Biomass role in achieving the Climate Change & Renewables EU policy targets. Demand and Supply dynamics under the perspective of stakeholders. **IEE 08 653 SI2. 529 241**

Use of sustainable biomass to produce electricity, heat and transport fuels in EU27

A model-based analysis of biomass use for 2020 and 2030

Deliverable D5.3

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Preface

This publication is part of the BIOMASS FUTURES project ('*Biomass role in achieving the Climate Change & Renewables EU policy targets. Demand and Supply dynamics under the perspective of stakeholders*' - IEE 08 653 SI2. 529 241, www.biomassfutures.eu) funded by the European Union's Intelligent Energy Programme.

In this publication a scenario based modelling analysis of biomass use to produce electricity, heat and transport fuels in 2020 and 2030 is presented. The analysis is focused particularly on reaching the biomass demands included in the National Renewable Energy Action Plans (NREAPs). NREAPS detail how the Member States plan to reach their renewable energy target set by the Renewable Energy Directive in 2009.

INTELLIGENT ENERGY EUROPE

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Introduction

The overall objective of the Biomass Futures project is to address the role biomass resources can play to meet the renewable energy targets laid down by the Renewable Energy Directive (RED) (Directive2009/28/EC, 2009) and detailed in the National Renewable Energy Action Plans (NREAP).

According to the National Renewable Action Plans submitted to the Commission bioenergy accounts for almost 54.5% of the 2020 renewable energy target (electricity, heat and transport fuels). The contribution of bioenergy to final energy consumption is expected to double, from 5.4 % in 2005 to almost 12 % in 2020 with a significant increase in absolute values (Atanasiu, 2010). Thus, bioenergy will remain the main contributor to the renewable energy sector.

However, increasing scepticisms and the negative media coverage raised the question how and to what extent biomass can contribute to a sustainable energy future without causing negative impacts on the environment. In this context, WP5 aims at providing a framework for exploring sustainable and realistic bioenergy futures for EU27 through scenario analysis, applying the ECN modelling tool kit. The analysis illustrates the distribution of different biomass feedstocks over three different sectors (electricity, heat, and transport), their costs and avoided[1] greenhouse gas emissions for 2020 and 2030.

More specifically, WP5 objectives are to:

- Perform model-based analysis of biomass utilization to produce electricity, heat and transport fuels, in which the targets set in the NREAPs are achieved in a cost efficient manner.
- Analyse the implications of the sustainability criteria on demand, both at EU27 and Member State disaggregation, and give up-to-date answers to what extent and how a sustainable production and use of domestic and imported biomass sources can contribute to EU27 energy requirements for 2020 and 2030.
- Assess the effects of policy measures on demand.
- Calculate the generation costs of biomass electricity, heat and biofuels.
- Analyse the GHG emission impacts of bioenergy use in Europe

This report consists of 4 chapters, in which Chapter 2 lays down the methodology and presents the data included in order to conduct the modelling work. This chapter also introduces the scenarios developed. Next chapter presents the modelling results , followed by the country results. Chapter 4 synthesis the outcomes of the modelling work and gives recommendations to the policy makers and the relevant stakeholders.

[1] Avoided GHG emissions in comparison to a supply based on conventional energy systems

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Methodology

A model-based scenario analysis is conducted to analyse the use of biomass for energy purposes. Three scenarios are developed to explore the effects of sustainability criteria on the policy driven ambitions for bioenergy. The biomass feedstock potentials and costs – the cost-supply curves – are derived from WP3, Atlas of EU Biomass Potentials (Elbersen et al, 2012). The greenhouse gas (GHG) emissions for the respective biomass-to-energy pathways and the conventional reference energy systems are also produced within the WP3 using the Global Emissions Model for Integrated Systems (GEMIS) database. The section below introduces the scenarios concept, followed by a concise overview of the input data. Section 2.5 introduces the model set applied in this study.

2.1 Scenario description

This study focuses on three scenarios – reference scenario, sustainability scenario and the high biomass scenario – that aim at illustrating the likely impacts of sustainability criteria on biomass supply to meet bioenergy targets of the EU27 Member States. These scenarios are briefly introduced below. Further details of the scenarios developed can be found in Deliverable 5.2, Scenarios for the analysis of biomass use in the EU in the time frame 2010-2030 (Uslu and van Stralen, 2012).

Reference scenario

This scenario aims at re-analysing the contribution of bioenergy in reaching the national renewable energy targets. In their NREAPs Member States illustrated the total contributions expected from biomass to electricity, heating and cooling, and transport sectors up to 2020. However, the Member States did not indicate whether they included the sustainability criteria for biofuels into their estimates. Therefore, the objective of this scenario is to provide a refined basis for assessing sustainable bioenergy supply based energy demand per Member States.

As this scenario looks into the current policy process **sustainability criteria are only applied to biofuels for transport sector**. An important dilemma within the sustainability criteria – the indirect land use change issue – is not addressed.

Sustainability scenario

This scenario considers **binding sustainability criteria for bioenergy that covers all energy sectors (electricity, heating and cooling, and transport sectors), and imports**. Different than the reference, this scenario applies higher GHG mitigation targets-increasing to 80% by 2030. Furthermore, this storyline presents a future in which the indirect land use change implications of the biofuels are compensated through crop specific indirect Land Use Change (iLUC) factors. Crop specific iLUC factors are derived from Elbersen et al. (2012) and presented in Table 1.

