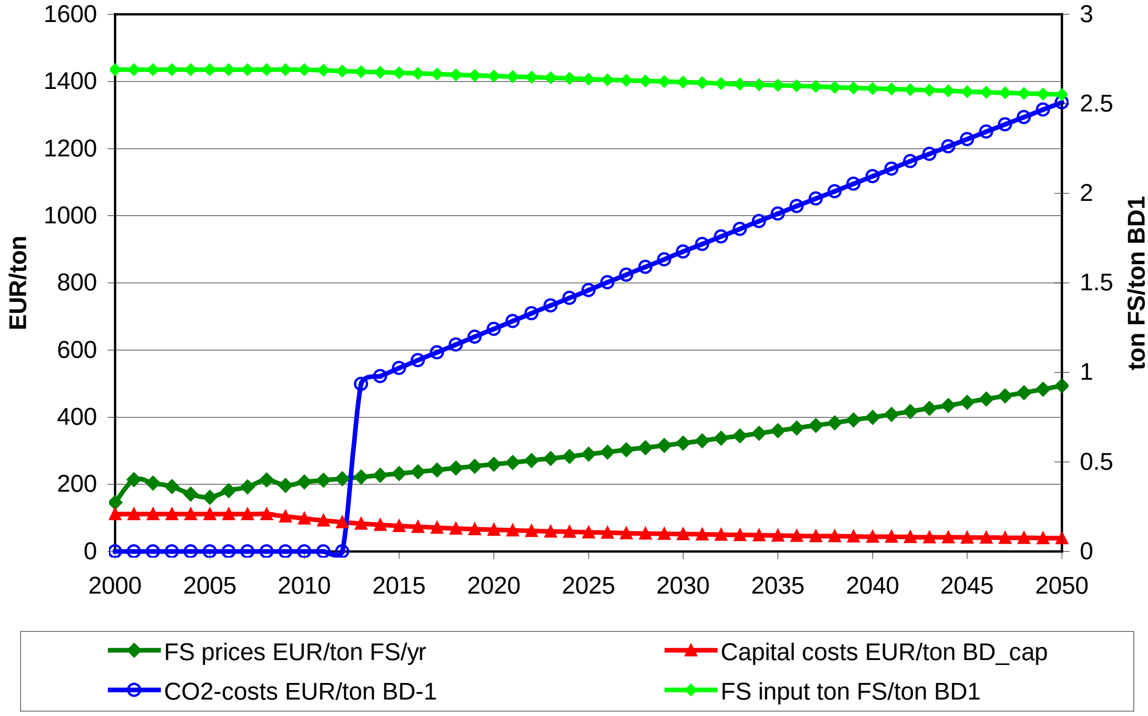

Figure B-7 Trends of different impact parameters on the costs of biodiesel 1st generation up to 2050

B.2. Bioethanol

Bioethanol is chemical union of hydrocarbons, water and one alcoholic group. It is colourless liquid fuel, with an aromatic odour and is easily flammable. Worldwide is bioethanol the most common biofuel. The largest bioethanol producer is USA followed by Brazil. EU is on the third place. Bioethanol is produced from starch crops like corn (in USA), wheat and from sugar crops like sugarcane (in Brazil) and wheat, barley and sugar beet (in Europe). Bioethanol is usually used blended with gasoline e.g. E5, E10, E15 – these blendes (up to E25) do not require too much changes at the engine.

Cumulated primary energy demand of bioethanol from wheat in 2010 vs. 2050 is shown in Figure B-8 and Figure B-9. WTW-GHG emissions of bioethanol from wheat are depicted in Figure B-10 and Figure B-11.

Economic assessment is presented in Section B.2.3. Depending on land availability and climatic factors different feedstocks could be used for bioethanol production in different regions. However, due to the use of different feedstocks, different feedstock and energy costs, bioethanol costs are very different in different regions. The cheapest bioethanol production is currently in Brazil – less than half of the costs in EU. As shown in Figure B-12 largest impact on bioethanol costs have feedstock costs, followed by capital costs. It is also obvious that bioethanol costs are significantly lower by large scale production.

Figure B-13 depicts the cost structure of bioethanol 1st generation in 2010 vs. 2050. Till 2050 bioethanol costs could be significantly higher mostly due to higher feedstocks prices and CO_2 based tax, see Chapter 6. Capital costs could be slightly lower in the future due to the technological learning. However, the most important impact parameters on costs are the feedstock prices and CO_2 tax.

Trends of different impact parameters on the costs of bioethanol till 2050 are shown in Figure B-14. The slight energetic improvement, as well as reduction of capital costs through the increasing production scale and learning effect, cannot compensate the increase of CO_2 tax and feedstock prices.

B.2.1. Cumulated primary energy demand

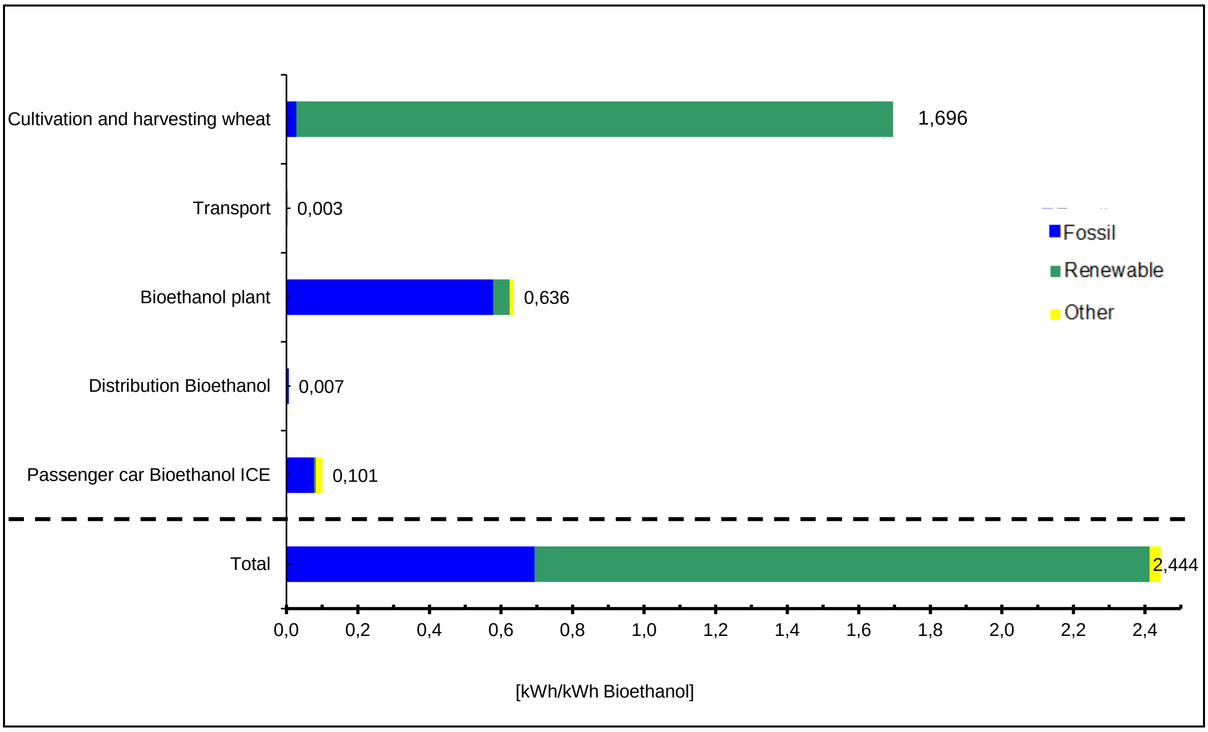

Figure B-8 WTW Cumulated primary energy demand of bioethanol from wheat (2010)

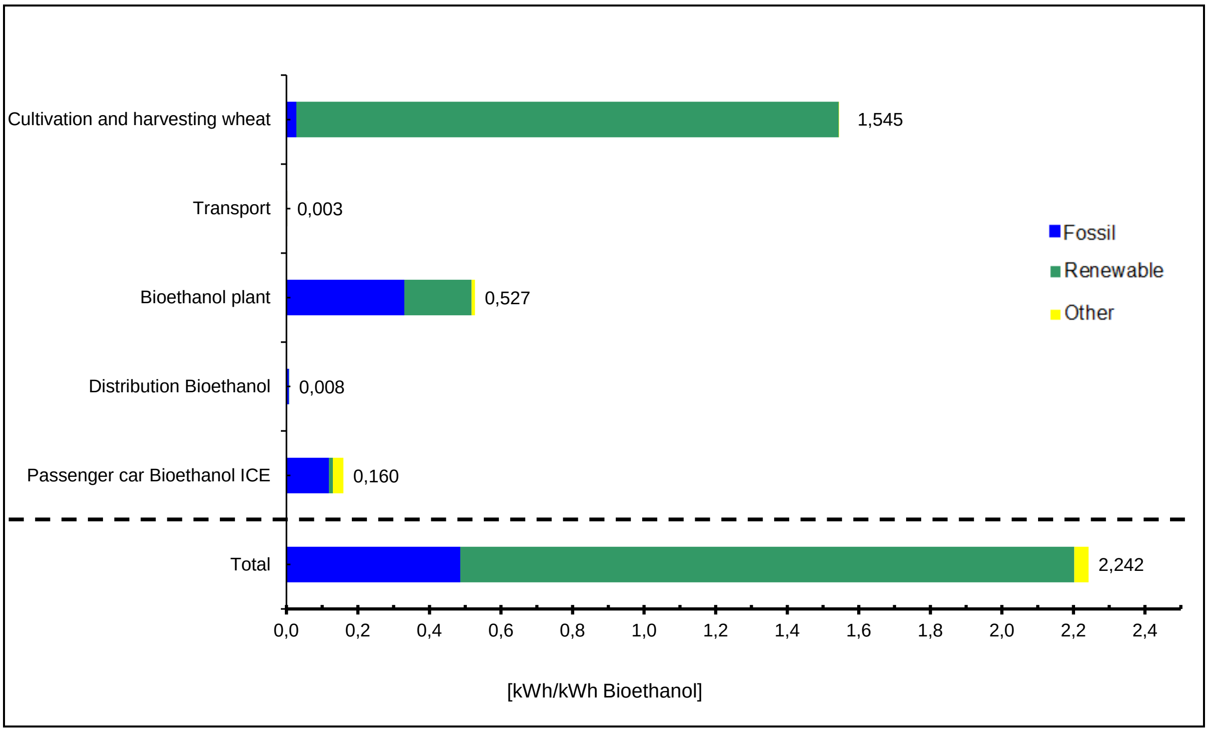

Figure B-9 WTW Cumulated primary energy demand of bioethanol from wheat (2050)

B.2.2. Greenhouse gas emissions

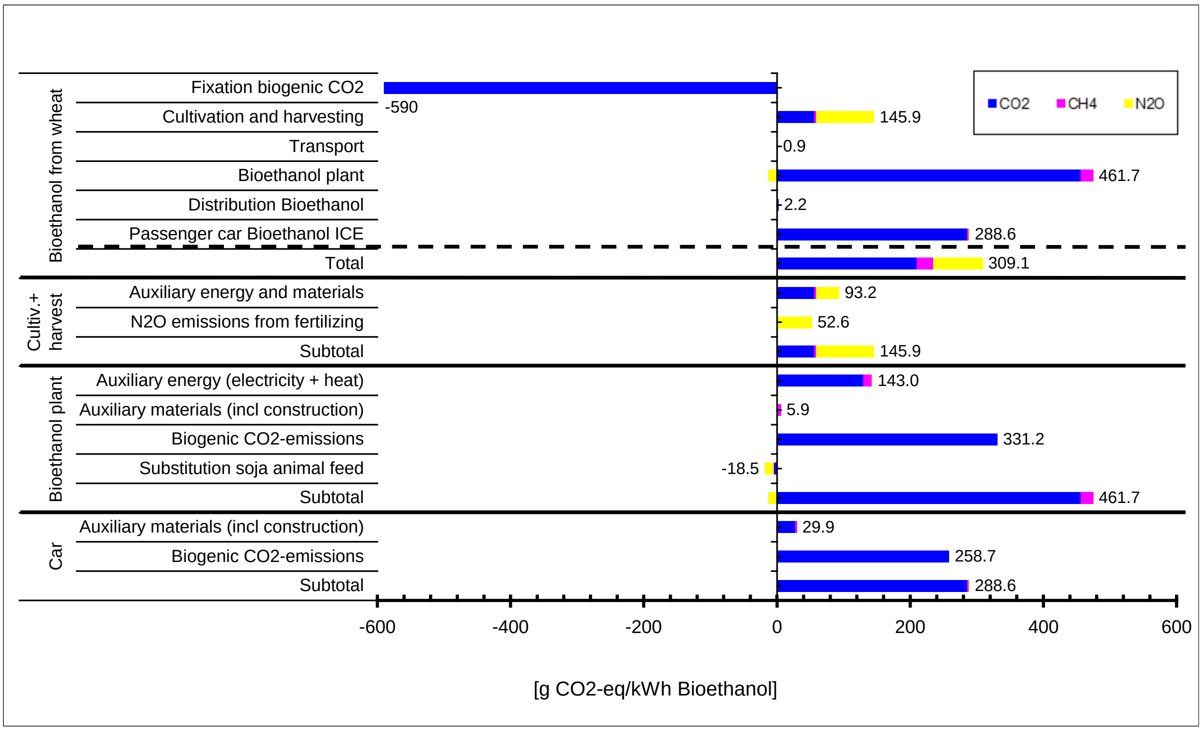

Figure B-10 WTW – GHG emissions of bioethanol from wheat (2010)

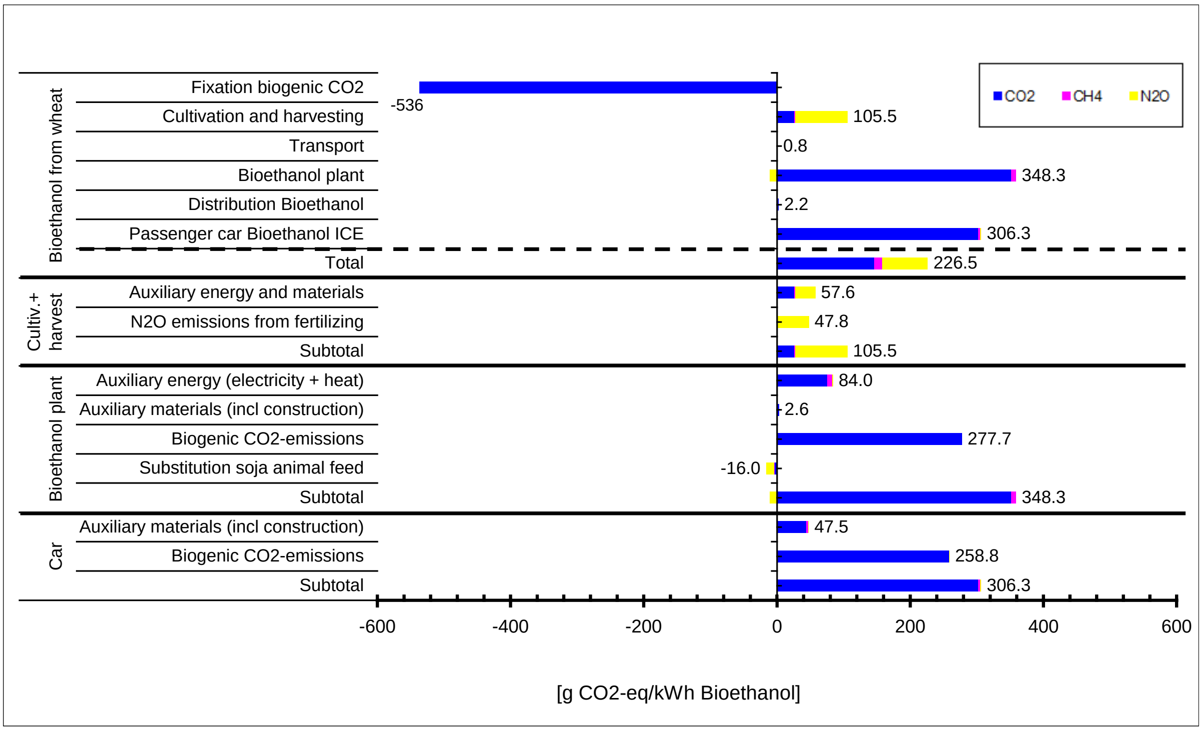

Figure B-11 WTW – GHG emissions of bioethanol from wheat (2050)