Table 1: Crop specific indirect Land Use Change (iLUC) factors

Type of biofuel	Median from average values ($g\ CO_2$ eq./MJ)
Biodiesel based on rapeseed from Europe	**77**
Ethanol based on wheat from Europe	**73**
Ethanol based on sugar beet from Europe	**85**
Biodiesel based on palm oil from South-East Asia	**77**
Biodiesel based on soy from Latin America	**140**
Biodiesel based on soy from US	**65**
Ethanol based on sugar cane from Latin America	**60**
Bio-electricity based on perennial on arable land	**56**

High biomass scenario

While the first two scenarios aim at analysing the biomass role defined by the NREAPs this scenario considers stronger policy ambitions. The objective of this scenario is to analyse the role of biomass given the fact that there is quite a large amount of unutilised biomass potential in the EU. As a starting point 25 % higher targets for solid biomass for bio-electricity and bio- heat (in comparison to NREAP figures) are targeted. As a next step, it is assumed that the EU Member States are willing to pay the required policy costs as they will replace fossil fuel based conventional energy systems, improve their security of energy supply and at the same time combat climate change. Besides, they will benefit from increased employment opportunities .

This scenario builds on the reference scenario bioenergy potentials and applies national policy measures that are stronger than the current ones. Thus, the sustainability criteria in line with the current RED directive is only applied to biofuels for transport.

The assumptions applied to the scenarios are presented in Table 2.

Table 2: Assumptions applied to the scenarios

	Reference		Sustainability		High Biomass	
	2020	2030	2020	2030	2020	2030
Bioenergy demands	NREAPs	NREAPs increased applying the PRIMES reference scenario 2020-2030 increase	NREAPs	NREAPs increased applying the PRIMES reference scenario 2020-2030 increase	Bio-electricity and bio-heat using solid biomass >25% than NREAPs	Bio-electricity and bio-heat using solid biomass >25% than reference scenario 2030 figures
Total energy demands	NREAPs	NREAPs increased applying the PRIMES reference 2020-2030 increase	NREAPs	NREAPs increased applying the PRIMES reference 2020-2030 increase	NREAPs	NREAPs increased applying the PRIMES reference 2020-2030 increase
GHG emissions	Only to biofuels as in the RE Directive No iLUC	Only to biofuels as in the RE Directive No iLUC	All sectors (70 % mitigation compared to fossil energy (biofuel comparator EU average diesel and petrol emission, bio-electricity and heat comparator country specific depending on 2020 fossil mix). Includes crop specific iLUC factor	All sectors (80% mitigation as compared to fossil energy (biofuel comparator EU aver diesel and petrol emission, bio-electricity and heat comparator country specific depending on 2030 fossil mix). Includes crop specific iLUC factor	Only to biofuels as in the RE Directive No iLUC	Only to biofuels as in the RE Directive No iLUC
Policy measures	Same as NREAPs	Same as NREAPS	Same as NREAPs	Same as NREAPS	Stronger policy measures	Stronger policy measures

2.2 The conventional reference energy system

Electricity sector

The development of electricity prices are based on the PRIMES reference scenario (2010) (Capros, et al, 2010). In the PRIMES reference scenario the international fuel prices are projected to grow over the projection period with oil prices reaching 88 $/bbl(73 €'08/bbl) in 2020 and 106 $/bbl in 2030. Gas prices follow a trajectory similar to oil prices reaching 62$'08/boe (51 €'08/boe) in 2020 and 77$'08/boe (66 €'08/boe) in 2030 while coal prices increase during the economic recovery period to reach almost 26$'08/boe (21 €'08/boe) in 2020 but then stabilize at 29$'08/boe (25 €'08/boe) in 2030.

The PRIMES reference scenario is characterized by lower ETS carbon prices: 16.5 €'08/t CO_2 in 2020 and 18.7 €'08/t CO_2 in 2030. Lower carbon prices result from the achievement of the RES target and additional energy efficiency policies agreed between April 2009 and December 2009 that lower energy consumption.

In this study the conventional electricity prices have been calculated through the COMPETES model using the PRIMES reference scenario fossil fuel prices. Box I briefly introduces the COMPETES model and how it calculates the electricity prices. Table 3 presents the electricity demand applied in the modelling work.

Table 3: Electricity demand in 2020 and 2030

	BF- Competes (TWh)
Electricity demand 2020	3690
Electricity demand 2030	4045

BOX 1 COMPETES

COMPETES is a partial equilibrium model of a transmission-constrained power market. The model contains three different type of agents: Generators, Arbitrageurs and TSO's. The generators and arbitrageurs try to maximize their profit, the TSO's try to maximize the value of transmission, (Hobbs et al, 2004). Since in the Biomass Futures project it has been assumed that perfect competition is at place, the arbitrage type of agents become irrelevant. COMPETES takes as input the RES-mix as well as the capacity development of conventional technologies and calculates an electricity price representing the short-run marginal cost of the system. This means that the electricity price is mainly determined by the marginal variable costs. Therefore technologies where the fuel costs are dominant are the marginal technologies and determine the price.

The time horizon is one year, but it can be run for an arbitrary year. One year consist of 12 periods: winter, summer and midseason with each of these divided by off peak, peak, super peak and shoulder.

Heat sector

While the PRIMES reference scenario has been applied for the electricity sector, the required breakdown in final end-user demand sectors for heating has been derived from the ODYSSEE database[2]. The renewable heat model (RESolve-H, see section 2.5) assesses three demand sectors, namely the residential sector, the tertiary or service sector and the industry sector. Within these sectors, the ODYSSEE database provides almost complete datasets for all conventional and (where applicable) biomass-based energy carriers. In the energy demand data, the following subsectors have been covered:

- Residential sector: space heating, water heating and cooking
- Tertiary sector: services and agriculture
- Industry: 14 subsectors, consisting of various industrial activities

Since ODYSSEE only covers historical data, the future development is estimated using a different data source; the heat demand projections of the NREAPs. Growth rates have been deduced for the years 2005 – 2020, which have then been superposed on the 2008 historical data.

According to the constructed conventional heat system the repartitions of the demand sectors remain practically unchanged: on an aggregate EU27 level the most important heat sectors are the residential (40%) and the industry sector (39%). The tertiary sector is roughly sized half of these (21%). Within the residential sector, the largest demand is for space heating. Table 4 presents the breakdown of the EU27 final heat consumption for 2020 and 2030.

Table 4: Final energy consumption broken down into various end-user demand sectors. Energy values refer to consumption of heat [Mtoe] in each demand sector

Mtoe	2020	2030
Residential	257.9	258.2
Tertiary	134.4	134.4
Industry	255.4	254.1
Total	647.7	646.8

Table 5 shows the comparison of different data sources. As can be seen, an important difference exists between the final heat demand according to Biomass Futures and the NREAPs. Reasons for this can be found in the fact that different base years is reported on and in the definitions applied in the two approaches: the NREAPs follow the method outlines in the NREAP template, from which the ODYSSEE method differs, possibly the most for the industry sector and on the treatment of electricity from biomass. Connecting historical time series to future energy consumption projections is thus not straightforward. A step in this connection is allowed here, since the main focus is on the years 2020 and 2030.

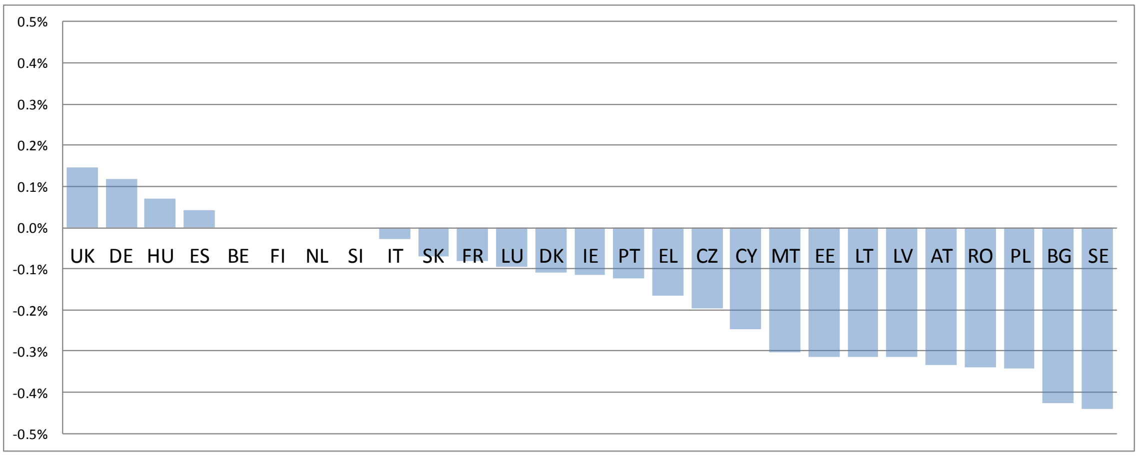
Table 5: EU27 Comparison of RESolve-H final heat demand with the NREAPs, broken down in demand sectors (not available for NREAPs) and energy carriers (not available for NREAPs) for EU27

	Biomass Futures final heat demand 2020 (Mtoe)	Biomass Futures final heat demand 2030 (Mtoe)	Final heat demand NREAP 2020 (Mtoe)
By sector			
Residential	258	258	n.a.
Tertiary	134	134	n.a.
Industry	255	254	n.a.
Total	648	647	521

[2] The ODYSSEE database is accessible through http://www.odyssee-indicators.org

The projection for the energy demand in the heating sector is relatively stable. For most countries, a slight decrease in energy consumption can be observed, mainly as a result of energy saving efforts. Four countries show a small increase in energy use: United Kingdom, Germany, Hungary and Spain (but all less than 0.2 %/year for the period 2008 – 2030). Nineteen other countries show annual savings up to -0.44 %/year for that same period: Italy, Slovakia, France, Luxembourg, Denmark, Ireland, Portugal, Greece, the Czech Republic, Cyprus, Malta, Estonia, Lithuania, Latvia, Austria, Romania, Poland, Bulgaria and Sweden (See Figure 1). The repartition among demand sectors indicates that the expected total heat demand largely remains constant, but with varying and counter-effective changes on the Member State level. The total 2010 estimate for the heat use is 653 Mtoe , from which for the period 2010 to 2020 an average annual decrease in demand results from -0.1% per annum.

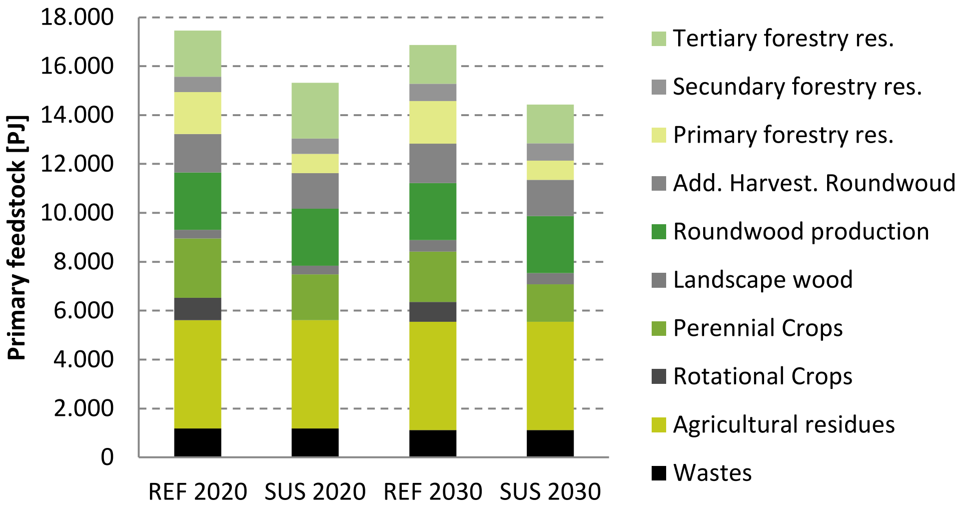
Figure 1: Calculated average annual growth figures for all Member States for the period up to 2030