B.2.3. Economic assessment

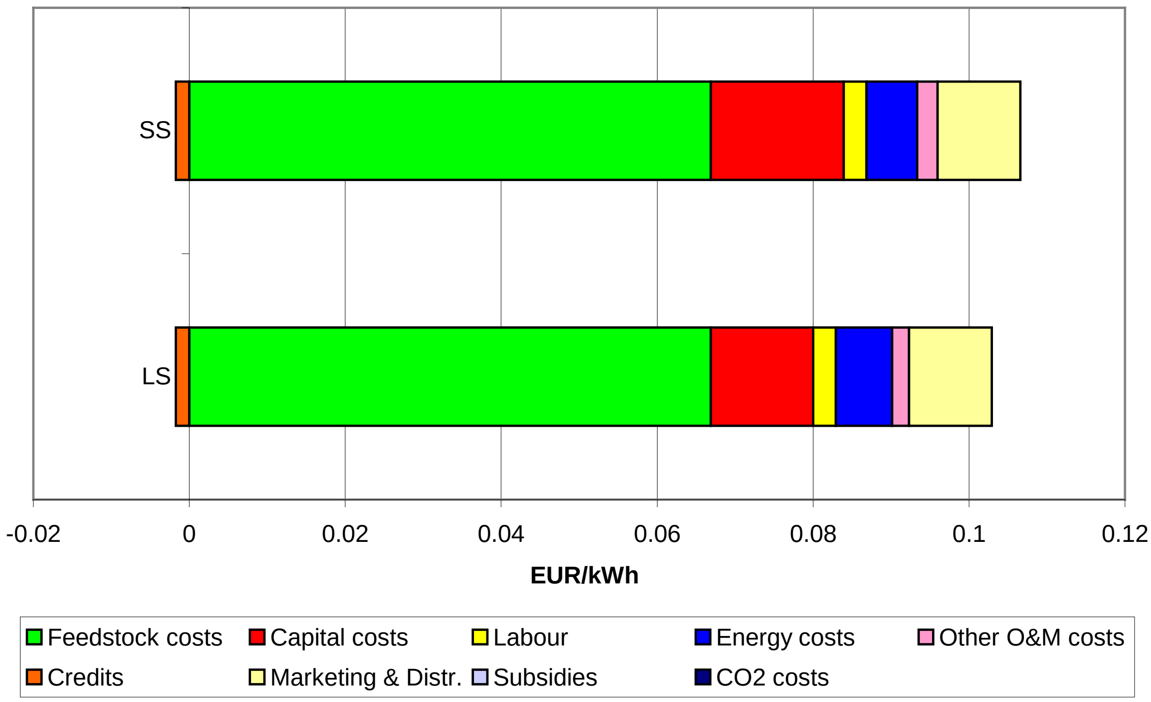

Figure B-12 Cost structure of bioethanol 1st generation in 2010

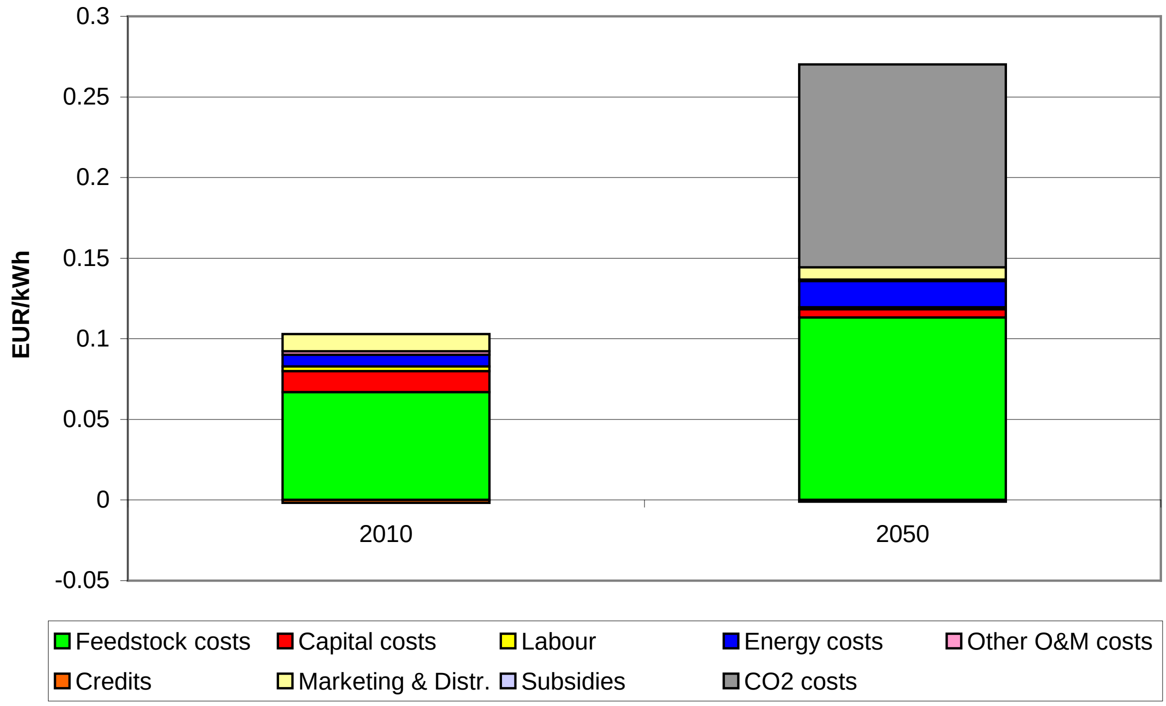

Figure B-13 Cost structure of bioethanol 1st generation in 2010 vs. 2050

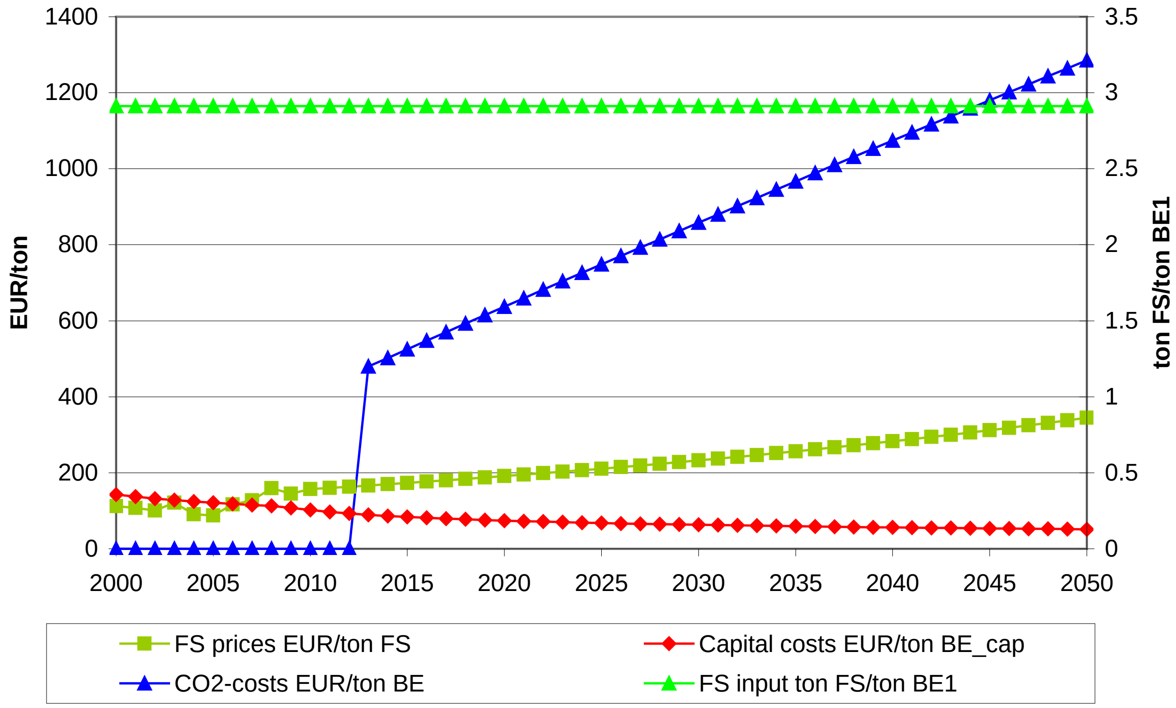

Figure B-14 Trends of different impact parameters on the costs of bioethanol 1st generation up to 2050

B.3. Biogas

Biogas is gas produced by biological breakdown of organic matter in the absence of oxygen. It can be produced from a huge variety of organic waste (e.g. containing carbohydrates, fatty acids, cellulose and proteins). Biogas can be used to generate electricity, heat and biofuel. Upgraded biogas to the required level of purity (biomethane) can be used as an alternative fuel in the same way as conventional natural gas.

In the following the energetic, ecological and economic assessment of biogas are presented. It is important to note that we show all comparisons for the case of corn silage. Within the economic assessment we differ between large-scale and small-scale plants and consider different types of feedstocks: manure, corn silage, grass and organic waste.

B.3.1. Cumulated primary energy demand

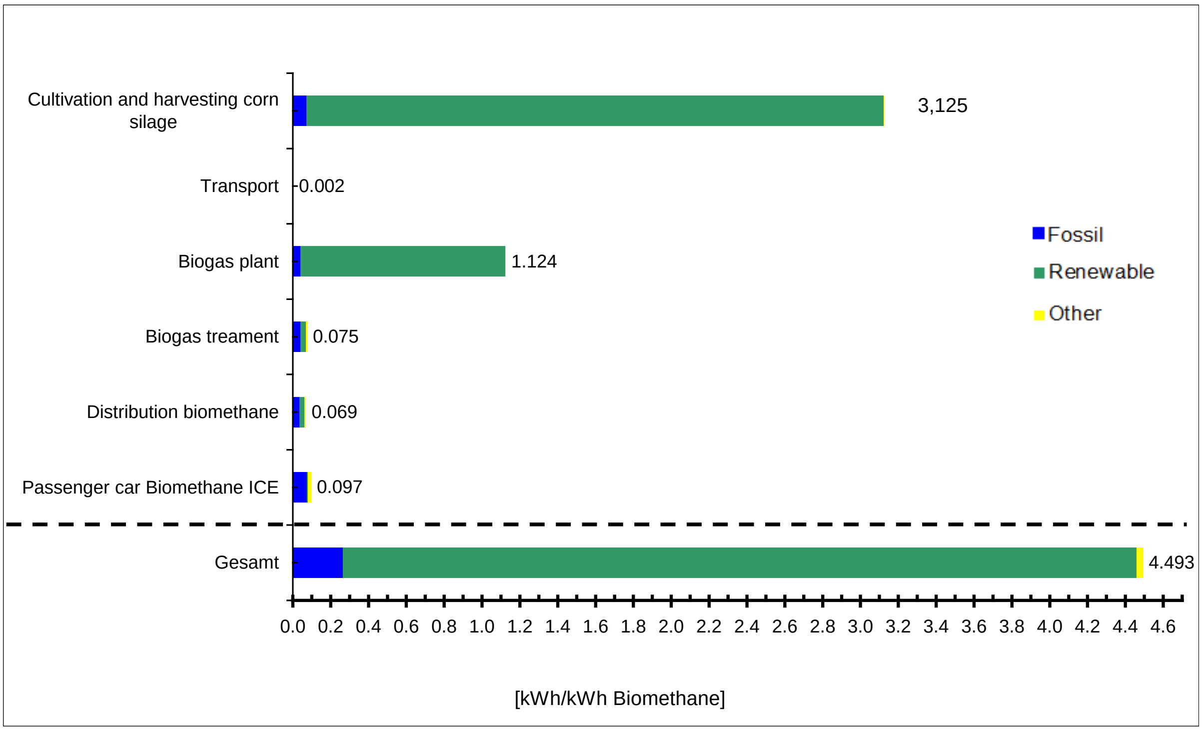

Figure B-15 WTW Cumulated primary energy demand of biomethane from corn silage (2010)

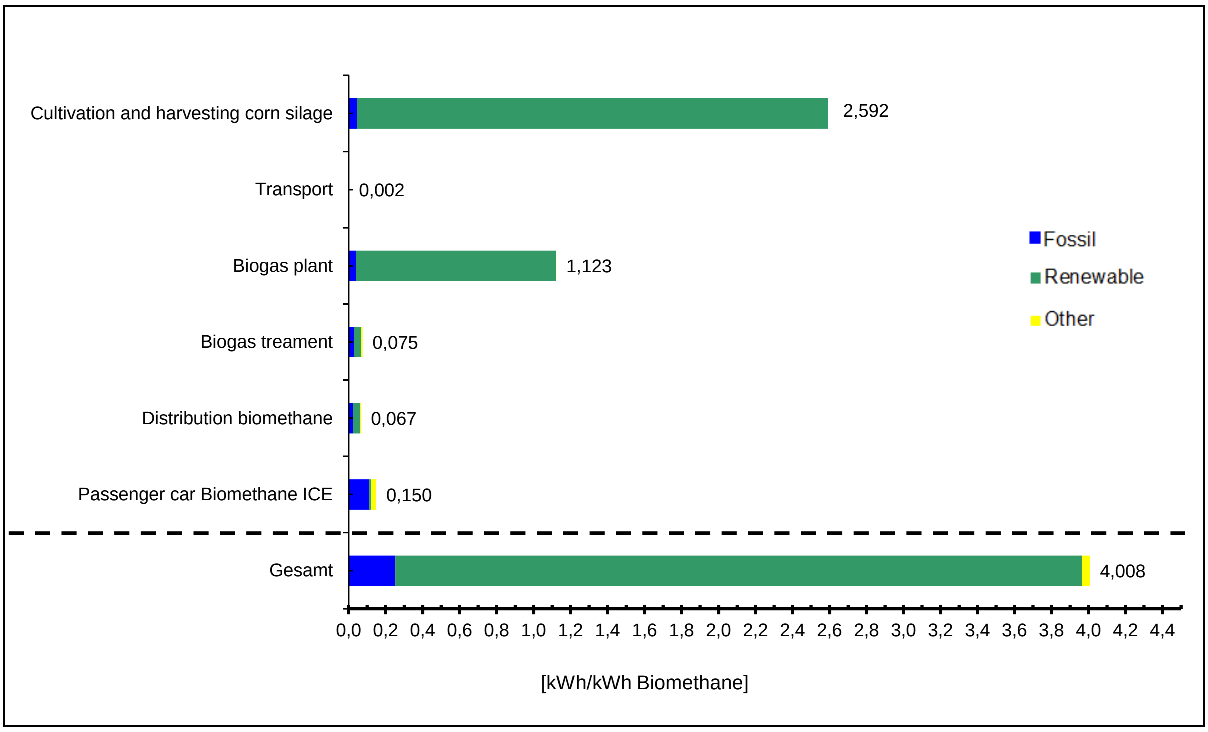

Figure B-16 WTW Cumulated primary energy demand of biomethane from corn silage (2050)

B.3.2. Greenhouse gas emissions

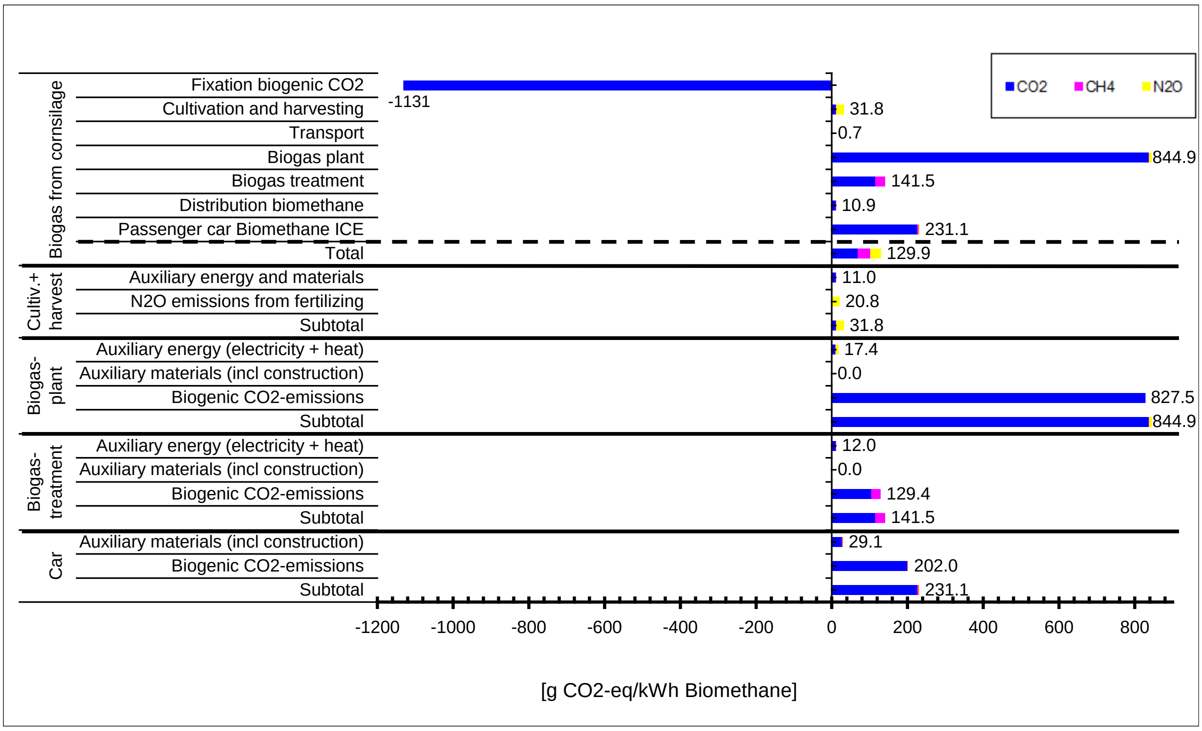

Figure B-17 WTW – GHG emissions of biomethane from corn silage (2010)

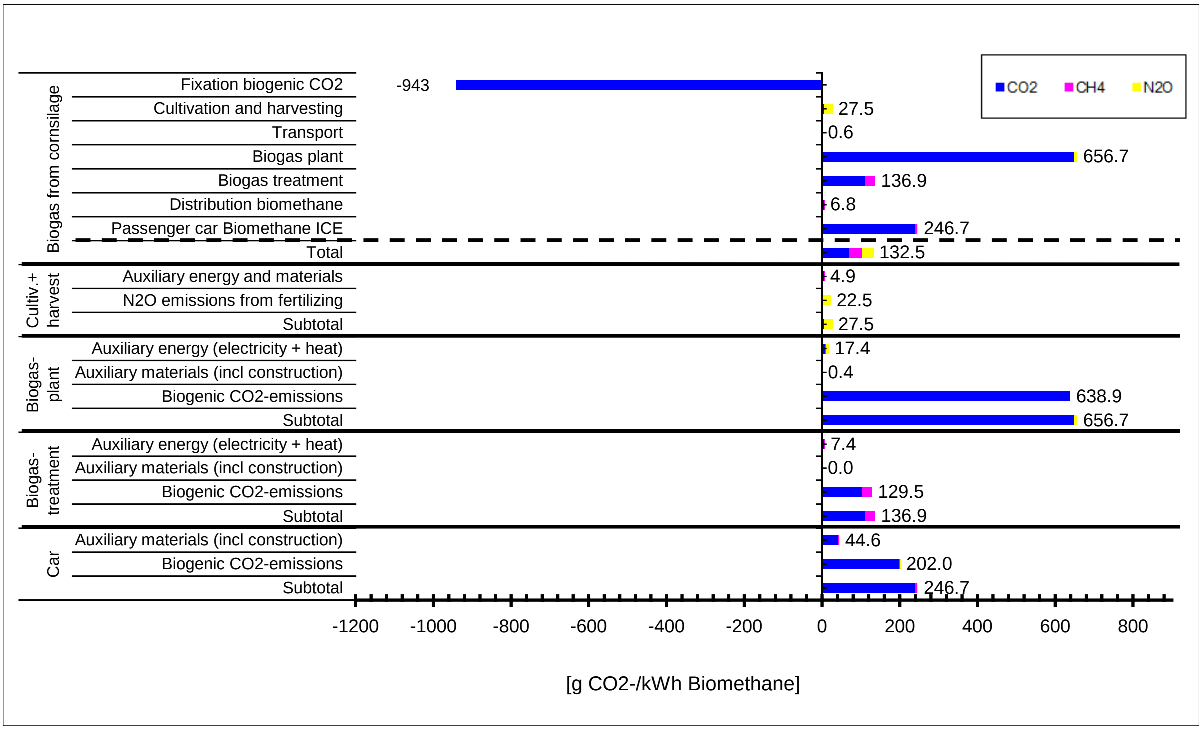

Figure B-18 WTW – GHG emissions of biomethane from corn silage (2050)

B.3.3. Economic assessment

As mentioned above for the economic assessment we differ between large-scale and small-scale plants and we consider different cases for feedstocks: organic waste, manure, grass and corn silage. Moreover, different, more complex, chains of converting AEC from one type into another can be created with biogas. In the following we show the economic assessment of raw biogas as well as the economic evaluation of electricity from biogas and the production of methanegas which is fed into the natural gas grid. Table B-1 summarizes the major assumptions for capacities of small and large plants and for corresponding investment costs.

Figure B-19 shows the cost structure of raw biogas in 2010 for small and large plants for the feedstocks organic waste, manure, grass and corn silage.

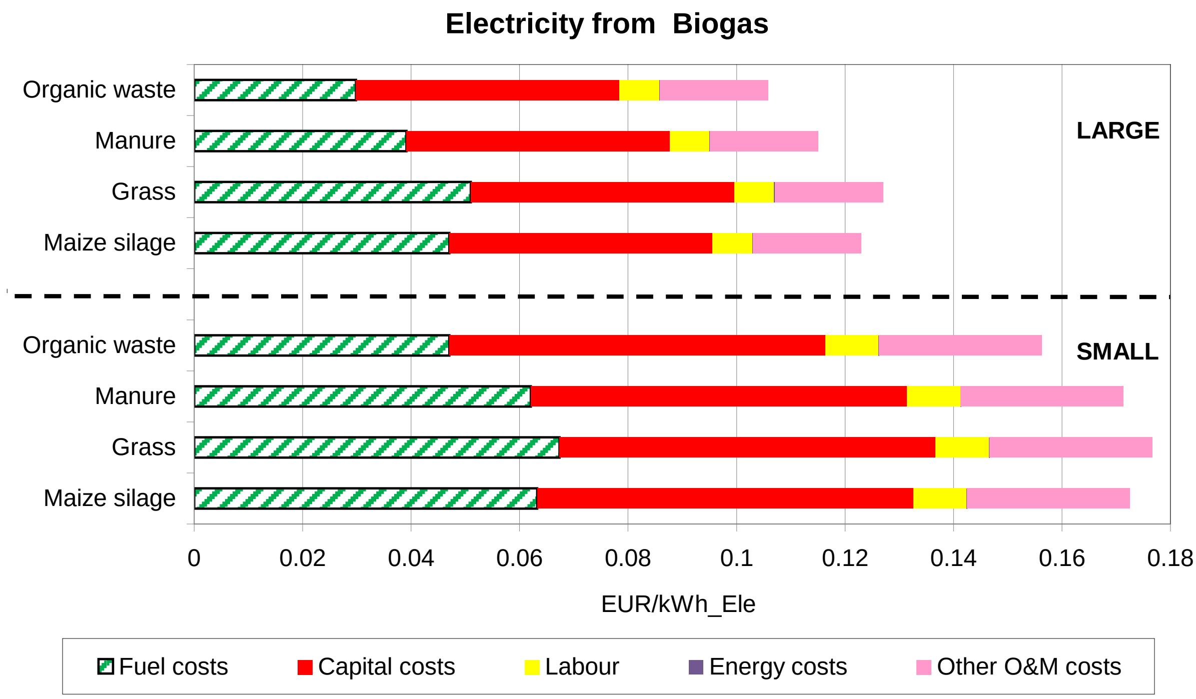

Figure B-20 and Figure B-21 depict the corresponding costs of electricity from biogas and methane gas prepared for grid feed-in.