2.3 Biomass feedstock potential included in the models

Work Package 3, deliverable 3.3 , the '*Atlas of EU Biomass Potentials*' provides two sets of biomass feedstock cost-supply data through a comprehensive strategic analysis of biomass supply options and their availability in response to different sustainability criteria in a time frame from 2010 - 2030 at the Member States level. First set of data serves to the purpose of the reference scenario, which considers the sustainability criteria for biofuels as in the RED Directive, whereas the second set of data includes expansion of these criteria to all uses of biomass (including electricity and heat sector). Figure 2 illustrates the domestic biomass potentials for the EU 27 in 2020 and 2030 for the reference and the sustainability scenario. More details about the biomass potentials and the costs can be found in Deliverable 3.3 (Elbersen et al., 2012 b).

Figure 2: Domestic Biomass potentials [PJ] for the EU27 in 2020 and 2030 for the reference (REF) and the sustainability (SUS) scenario



2.4 Life Cycle GHG emission data

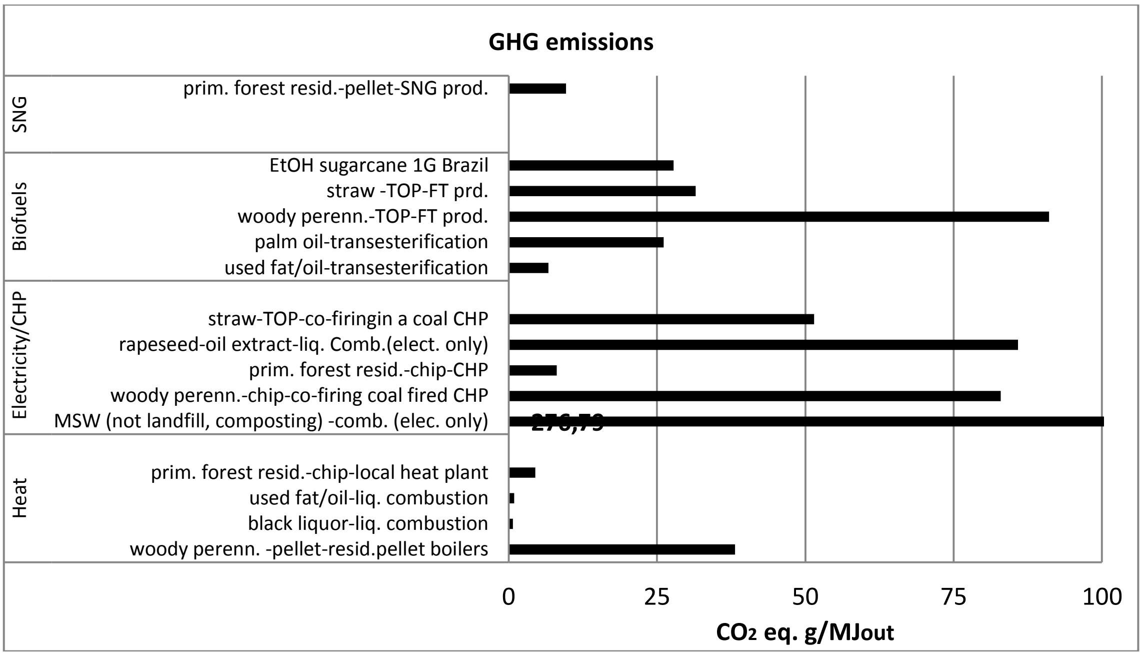
One of the objectives of this project was to assess the GHG emission impacts of bioenergy use in the EU27. In order to do that the LCA[3] GHG emissions of the bioenergy systems and the conventional energy systems are derived from the GEMIS[4] database.

The following figure gives examples of LCA GHG emissions of some of the bioenergy pathways in 2020.

[3] LCA includes both the direct and the indirect emissions values stemming from "upstream" activities like mining, processing and transport are included, as well as the materials (and energy) needed to manufacture all processes

[4] GEMIS = Global Emissions Model for Integrated Systems, a public-domain software available at no cost (see http://www.gemis.de for more details).

Figure 3: LCA GHG emissions of the bioenergy pathways for a selected number of feedstocks (Source: GEMIS 4.7)



2.5 Description of ECN model tool

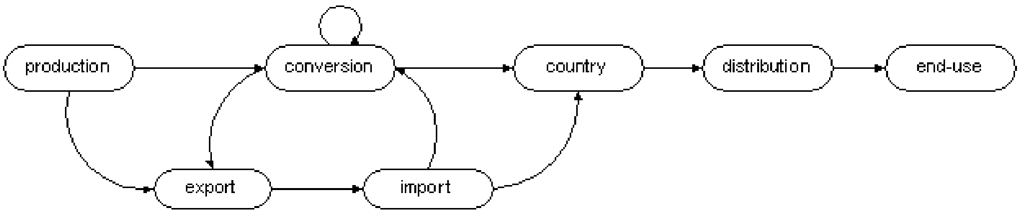
The ECN RESolve model consists of a set of three independent sub-models, known as RESolve-biomass (developed during this project to enable biomass allocation), RESolve-E and RESolve-H. model. A brief introduction of the models are presented below. Further details of the model can be found in D5.1(van Stralen, et al, 2012).

RESolve-biomass model

The RESolve-biomass model calculates the most cost effective way to fulfil the specified bioenergy demand (for electricity, heating and cooling and the transport sector), given and constrained by a number of assumptions on economic and technological parameters in a specific target year, in terms of bioenergy production, cost and trade (trade of primary feedstock and/or biofuels) (see Figure 4). The model includes feedstock production, processing, transport and distribution. Constraints on avoided emissions, over the entire chain, are included in the model as well. One of the most important features of the RESolve-biomass model is the ability to link the national production chains allowing for international trade. By allowing trade, the future cost of biofuels/bioenergy can be approached in a much more realistic way than when each country is evaluated separately.

RESolve-biomass allows for trade of feed stocks and final products by means of trucks, trains and short sea shipments. The only costs associated with international trade are transport costs (including handling), for which generalised distances between countries are used. All domestic transport is assumed to take place using trucks. Moreover, the possible economic benefits of important by-products are taken into account.

Figure 4: Supply chain in RESolve biomass (Lensink et al, 2007)

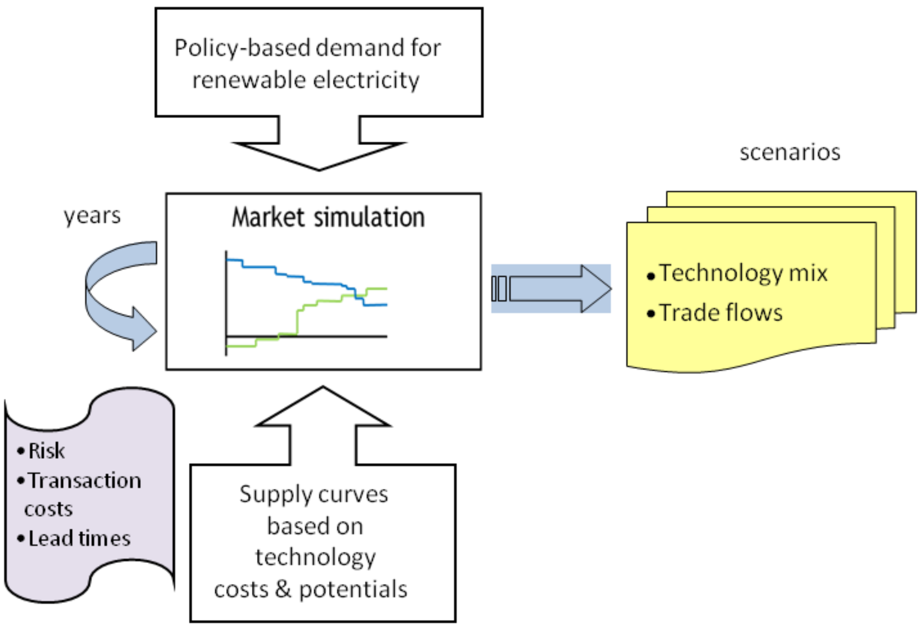


RESove-E model

For the simulation of the renewable electricity (RES-E) (including bio-CHP) developments in the EU the RESolve-E model is used (Daniëls and Uyterlinde, 2005). The RESolve-E model is based on a dynamic market simulation in which national RES-E supply curves are matched with policy-based demand curves. The simulations is done for several target years up to 2030, taking account of various other factors complicating investment in renewables, such as (political) risks, transaction costs and delays due to planning and permitting processes. These factors contribute to a realistic simulation of the effectiveness of different policy instruments.

A schematic overview of the RESolve-E model is presented in Figure 5.

Figure 5: Schematic overview of the RESolve-E model

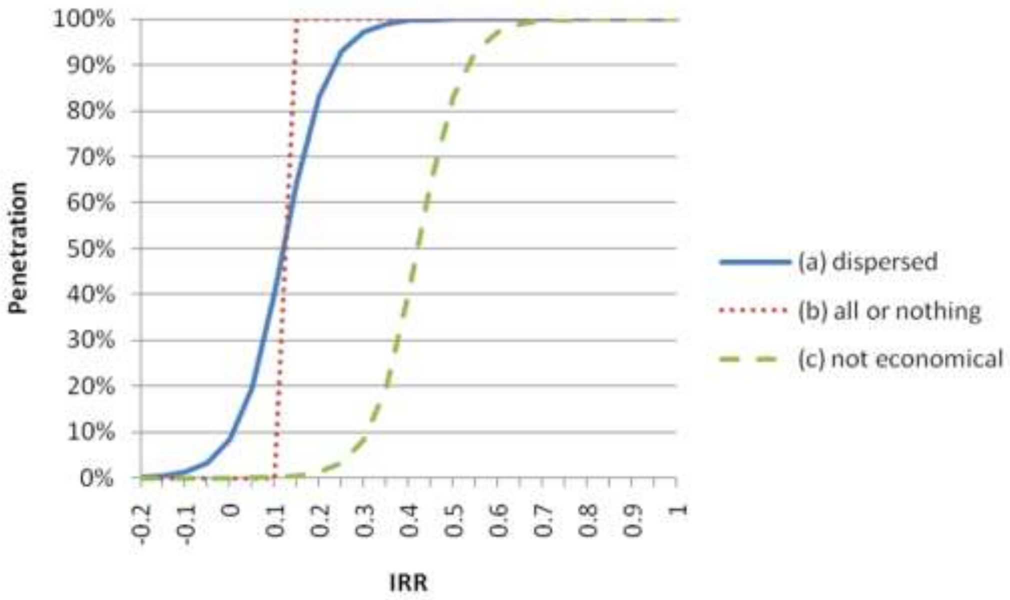


RESolve-H model

RESolve-H is a simulation model that calculates the penetration of RES-H options based on a *dispersed S-curve* description of consumer's behaviour, Figure 6 (a).