Table B-1 Assumptions for capacities of small and large plants and for corresponding investment costs

	SMALL			LARGE		
	Capacity	*Specific costs*	*Total costs*	*Capacity*	*Specific costs*	*Total costs*
Biogas (Raw)	500 kW_f	2160 EUR/kW_f	1.08 Mio EUR	2 MW_f	1120 EUR/kW_f	2.24 Mio EUR
	4000 MWh/yr	270 EUR/MWh		16000 MWh/yr	140 EUR/MWh	
Synthetic Natural gas from lignocellulosis	10 MW_{th}	10000 EUR/kW_{th}	100 Mio EUR	80 MW_{th}	5300 EUR/kW_{th}	424 Mio EUR
Electricity from Biogas (w/o Biogas production)	80 kW_{Ele}	4000 EUR/kW_{Ele}	0.32 Mio EUR	2 MW_f	2800 EUR/kW_{Ele}	5.6 Mio EUR
Methanegas (only preparation and feed-in)	1.3 MW_{th} (130 m^3/h)	2400 EUR/kW_{th}	3.12 Mio EUR	8 MW_{th} (800 m^3/h)	1400 EUR/kW_{th}	11.2 Mio EUR

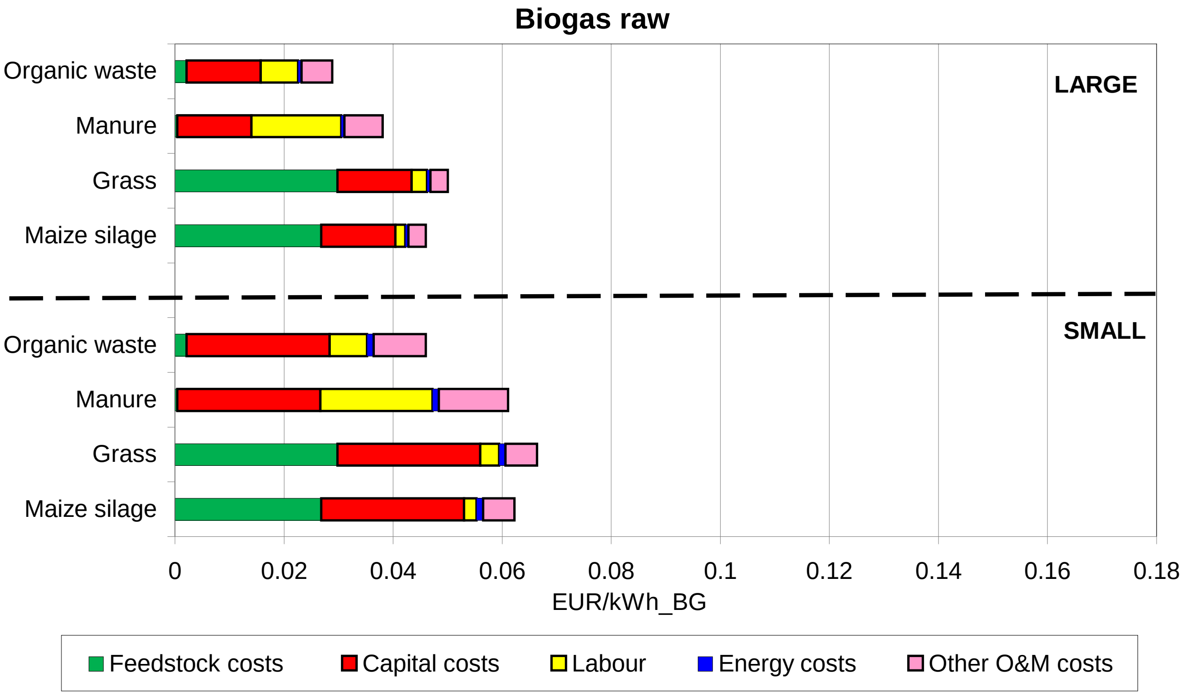

Figure B-19 Cost structure of raw biogas in 2010 for small and large plants for the feedstocks organic waste, manure, grass and corn silage

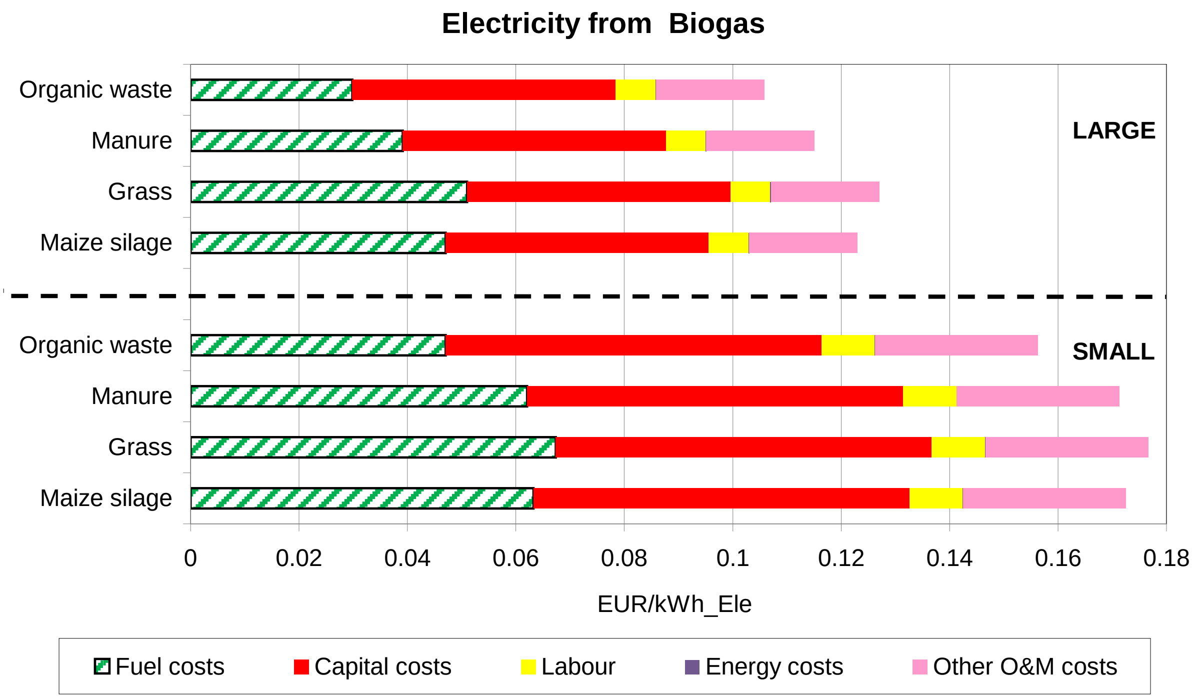

Figure B-20 Cost structure of electricity from biogas in 2010 for small and large plants for the feedstocks organic waste, manure, grass and corn silage

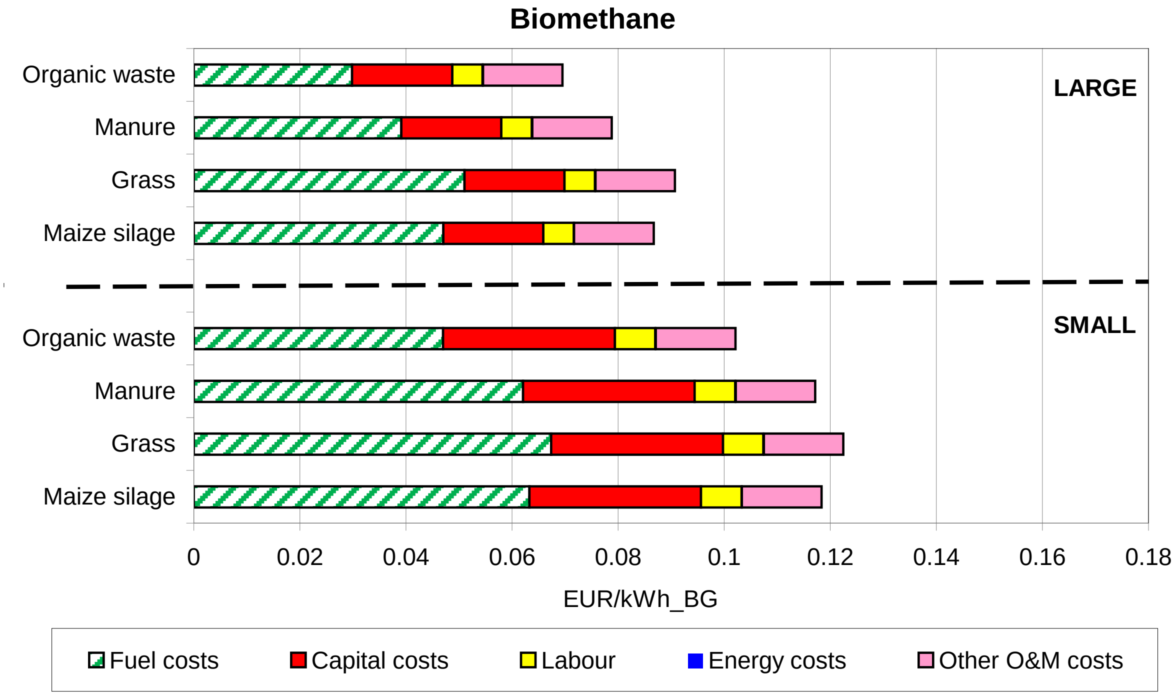

Figure B-21 Cost structure of biomethane in 2010 for small and large plants for the feedstocks organic waste, manure, grass and corn silage

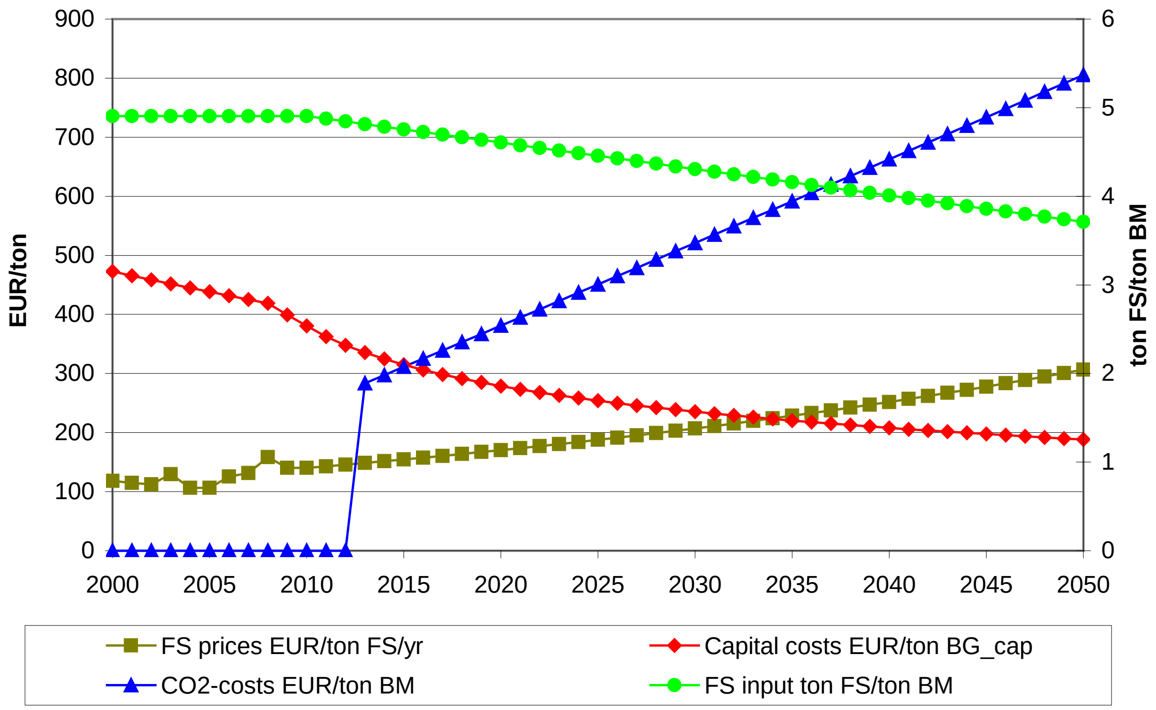

Figure B-22 Trends of different impact parameters on the costs of biogas up to 2050

B.4. 2nd generation biodiesel

Major advantage of 2nd generation biofuels is that they could be produced from different kinds of lignocellulosic materials. Since they are mostly derived from non-food crops and waste materials the competition between food and fuel production could be avoided. However, all 2nd generation biofuels are still in a developing stage und could become competitive on the market in the next decades.

2nd generation biodiesel could be used in the same way as the 1st generation biodiesel. It is usually produced via Fischer-Tropsch process.

The energetic and ecological life-cycle balances for FT-Diesel from wood are presented in Section B.4.1 and B.4.2.

The largest part of the 2nd generation biodiesel production costs are capital costs. These could be significantly reduced with the scale effect, see Figure B-27.

To make this fuel competitive on the market capital costs have to decrease significantly also due to the technological learning. Since 2nd generation biodiesel have better CO_2 balances than 1st generation biofuels, CO_2 based tax is lower in this case. The expected costs for 2nd generation biodiesel are shown in Figure B-28.

Trends of major impact parameters on the costs of biodiesel 2nd generation till 2050 are depicted in Figure B-29. As it can be noticed, significant reduction of capital costs are expected as well as energetic improvement.

B.4.1. Cumulated primary energy demand

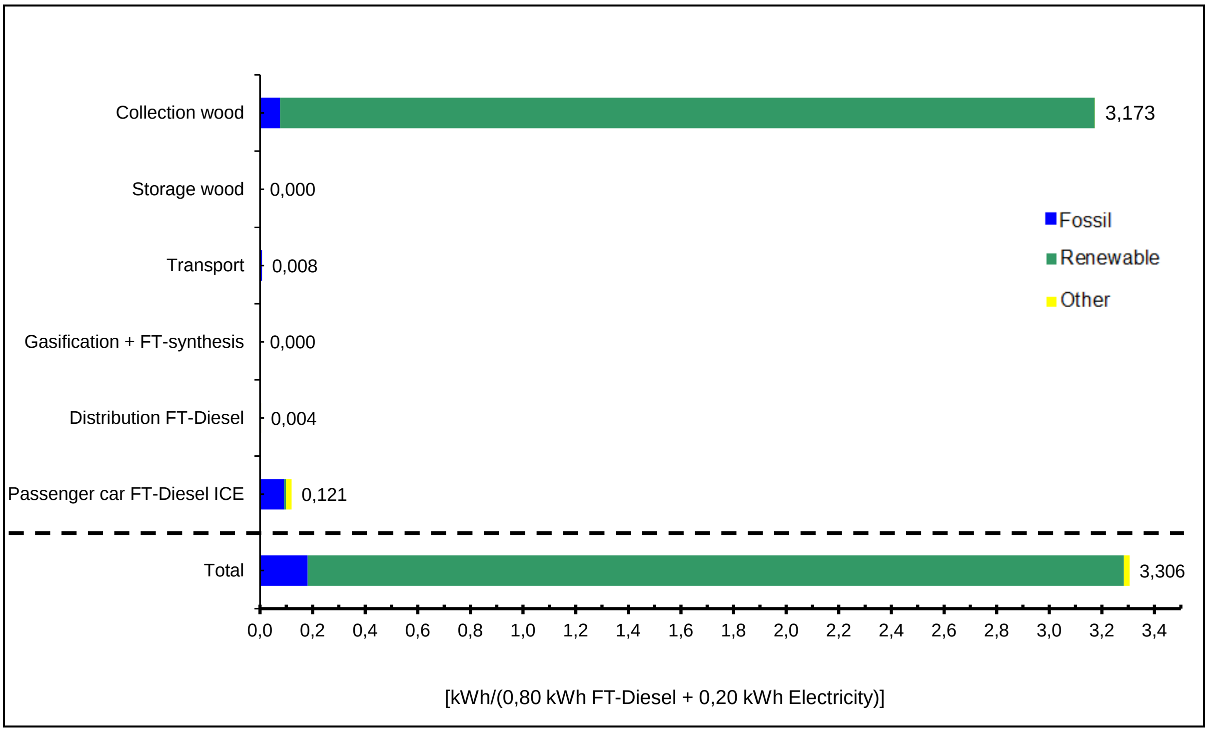

Figure B-23 WTW Cumulated primary energy demand of FT-Diesel from wood (forest) (2010)

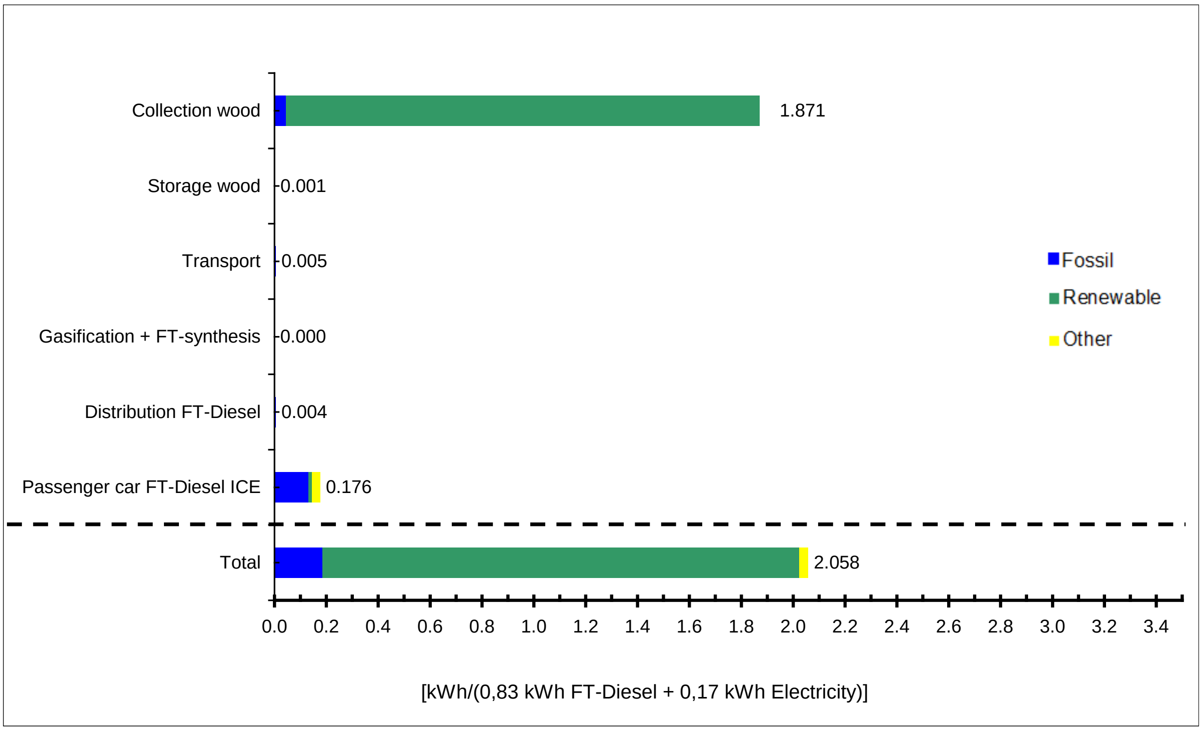

Figure B-24 WTW Cumulated primary energy demand of FT-Diesel from wood (forest) (2050)

B.4.2. Greenhouse gas emissions

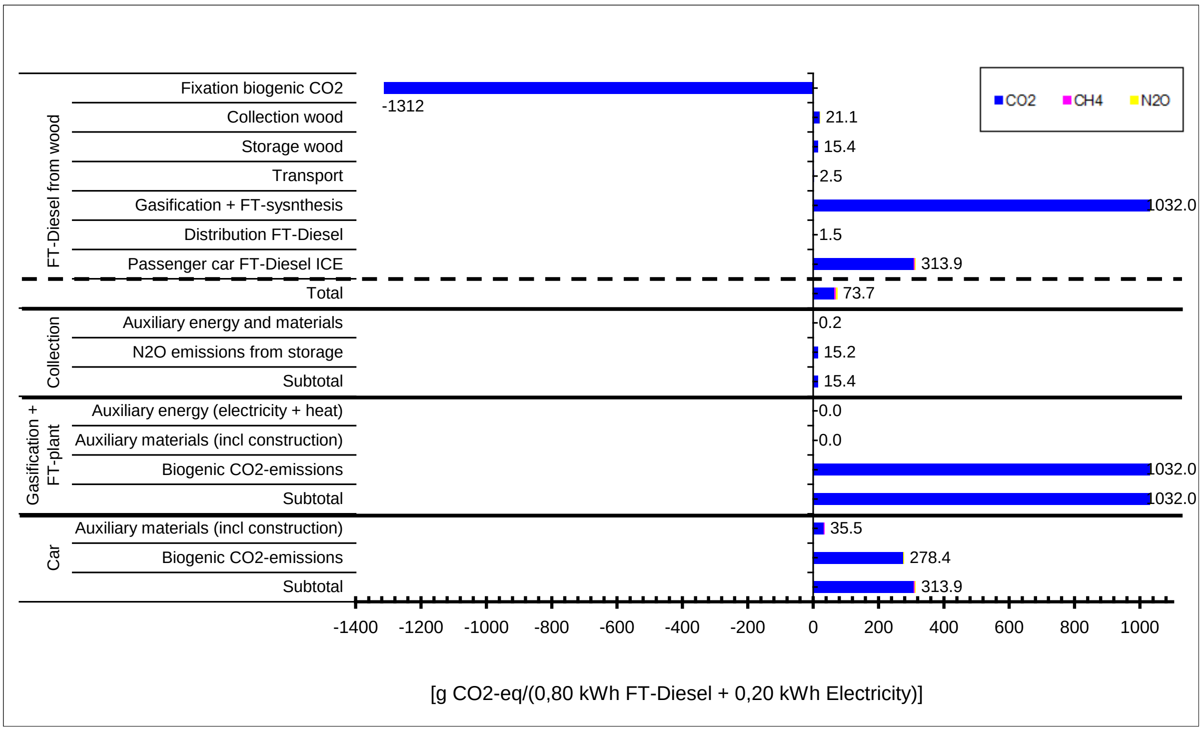

Figure B-25 WTW – GHG emissions of FT-Diesel from wood (forest) (2010)

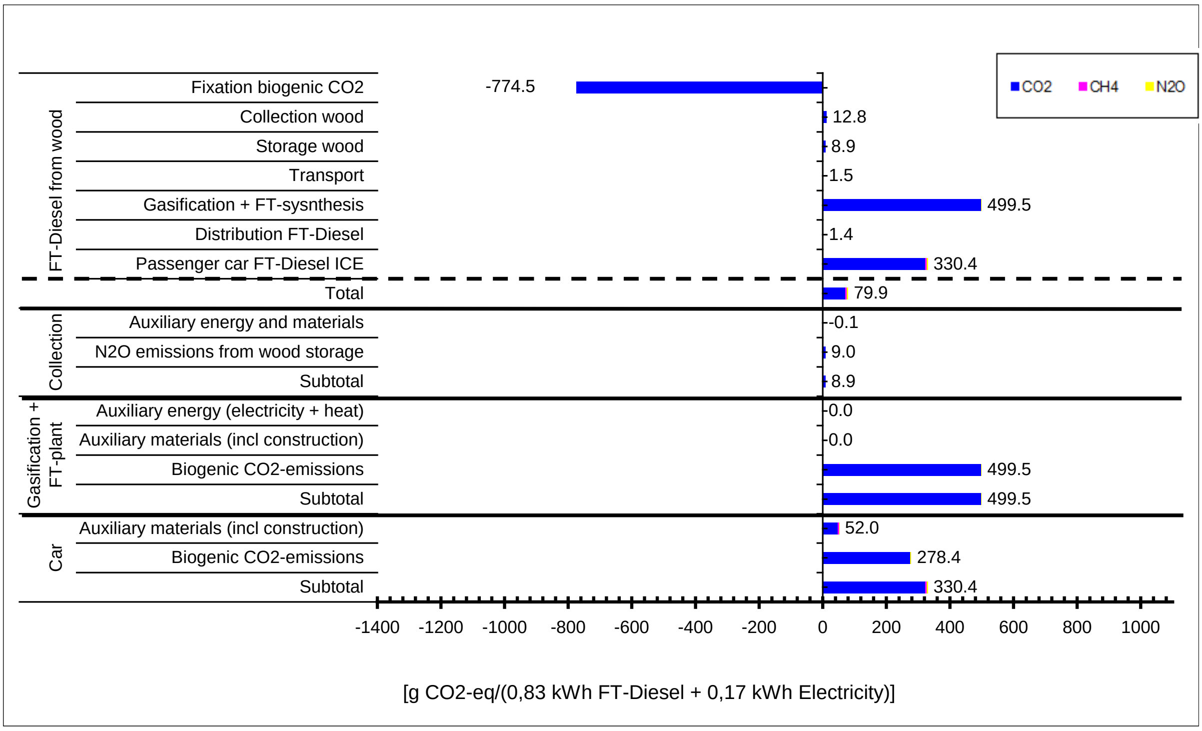

Figure B-26 WTW – GHG emissions of FT-Diesel from wood (forest) (2050)

B.4.3. Economic assessment

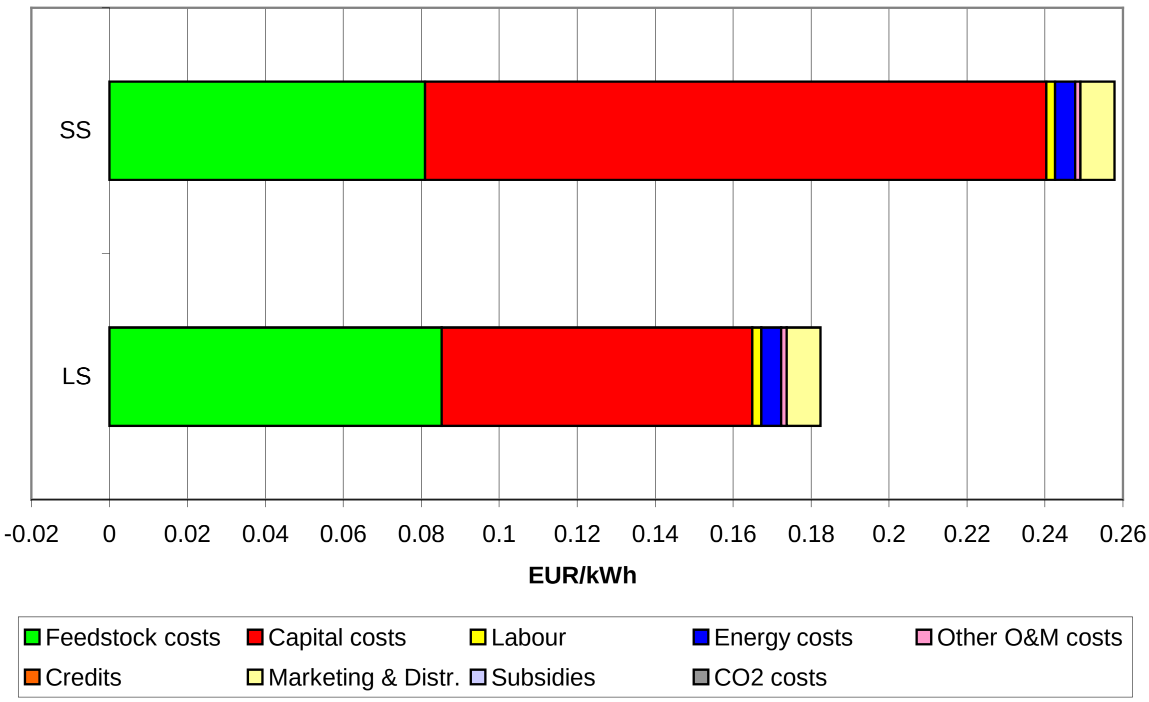

Figure B-27 Cost structure of biodiesel 2[nd] generation in 2010

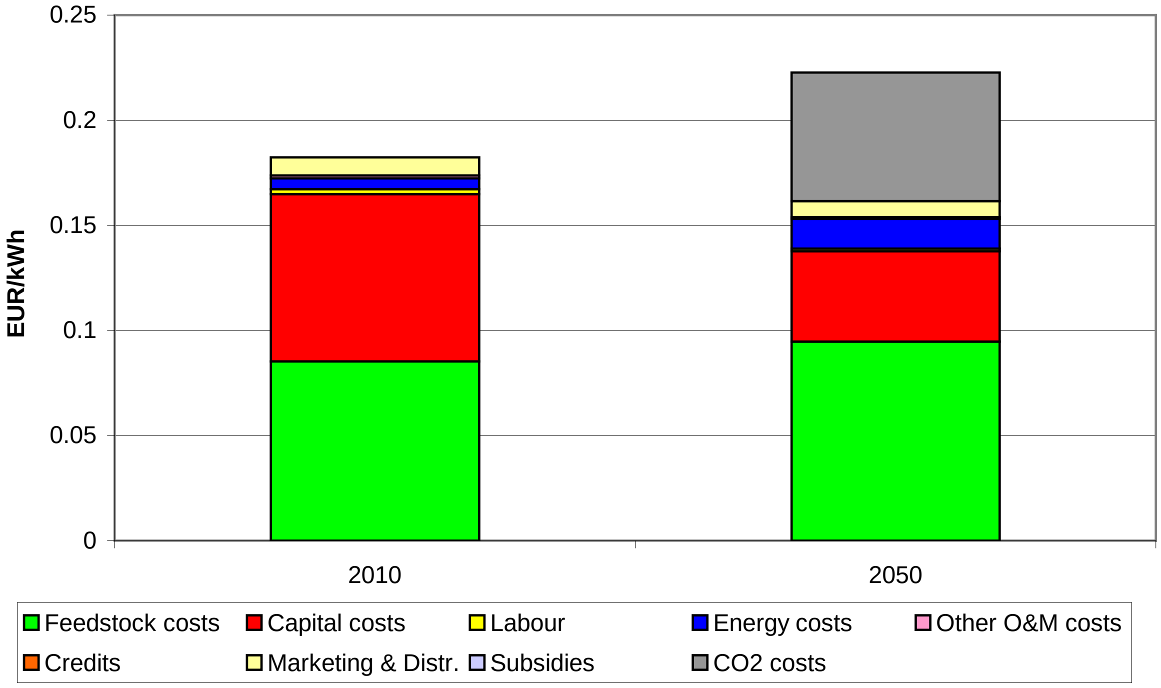

Figure B-28 Cost structure of biodiesel 2nd generation in 2010 vs. 2050

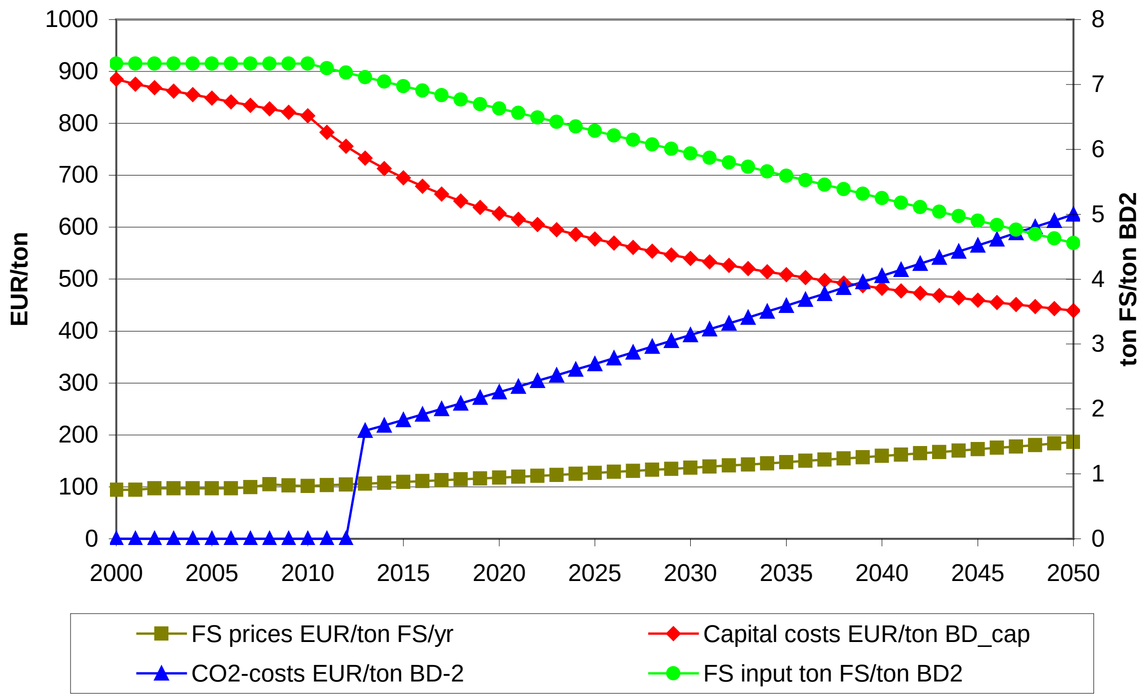

Figure B-29 Trends of different impact parameters on the costs of biodiesel 2nd generation up to 2050

B.5. 2nd generation bioethanol

2nd generation bioethanol is produced from lignocellulose and hemicellulose by pre-tretment and hydrolysis to sugars and subsequent fermentation [Toro et al, 2010]. It can be produced from agricultural and forest residues, wood waste and energy crops such as grasses and short rotation forestry. Byproduct of bioethanol production could be used as animal feed or for heat and power production. Ways in which byproduct are used has significant impact on total GHG- and energy balances.

Currently there are only several pilot plants in operation for the production of lignocellulosic ethanol. With the large scale production costs could be much lower.

In the following the energetic, ecological and economic assessment of 2nd generation bioethanol are presented.

B.5.1. Cumulated primary energy demand

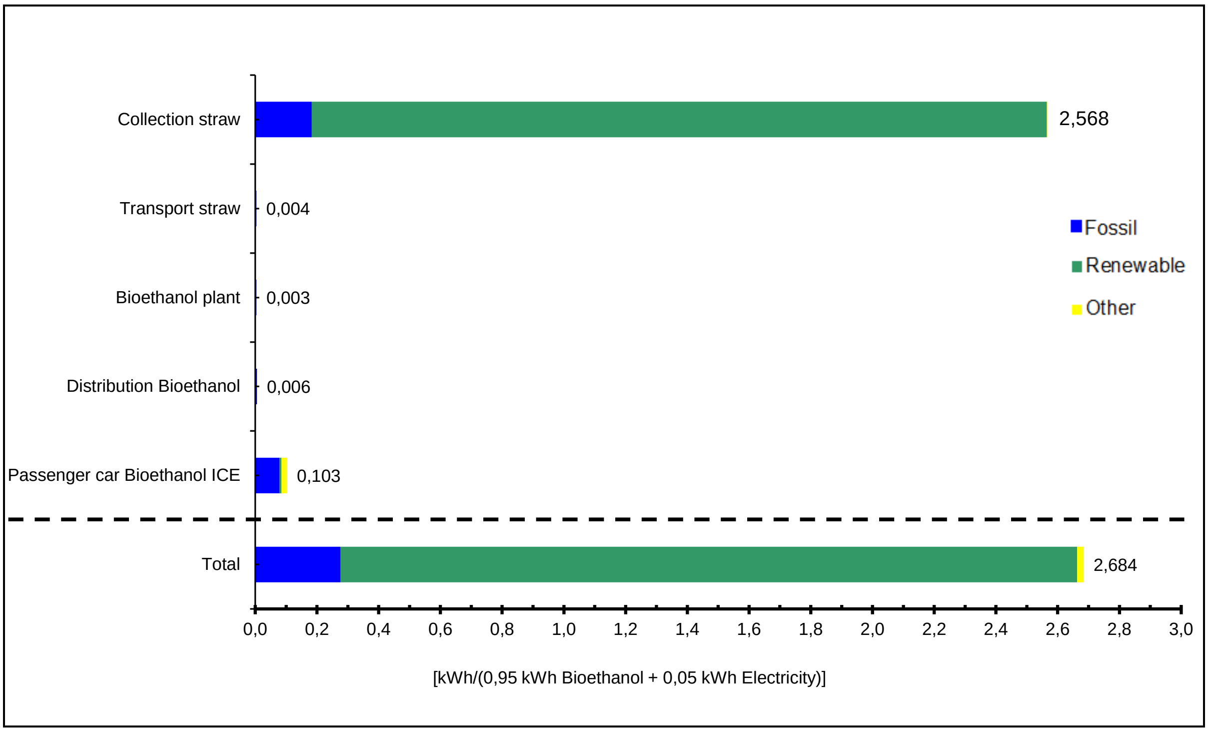

Figure B-30 WTW Cumulated primary energy demand of bioethanol from straw (2010)

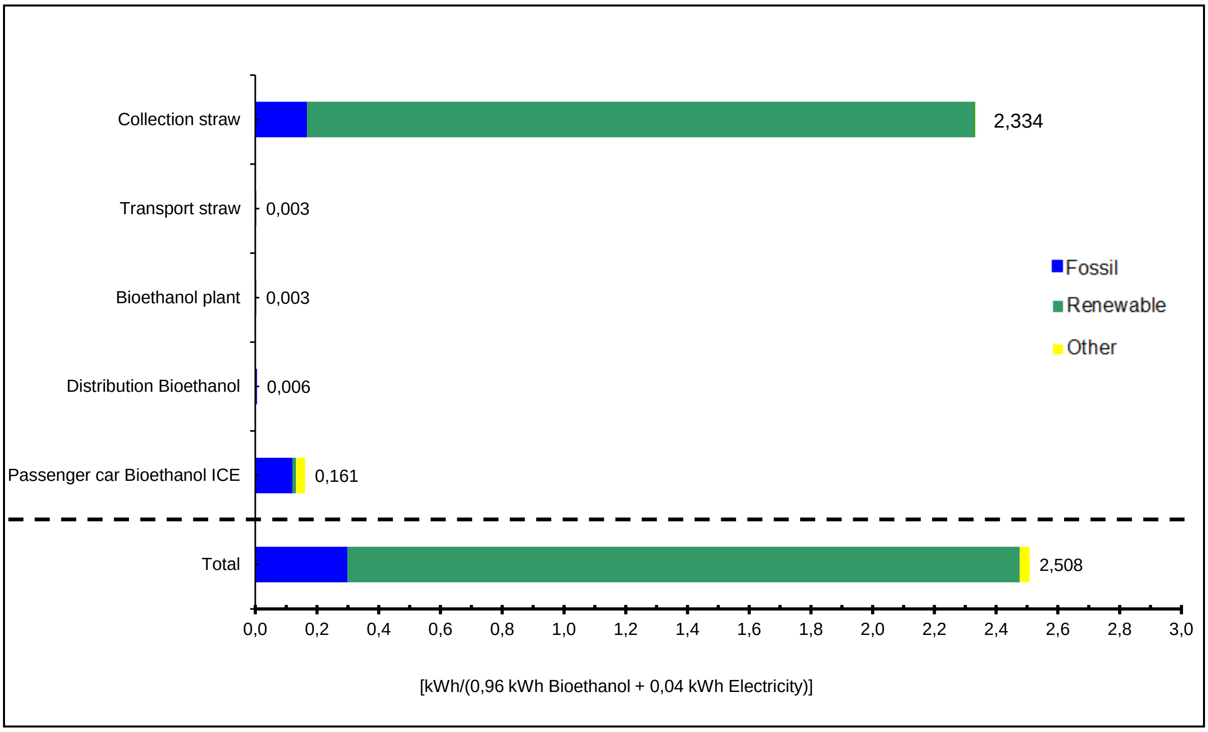

Figure B-31 WTW Cumulated primary energy demand of bioethanol from straw (2050)