Each RES-H option has a cost to the consumer, but it also brings along benefits, of which the avoided costs of using non-RES fuels is the most important. When the benefits for a certain option are comparable to the costs, the option starts to become economically attractive for the consumer. This is modelled by considering the Internal Rate of Return (IRR) of a certain option, taking explicitly into account the avoided costs of not using fossil fuels. In the example of Figure 6 (b) all consumers immediately switch to RES-H as soon as the IRR is higher than 0.12. This *all or nothing* case is obviously not very realistic, and the real consumer behaviour is better modelled by a *dispersed* S-curve such as the one in Figure 6 (a): early adopters would invest even at 'uneconomical' levels of the IRR (cf. the range below 0.12), whereas some players ('laggards') do not even invest as higher levels of the IRR (cf. the range above 0.12) because other, non-financial barriers prevent them from doing so.

Figure 6: Penetration vs. Internal Rate of Return (IRR) in RESolve-H



2.5.1 Techno-economic data

In the course of the project the techno-economic data sets have been harmonised among the project partners and presented in Annex I.

3

Modelling Results

3.1 Reference Scenario

3.1.1 Primary biomass utilisation[5]

The bioenergy targets set in the Members States' NREAPs can in principal be met through utilization of around 7000 PJ (167 Mtoe) primary biomass in 2020 and around 9000 PJ (215 Mtoe) in 2030. The EU domestic feedstock use represent around 40% and 50% of the total EU biomass potential for 2020 and 2030, respectively. Figure 7 illustrates the feedstock input to reach the 2020 bioenergy targets, and Figure 8 presents the fraction of domestic feedstock utilisation. While these figures indicate that the availability of domestic resources is not a barrier, the modelling exercise calculates the contribution of imported feedstock to be around 15% of the total primary biomass.

[5] These are the results of the static biomass allocation model thus these figures consider neither the barriers related to the current policy measures nor the technology diffusion barriers.

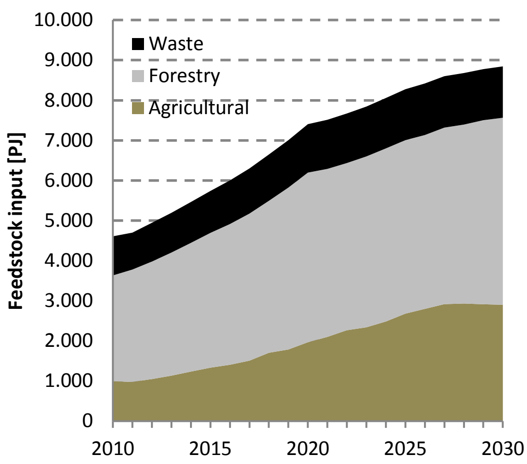


Figure 7 Primary biomass utilized in EU27

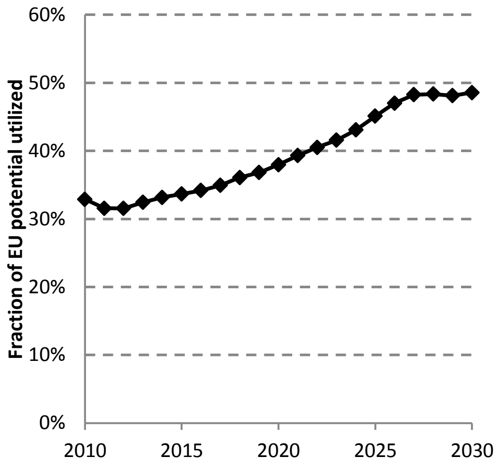


Figure 8 Fraction of the EU27 potential utilized

Figure 9 and Figure 10 illustrate the primary biomass use in comparison to the potentials for the different feedstock categories. Among the biomass feedstocks current roundwood production, additional harvestable roundwood, straw, grassy perennials and dry manure are the largest unutilized feedstocks while the cheapest resources such as industrial wood residues, black liquor, post-consumer wood, used fats and oils are fully utilised. Current roundwood and the additional harvestable roundwood remain very expensive(>400 €/toe) in comparison to the alternatives such as imported wood pellets. Between 2010 and 2030 total import comprises around 12-15 % of the total demand (see Figure 11). Wood pellets contribute around 1-7% of the total demand. The main countries of import are France (mainly for heating), the Netherlands and the UK. In 2030 further use of rotational crops and perennial crops are observed.

Figure 9: Domestic EU27 primary feedstock: potentials versus utilization in 2020

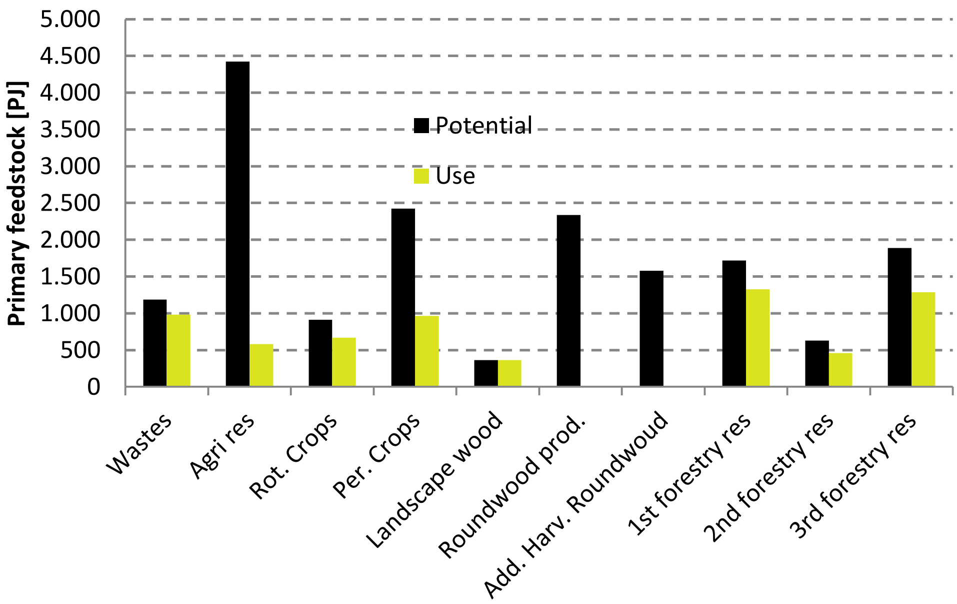


Figure 10: Domestic EU27 primary feedstock: potentials versus utilization in 2030