B.5.2. Greenhouse gas emissions

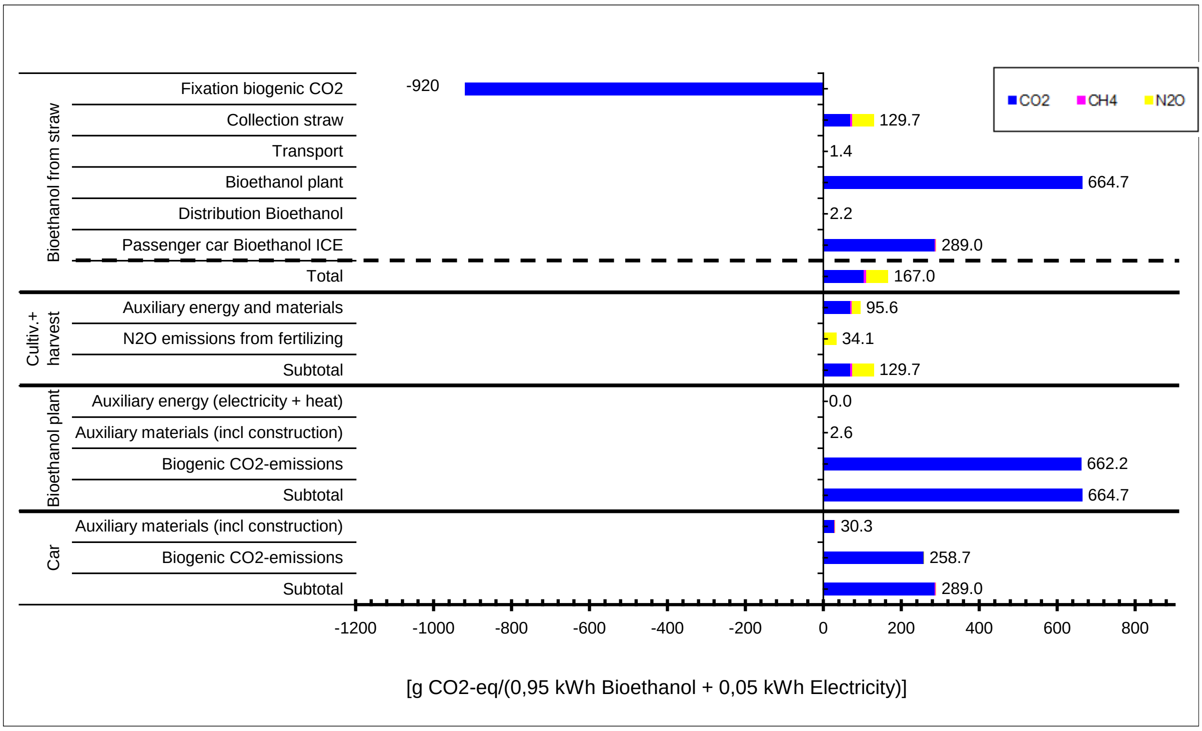

Figure B-32 WTW – GHG emissions of bioethanol from straw (2010)

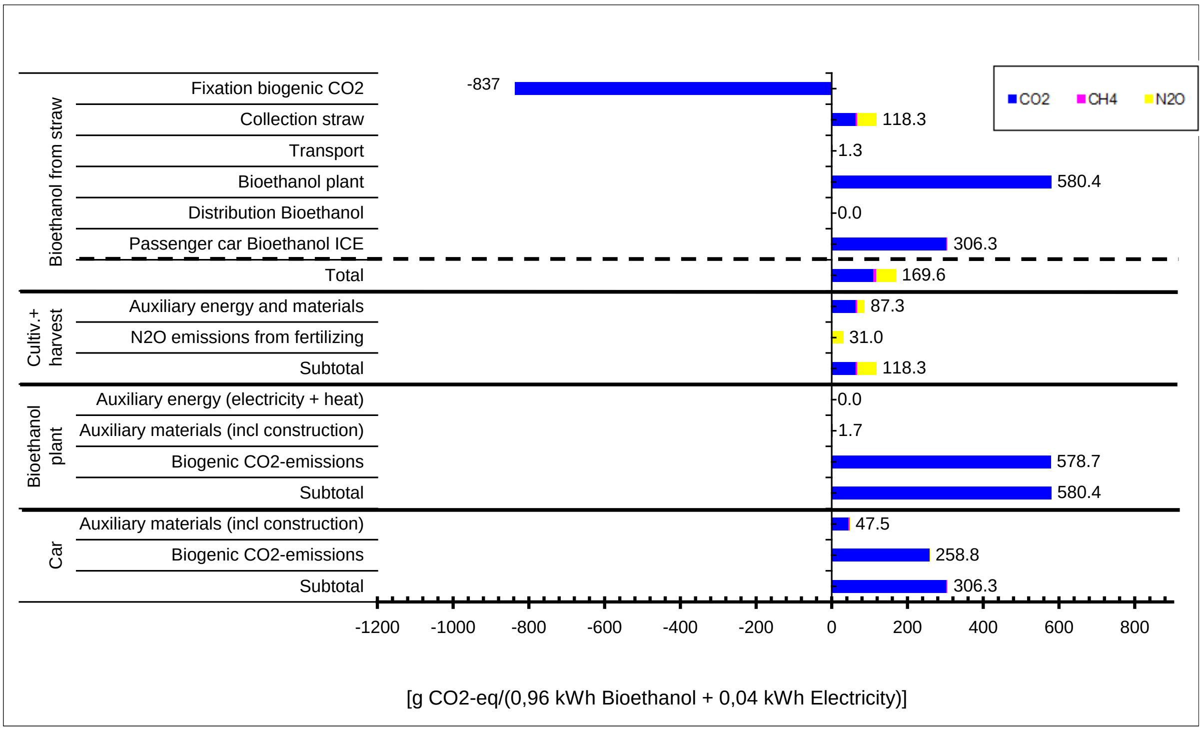

Figure B-33 WTW – GHG emissions of bioethanol from straw (2050)

B.5.3. Economic assessment

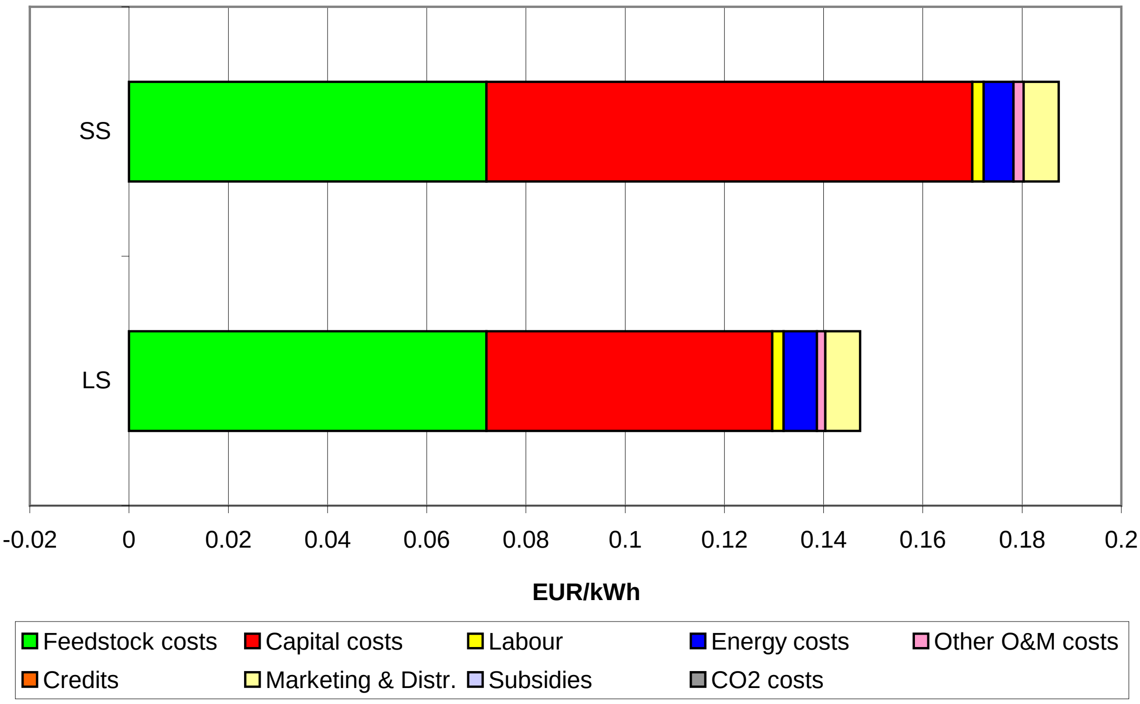

Figure B-34 Cost structure of bioethanol 2[nd] generation in 2010

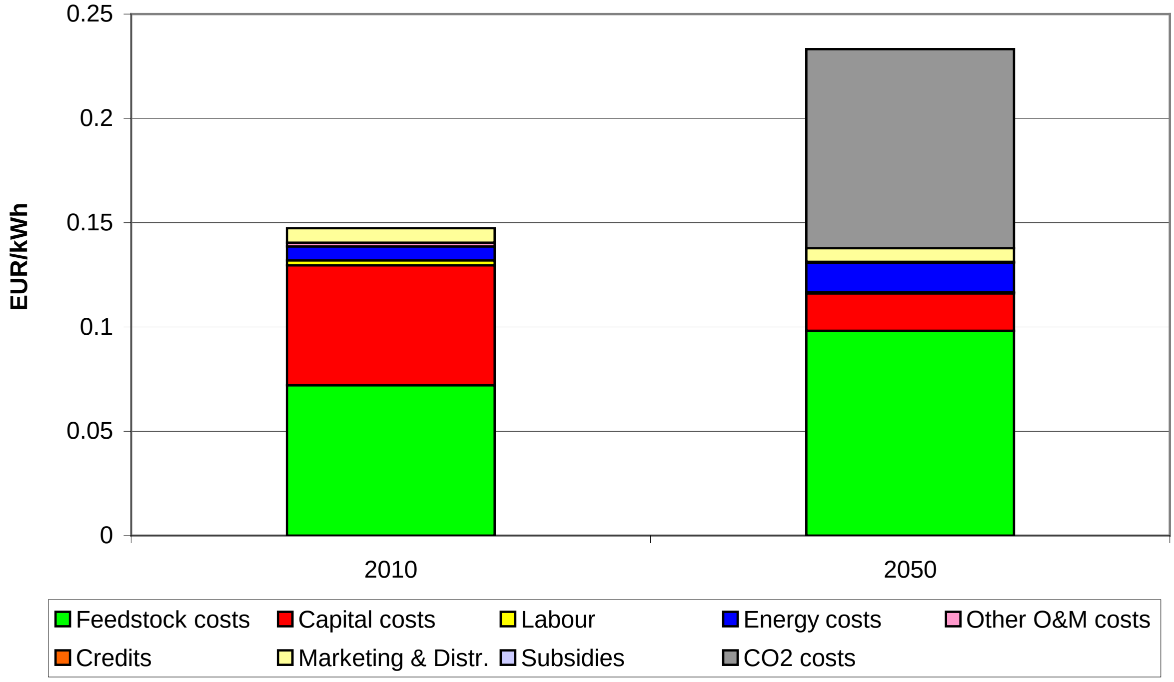

Figure B-35 Cost structure of bioethanol 2nd generation in 2010 vs. 2050

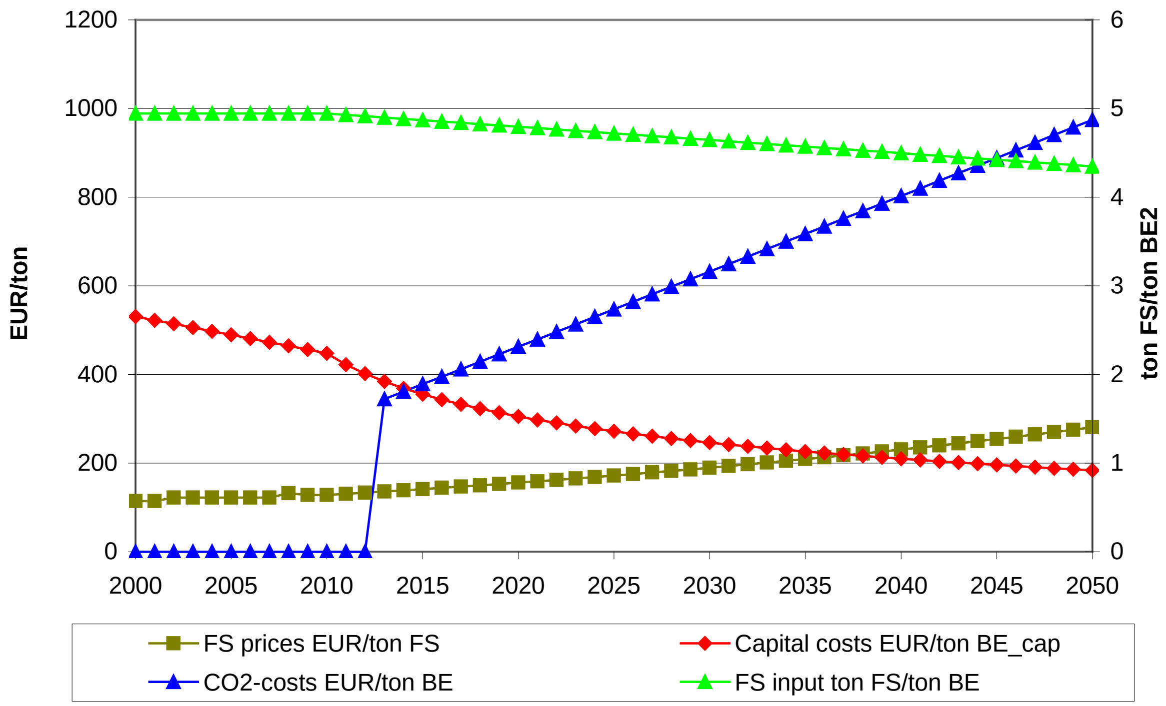

Figure B-36 Trends of different impact parameters on the costs of bioethanol 2nd generation up to 2050

B.6. SNG

Synthetic natural gas (SNG) is an artificially produced version of natural gas. It can be produced from coal, biomass, petroleum coke, or solid waste. The carbon containing mass can be gasified; the resulting syngas can then be converted to methane, the major component of natural gas [Chandel et,al, 2009]. Bio-SNG is produced by gasification of cellulosic materials e.g. forestry residues, energy crops. This renewable natural gas is a biogas which has been upgraded to a quality similar to fossil natural gas.

In the following the energetic, ecological and economic assessment of biogas are presented.

B.6.1. Cumulated primary energy demand

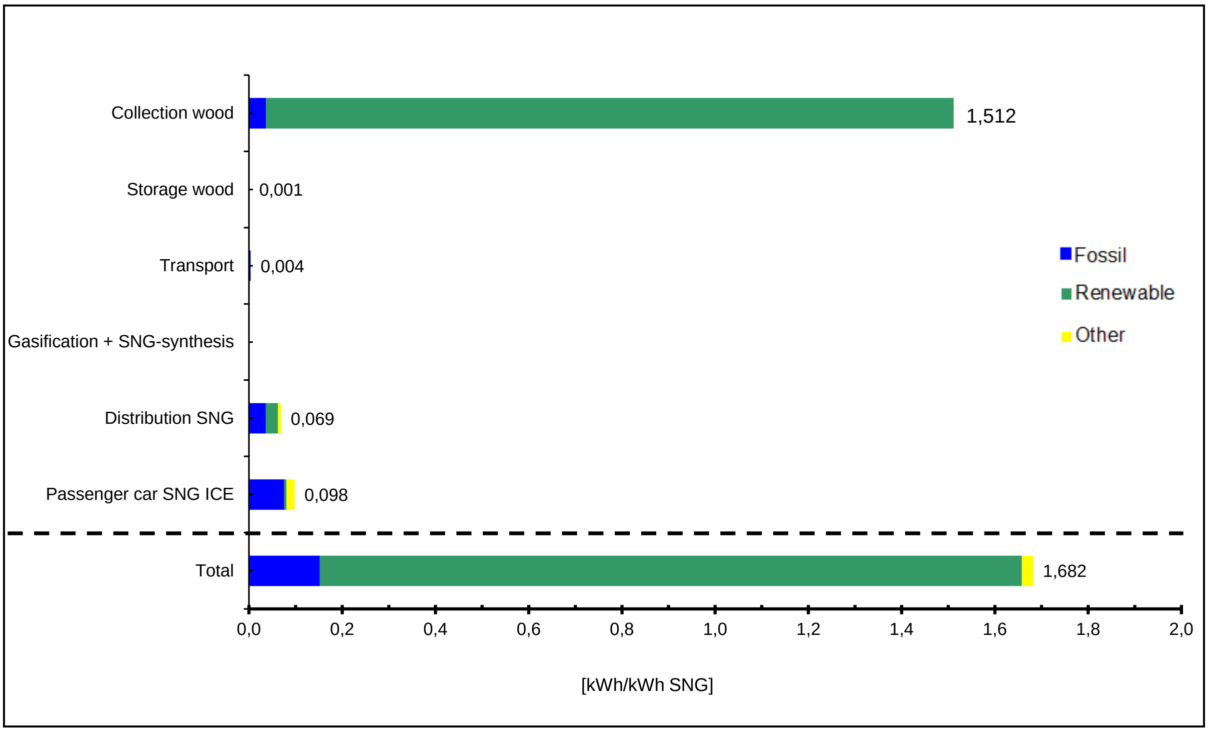

Figure B-37 WTW Cumulated primary energy demand of SNG from wood (forest) (2010)

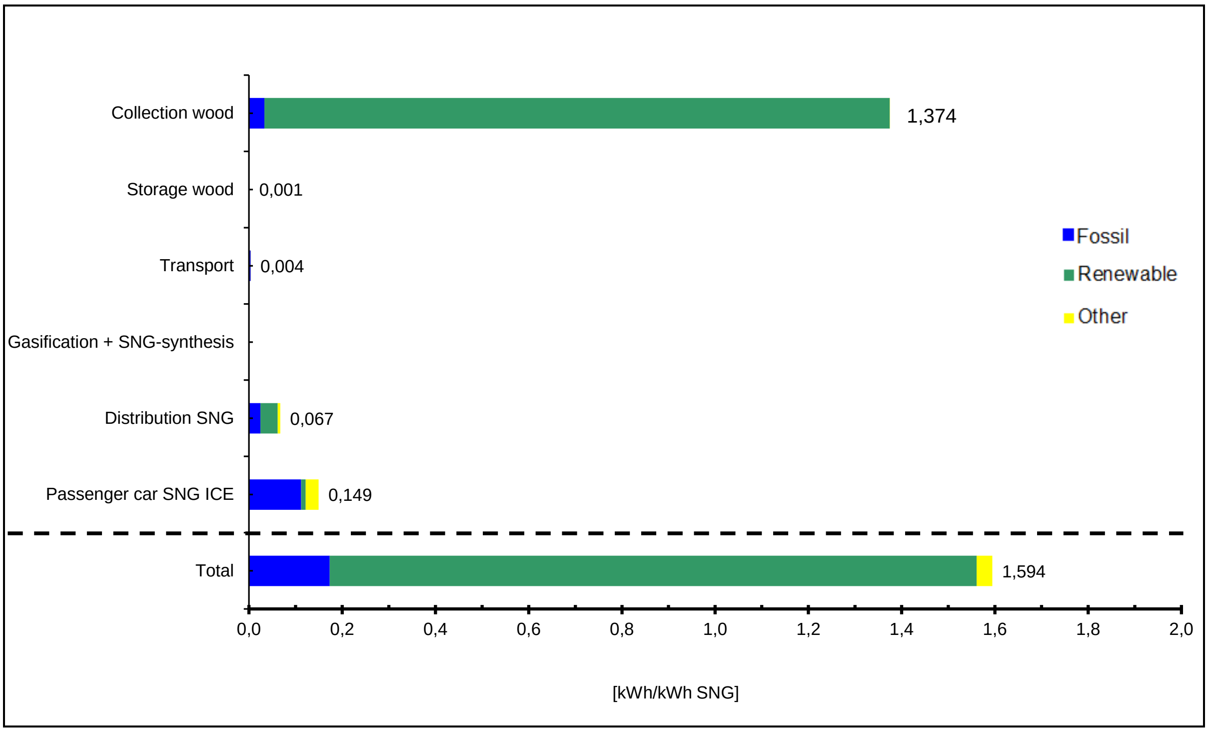

Figure B-38 WTW Cumulated primary energy demand of SNG from wood (forest) (2050)

B.6.2. Greenhouse gas emissions

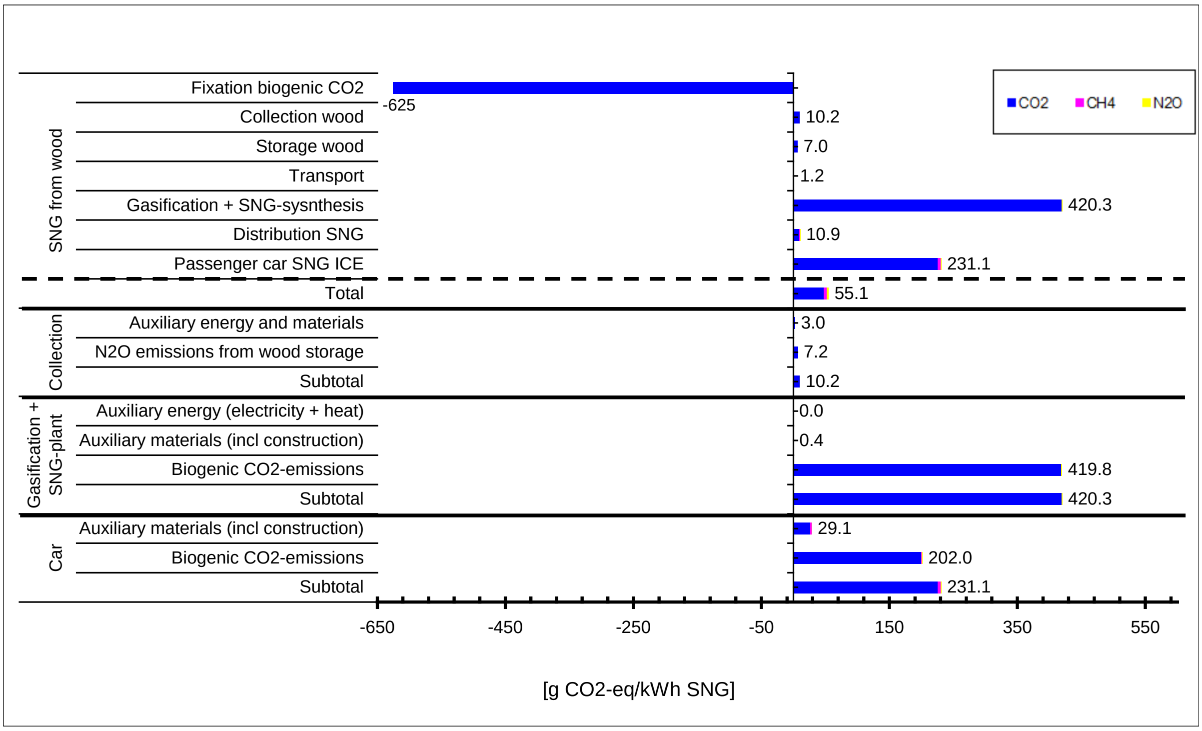

Figure B-39 WTW – GHG emissions of SNG from wood (forest) (2010)

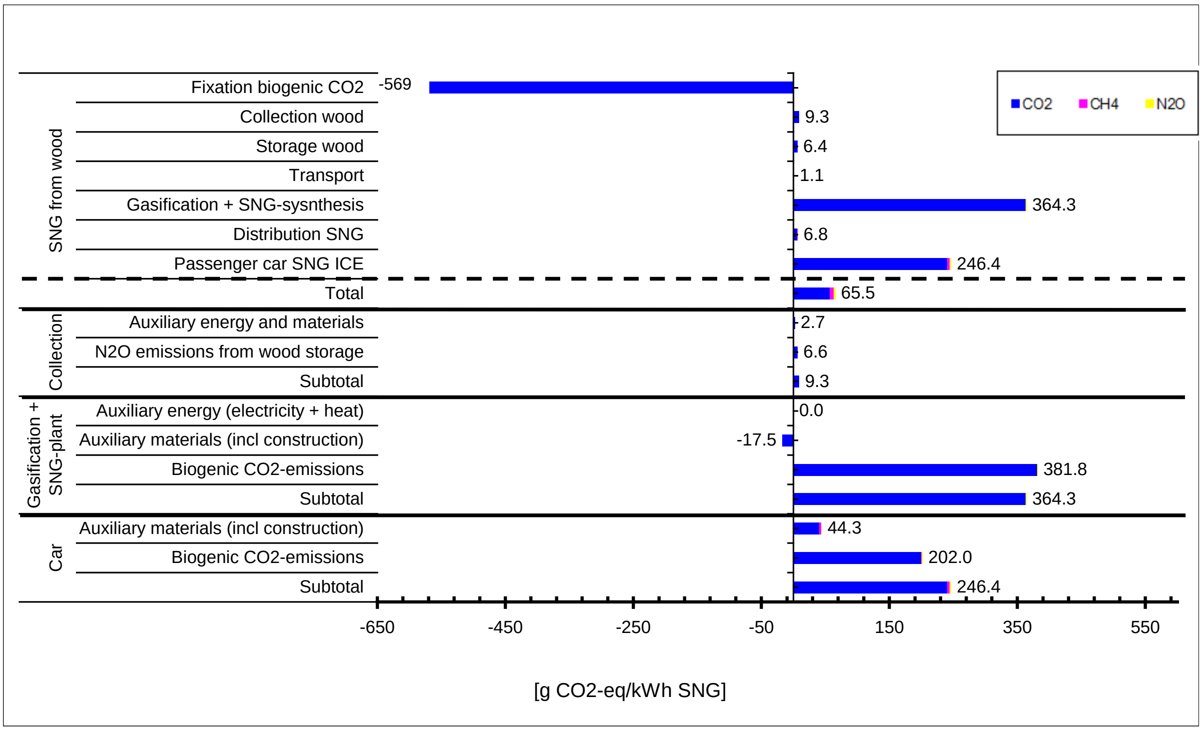

Figure B-40 WTW – GHG emissions of SNG from wood (forest) (2050)

B.6.3. Economic assessment

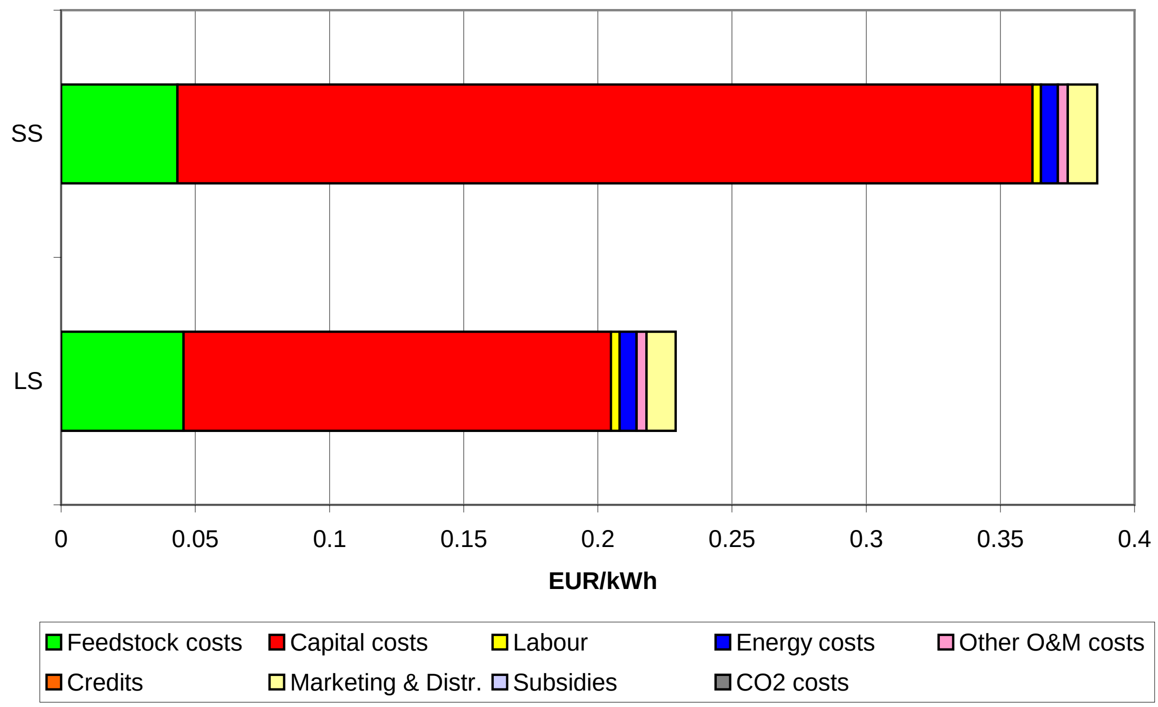

Figure B-41 Cost structure of SNG in 2010

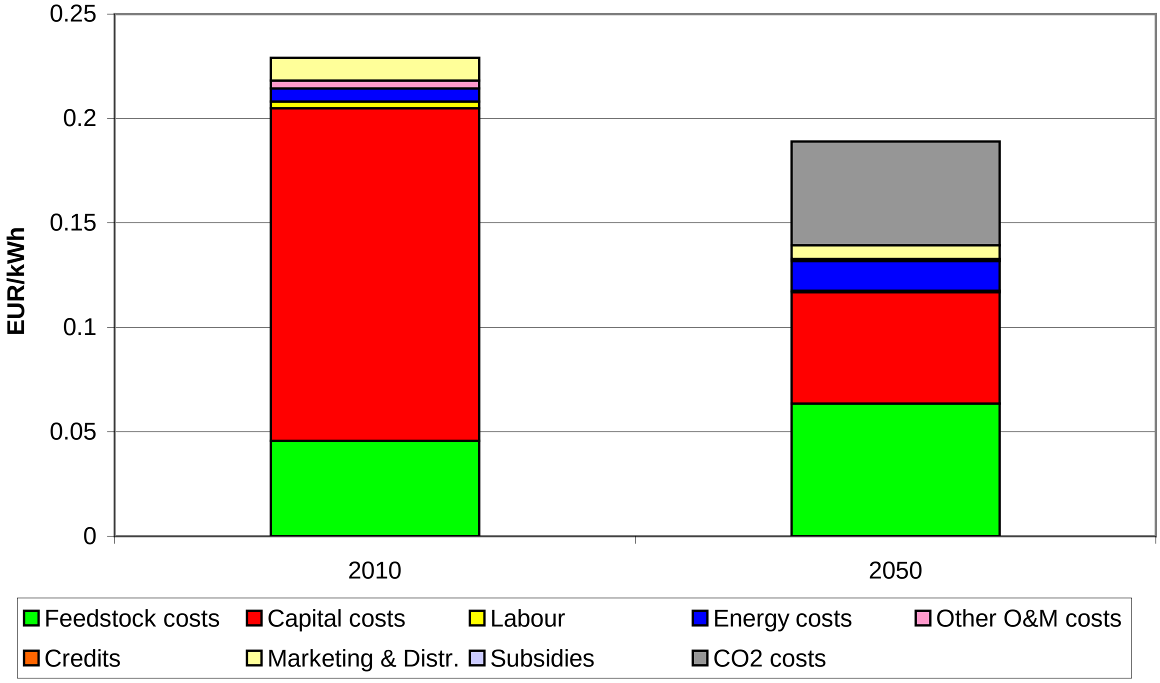

Figure B-42 Cost structure of SNG in 2010 vs. 2050

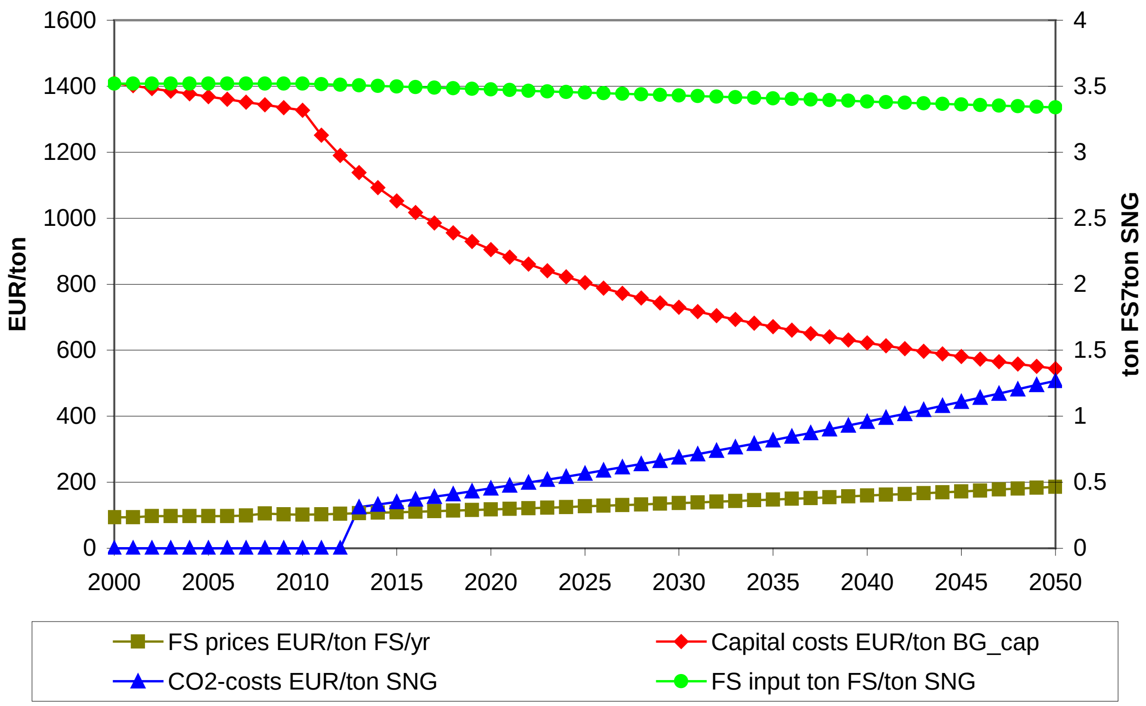

Figure B-43 Trends of different impact parameters on the costs of SNG up to 2050

B.7. Electricity from biomass

Electricity, as a secondary energy carrier, could be produced using different primary energy sources: fossil energy, renewable energy or nuclear energy. In the following cumulative energy demand, greenhouse gas emissions and costs of electricity from biomass are presented.

B.7.1. Cumulated primary energy demand

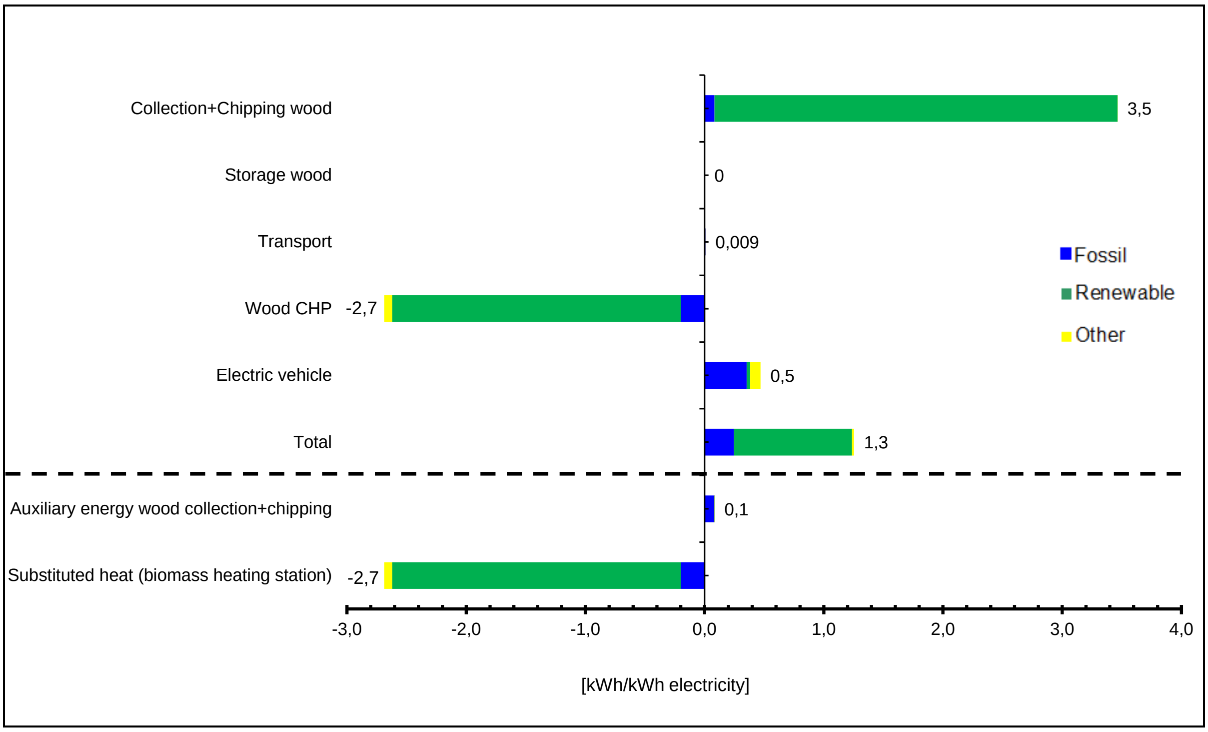

Figure B-44 WTW Cumulated primary energy demand of electricity from wood (forest) (2010)

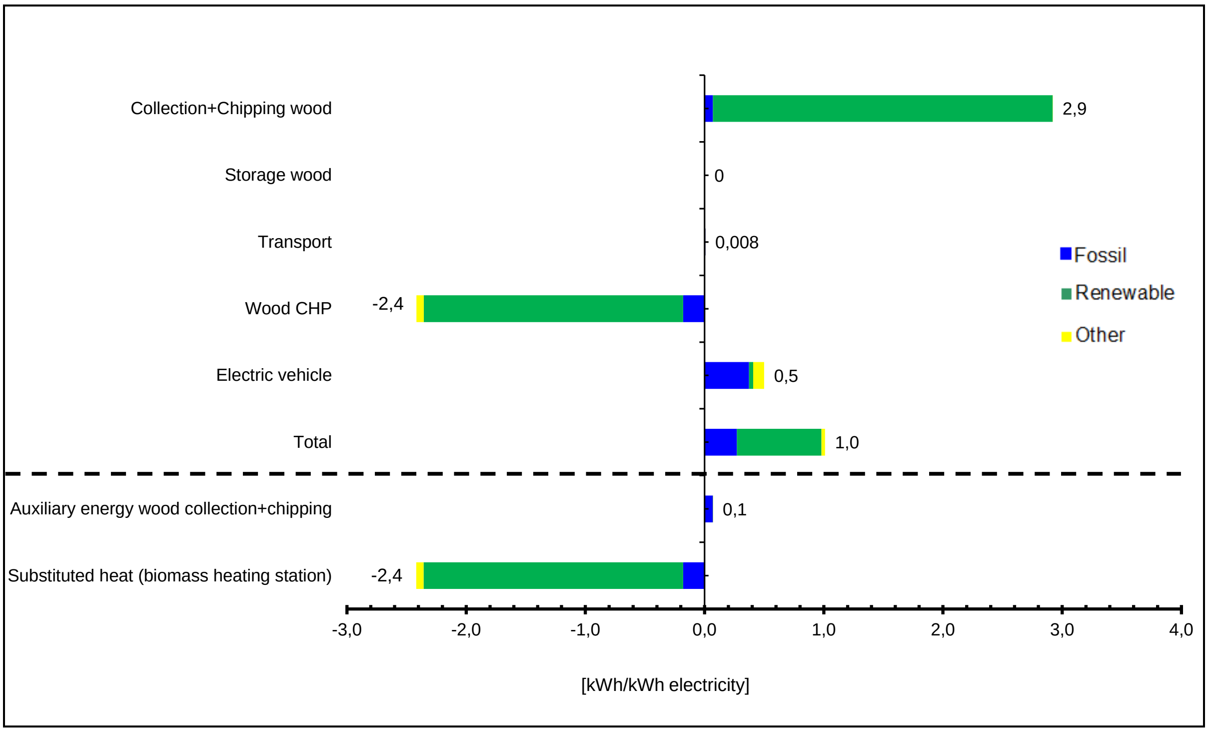

Figure B-45 WTW Cumulated primary energy demand of electricity from wood (forest) (2050)