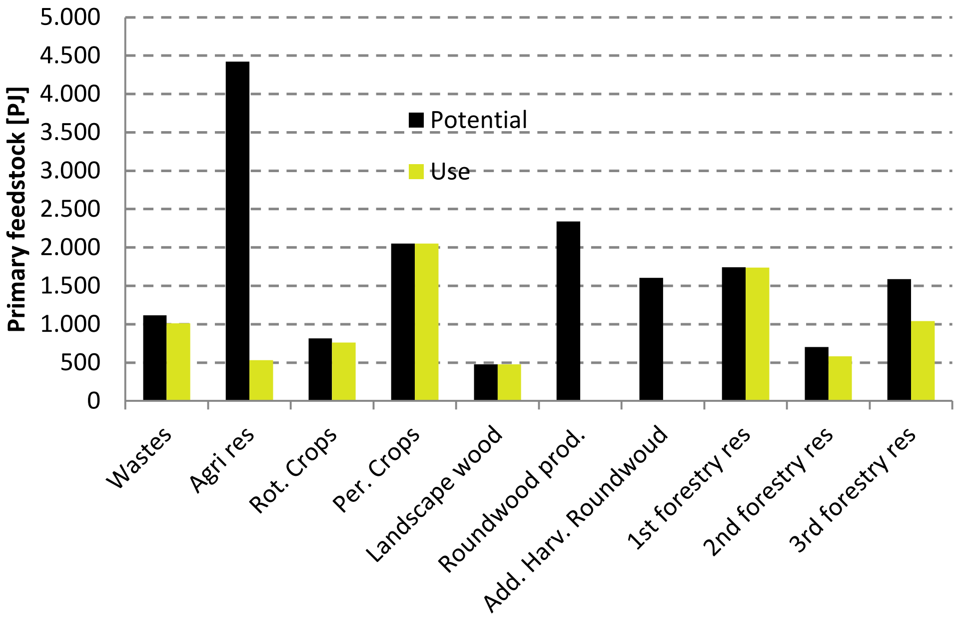
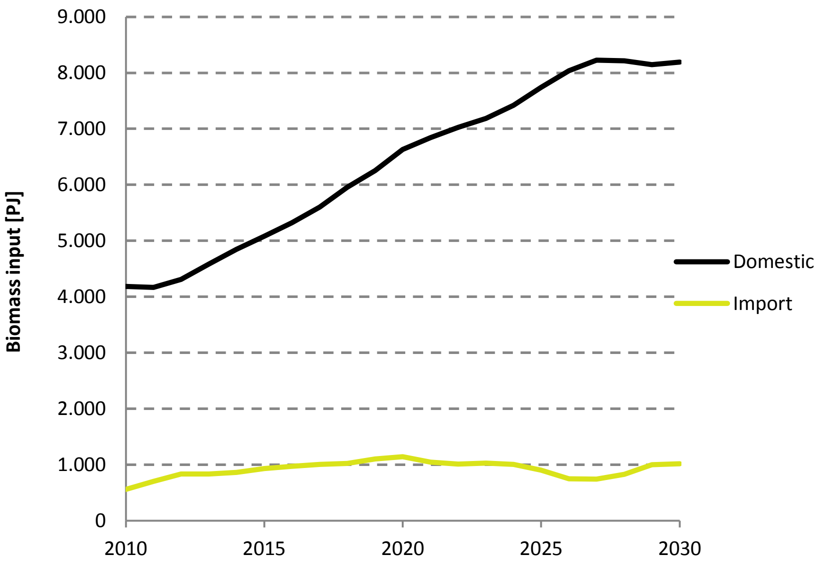


Figure 11: Utilisation of domestic versus imported biomass in EU27



3.1.2 Electricity production

This section analysis the EU27 bio-electricity demand given the fact that EU27 assumes (in their NREAPs) around 232 TWh bio-electricity production in 2020, contributing to approximately 6% of the total electricity demand[6]. However, such ambitions can only be realised when and if the appropriate policy instruments are in place to overcome both techno-economic and non-technical barriers. The RESolve model set assessed these targets based on the recent policy measures announced by the Member States. Figure 12 illustrates the total electricity production for the EU27 based on the policy measures promoted by the Member States in their NREAPS. It is modelled that in 2020 around 221 TWhe can be

[6] Based on the energy efficiency scenario figures of the NREAPs

produced from biomass, decreasing to 211 TWhe in 2030. While these figures indicate that the NREAP set targets in 2020 is achievable with some further efforts the deviations are significant in Member States level. A more detailed country by country analysis can be found in section 3.4. In 2020 the gap between NREAP figures and the RESolve-E market simulation model is around 4.7% for EU27. After 2025, utilisation of biomass declines. This decline is due to the reduction of certain feedstock potentials (i.e. black liquor, digestible biomass such as forage maize and cereals), the decline in coal fired power plant capacity, or completion with other RES-E options for certain countries.