B.7.2. Greenhouse gas emissions

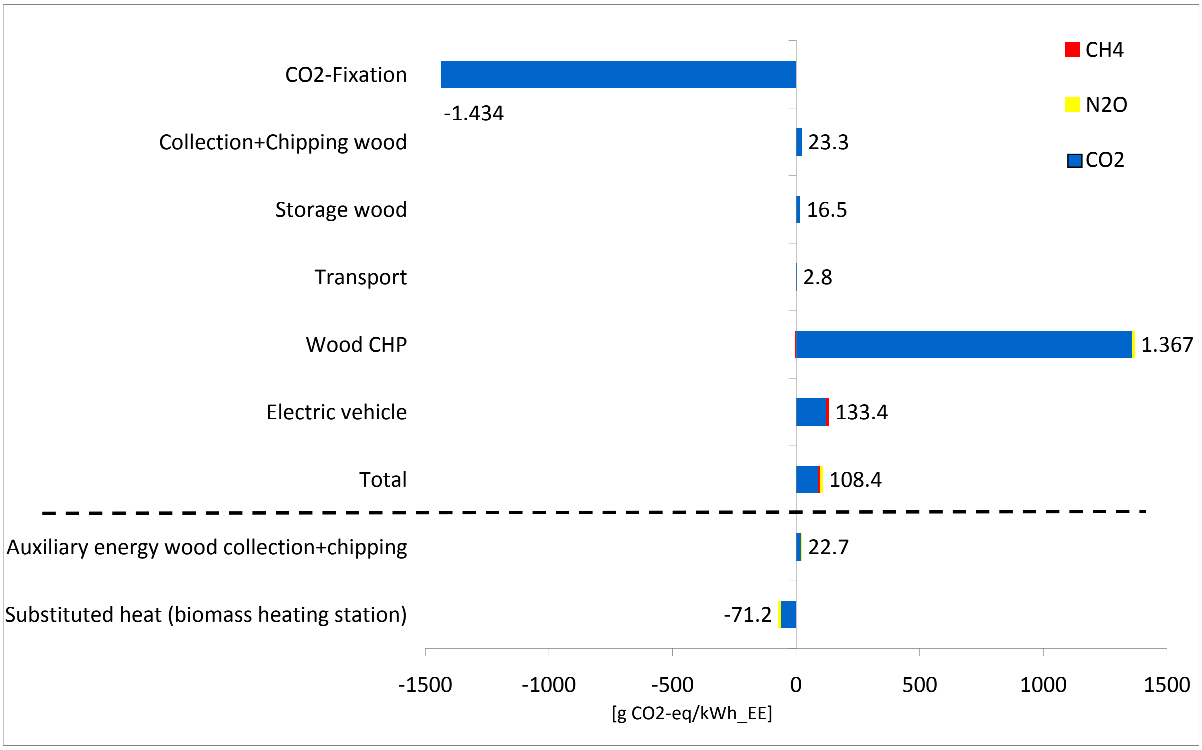

Figure B-46 WTW – GHG emissions of electricity from wood (forest) (2010)

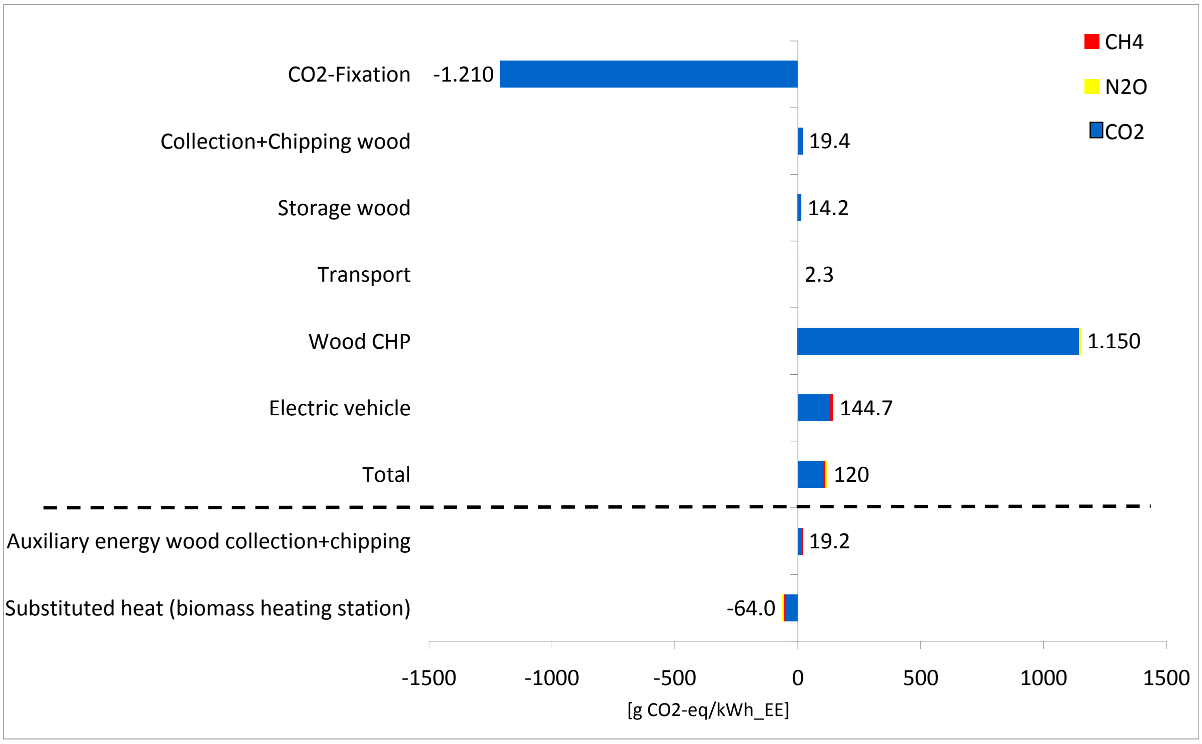

Figure B-47 WTW – GHG emissions of electricity from wood (forest) (2050)

B.7.3. Economic assessment

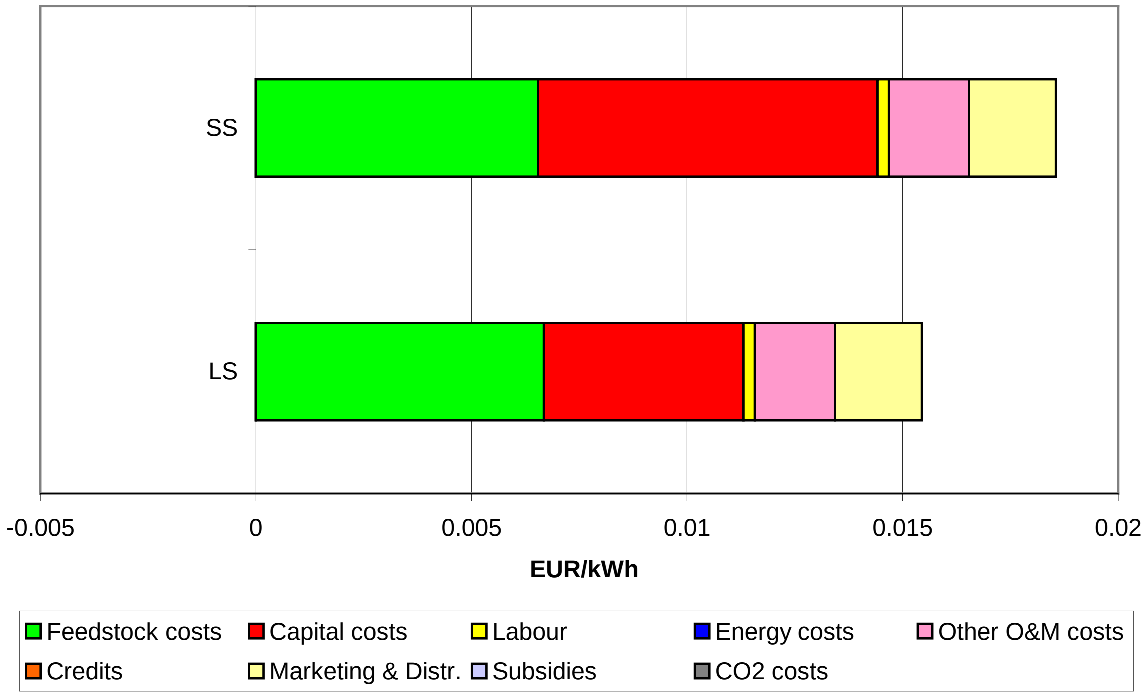

Figure B-48 Cost structure of electricity from biomass in 2010

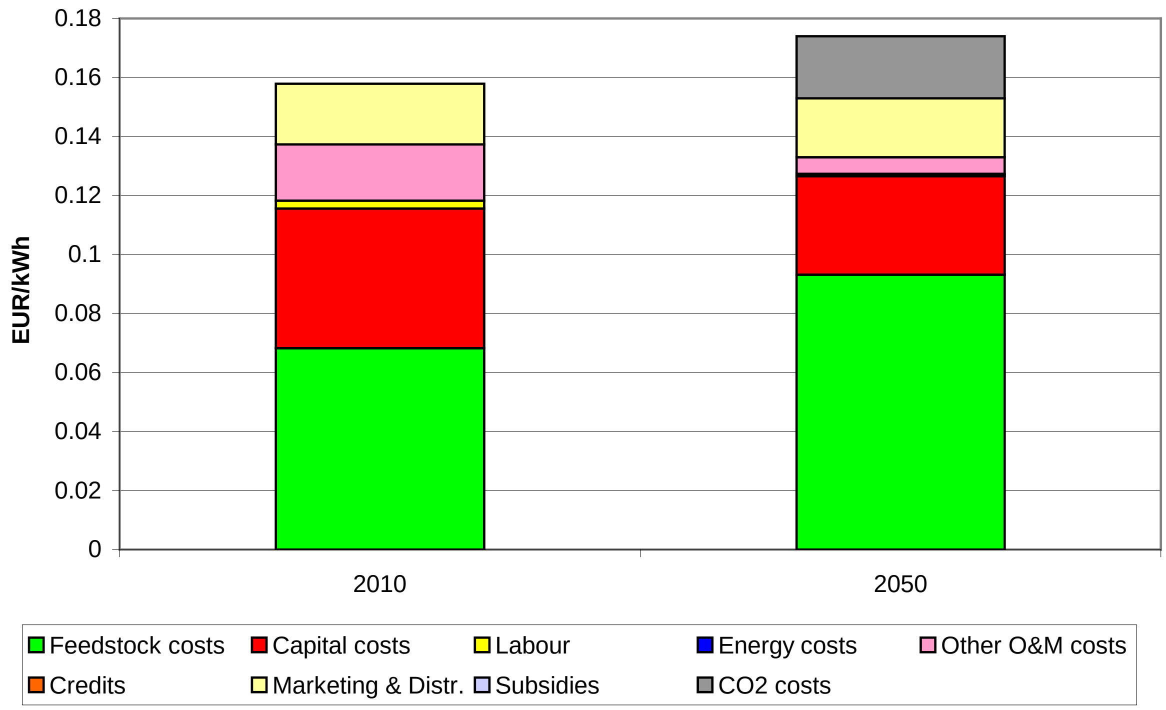

Figure B-49 Cost structure of electricity from biomass in 2010 vs. 2050

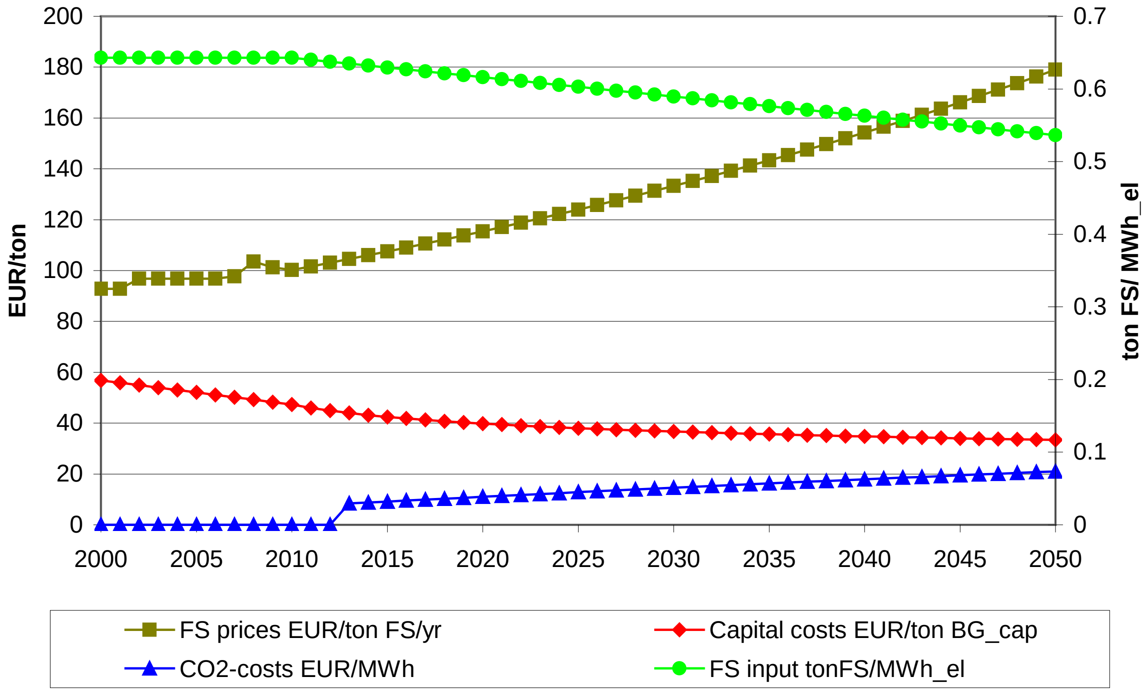

Figure B-50 Trends of different impact parameters on the costs of electricity from biomass up to 2050

B.8. Hydrogen

Hydrogen is, like electricity, secondary energy carrier which could be produced using different primary energy sources: fossil energy, renewable energy or nuclear energy. However, it has all advantages only if produced from renewable energy sources.

In the following figures cumulative energy demand, greenhouse gas emissions and costs of hydrogen from biomass are depicted.

B.8.1. Cumulated primary energy demand

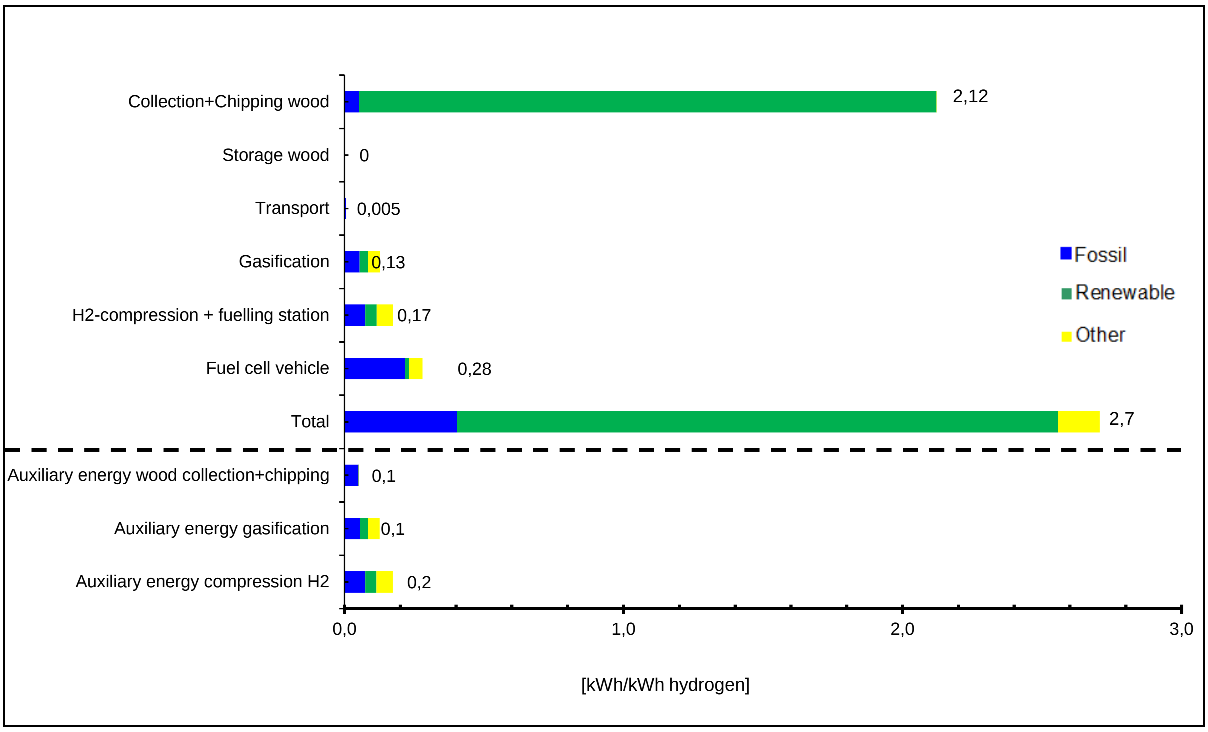

Figure B-51 WTW Cumulated primary energy demand of hydrogen from wood gasification (2010)

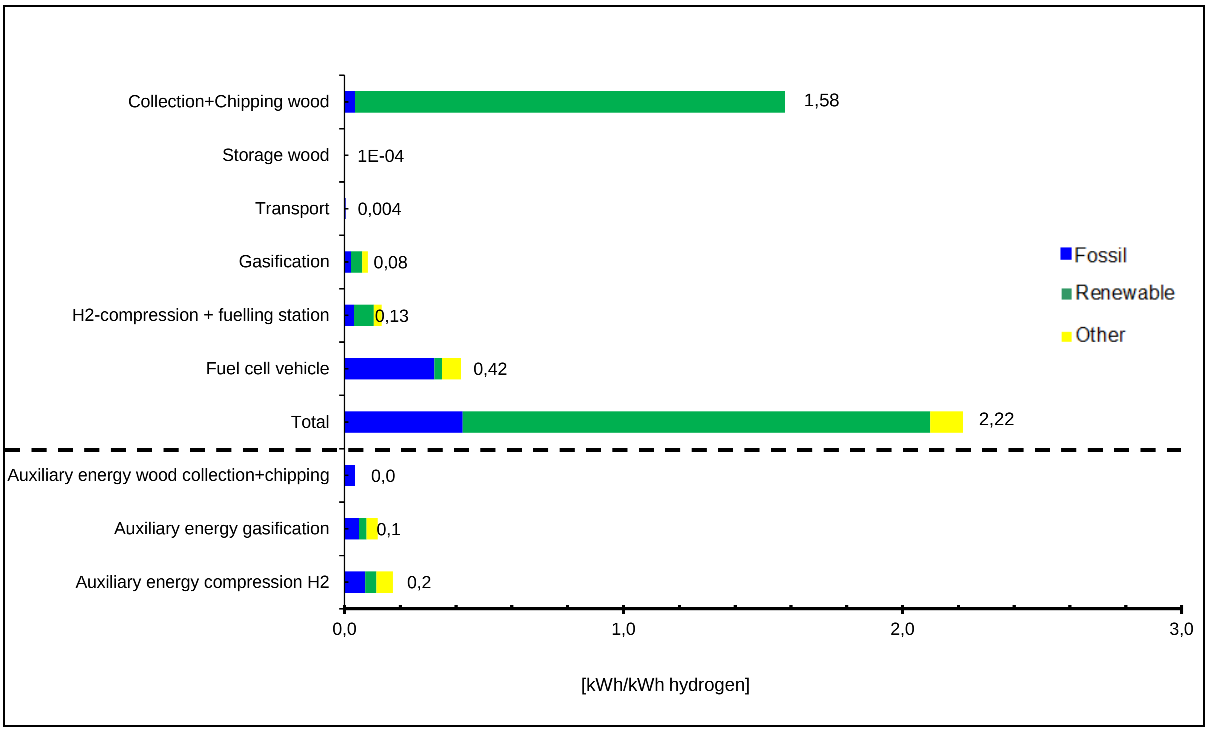

Figure B-52 WTW Cumulated primary energy demand of hydrogen from wood gasification (2050)

B.8.2. Greenhouse gas emissions

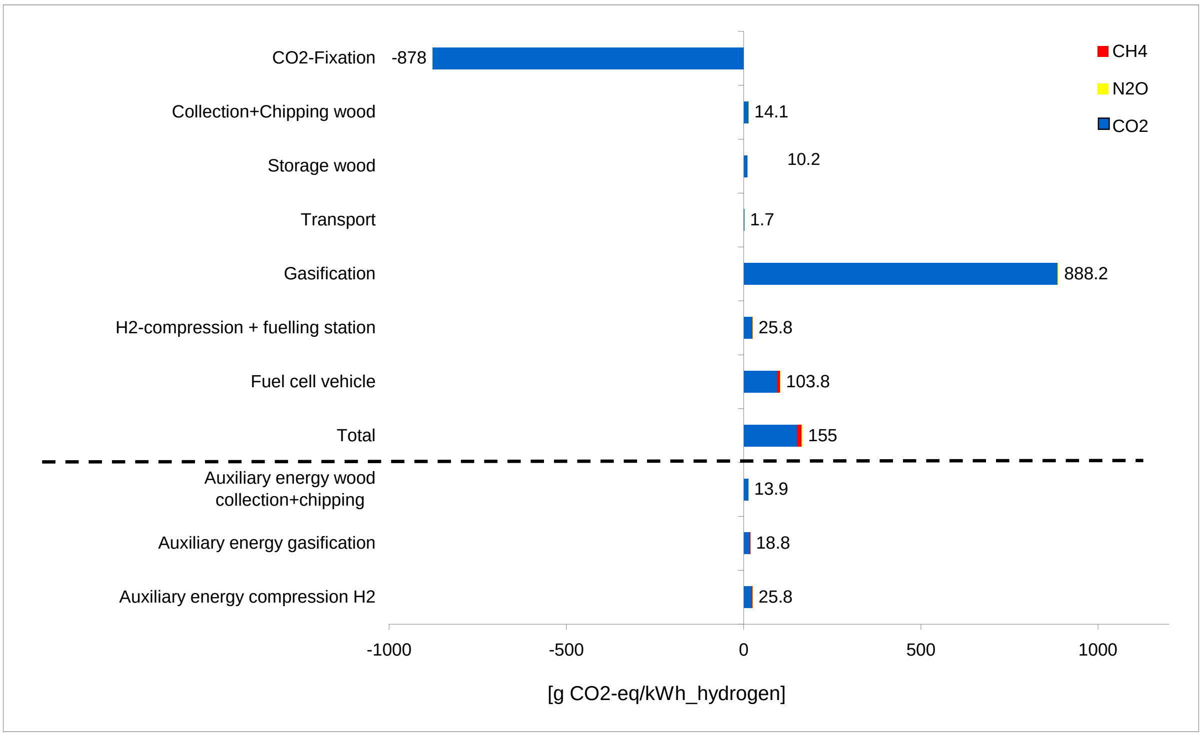

Figure B-53 WTW – GHG emissions of hydrogen from wood gasification (2010)

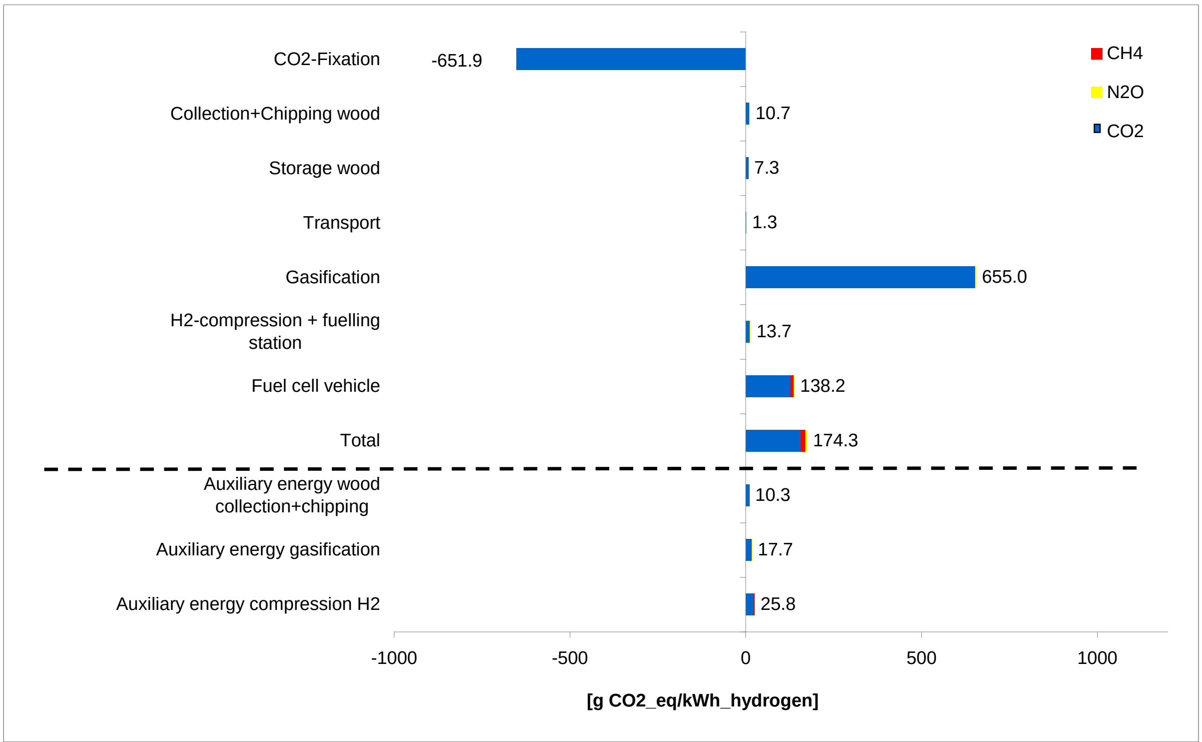

Figure B-54 WTW – GHG emissions of hydrogen from wood gasification (2050)

B.8.3. Economic assessment

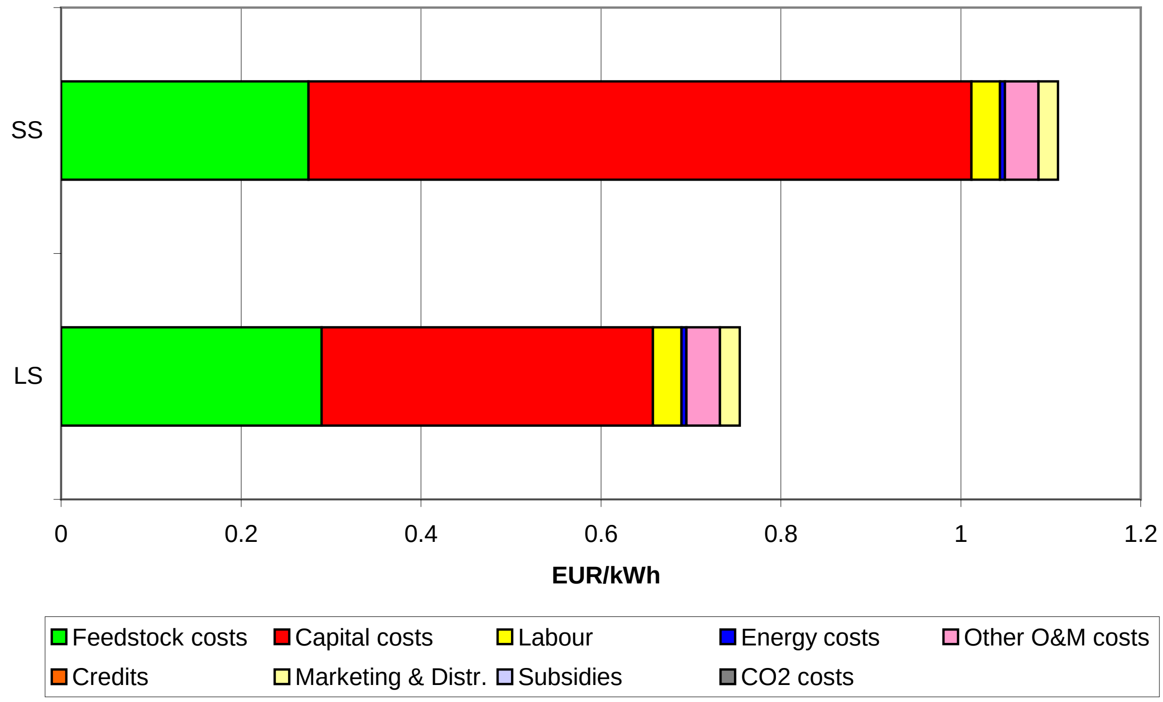

Figure B-55 Cost structure of hydrogen from biomass in 2010

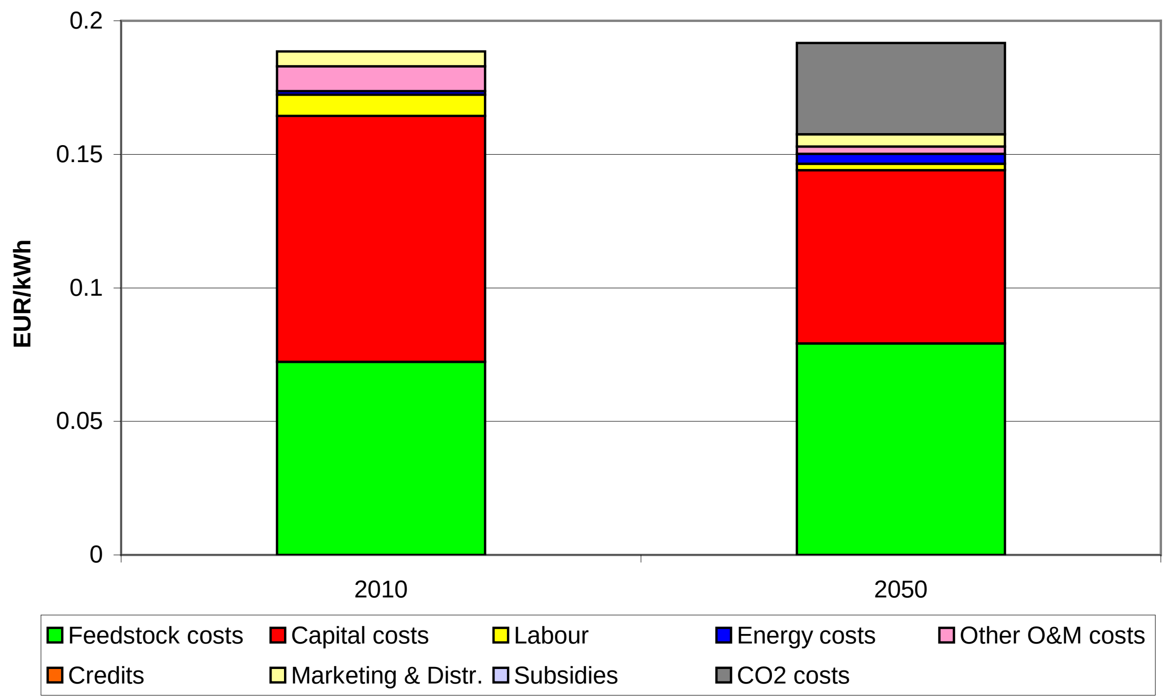

Figure B-56 Cost structure of electricity from biomass in 2010 vs. 2050

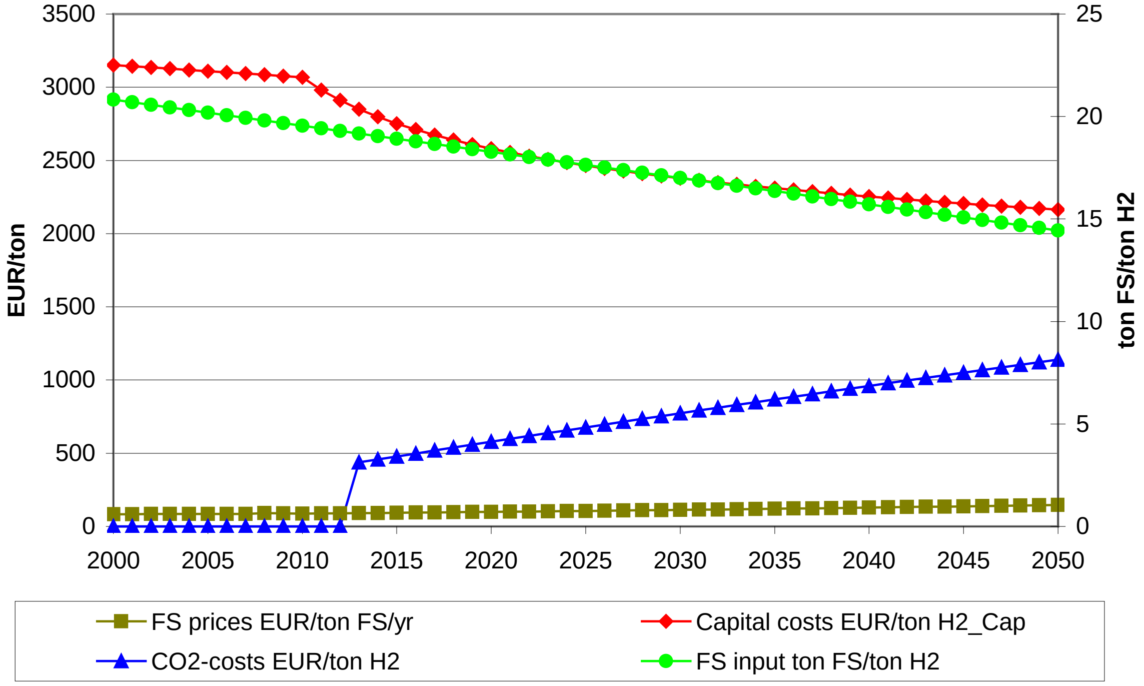

Figure B-57 Trends of different impact parameters on the costs of hydrogen from biomass up to 2050

Annex C: Major features of investigated energy carriers

	Density	*LHV*	*Energy content*		*CO_2-content*		*CO_2-WTW*
	kg/m3	*MJ/kg*	*kWh/litre*	*kWh/kg*	*kg/kg*	*gCO_2/MJ*	*gCO_2/MJ*
AEC:							
Bioethanol Wheat	794	28	6.18	7.78	1.91	68.21	62.9
Biodiesel Rapeseed	835	42.8	9.93	11.89	3.12	72.90	49.8
Biogas	835	43	9.97	11.94	3.16	73.49	36.8
Bioethanol Ligno	794	28	6.18	7.78	1.91	68.21	22.2
Biodiesel BTL-FT	720	43.7	8.74	12.14	1.38	31.58	47.1
SNG	1.003	29.988	0.01	8.33	3.16	105.38	23.2
Electricity (from biomass)						0.00	8.0
Hydrogen (from biomass)	0.0899	120.1	0.00	33.36	0	0.00	13.0
Conventional:							
Gasoline	745	43.2	8.94	12.00	3.17	73.38	85.6
Diesel	835	43.1	9.97	11.97	3.16	73.32	87.2
CNG	1.008	45.1		12.53	2.54	56.32	70.0
LPG	550	46	7.03	12.78	3.02	65.65	73.5

Annex D : Detailed results of the scenarios

	2010	2050 With arable land			2050 Without arable land			2050
	Actual	Biofuel	H2	No priority	Biofuel	H2	No priority	No Policy
BD-1	7.4	4.5	4.6	4.6	4.5	4.6	4.6	11.1
BE-1	6.2	1.3	1.3	1.3	1.3	1.3	1.3	5.8
BG	7.0	18.0	13.4	13.4	18.0	13.4	15.3	15.3
BD-2	0.0	73.7	69.0	72.6	10.8	0.1	7.2	0.1
BE-2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	10.3
SNG	0.0	30.6	0.1	0.1	30.6	0.1	0.1	0.1
Ele-BM	8.5	3.7	21.5	30.1	3.7	21.5	30.1	12.9
H2	0.0	0.1	15.1	0.1	0.1	11.3	0.1	0.1
Pellets	13.3	26.0	26.0	26.0	26.0	26.0	26.0	26.0
Wood chips	22.1	30.5	30.5	30.5	30.5	30.5	30.5	30.5
Fuel wood	62.9	86.8	86.8	86.8	86.8	86.8	86.8	86.8
Large Hydro	126.0	161.1	161.1	161.1	161.1	161.1	161.1	161.1
Small Hydro	14.5	34.5	34.5	34.5	34.5	34.5	34.5	34.5
Wind on-shore	7.6	65.9	65.9	65.9	65.9	65.9	65.9	65.9
Photovoltaics	0.1	72.0	72.0	72.0	72.0	72.0	72.0	72.0
TOTAL:	**275.5**	**608.7**	**601.8**	**598.9**	**545.8**	**529.1**	**535.5**	**532.4**

List of Abbreviations

AEC – Alternative energy carriers

BTL – Biomass to liquid

BD-1 – 1st generation biodiesel

BD-2 – 2nd generation biodiesel

BE-1 – 1st generation bioethanol

BE-2 – 2nd generation bioethanol

BF-1 – Biofuels 1st generation

BF-2 – Biofuels 2nd generation

BG – Biogas (upgraded biogas – biomethane)

BM - Biomass

CCS - Carbon capture and storage

CHP – Combined heat and power cogeneration

CNG – Compressed natural gas

CTL – Coal to liquid

DDGS - Distillers dried grain with solubles

DME – Dimethylether

Ele-PV – Electricity from photovoltaic

Ele-BM - Electricity from biomass

ETBE - Ethyl tertiary butyl ether

FT-Diesel – Fischer-Tropsch Diesel

FWR - Forest wood residues

GHG – Greenhouse gas

GTL – Gas to liquid

H2 – Hydrogen

H2-BM – Hydrogen from biomass

ICE – Internal combustion engine

LCA – Life cycle assessment

LNG – Liquid natural gas

LS – Large scale

O&M - Operation & maintenance

PLS – Policy lead scenario

PV – Photovoltaic

RES – Renewable energy sources

RME - Rapsdiesel

SNG – Synthetic natural gas

SRC – Short rotation coppice

SS – Small scale

TTW – Tank-to-wheel

VAT - Value added tax

WRI – Wood residues from industry

WTT – Well-to-tank

WTW - Well-to-wheel