Figure 12: EU27 total electricity production from biomass from RESolve-E in comparison to the NREAPs

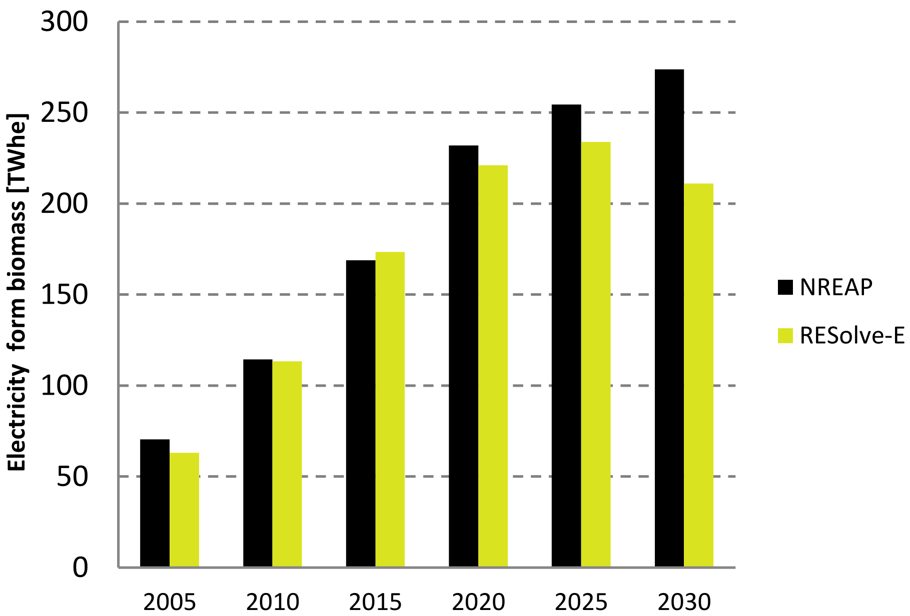


Figure 13 presents the technology development up to 2030 to produce electricity from biomass. CHP plays a dominant role in 2020, contributing around 3 % of the total electricity production in 2020. The contribution of CHP biomass electricity is 158 TWhe in 2020 increasing to 170 TWhe. in 2030. An important aspect - the economic use of heat - drives investment in CHP plants. In this study it is assumed that all of the heat produced at a CHP plant is sold. In fact, a cogeneration unit will not be able to operate in high efficiency mode without sufficient heat demand. In this respect it is important to consider both the heat demand in respective countries and the required investment to supply the produced heat to the end users (through district heating systems). In this study such aspects have not been considered.

According to EurObserv'ER (2010) biomass electricity from CHP is around 40 TWhe in 2008 and is estimated to be around 44 TWhe in 2009. Thus, around 4 times increase is needed to reach the projected CHP demand.

The second technology that uses a significant amount of biomass is co-firing. Biomass co-fi ring with coal in existing boilers is in fact the most cost effective option of electricity (and heat[7]) production from biomass[8]. Direct co-firing with up to about 10 % biomass (energy base) has been successfully demonstrated in pulverized fuel and fluidized bed boilers with a wide range of biomass feedstocks (wood and herbaceous biomass, crop residues, and energy crops). However, the co-firing rates in coal power stations are limited due to decrease in the boiler efficiency, the environmental issues on emissions (SO_2, NOx, and particulate material), the quality of by-products (fly-ash, bottom-ash and

[7] A heat efficiency of only 4% is inlcluded in the model(based on the NL data).
[8] E.C. Biomass action plan. COM(2005)628final,.Commission, E., 2005

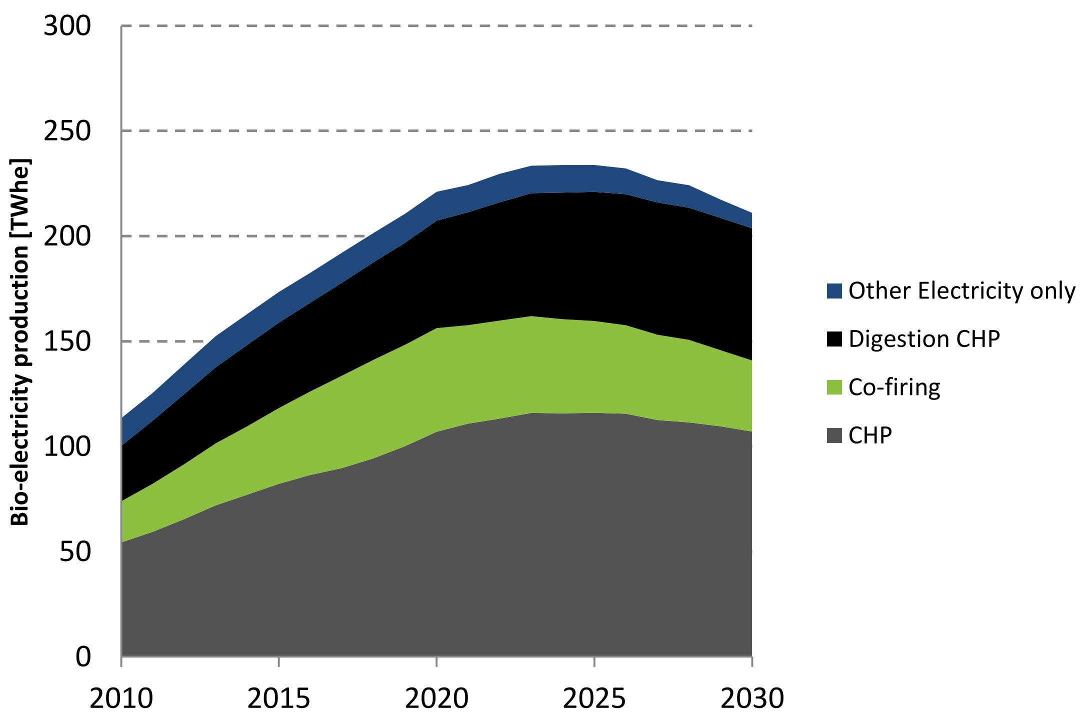
gypsum), the impacts in the fire-side of the boiler (deposition and corrosion) and the deterioration of downstream gas cleaning systems. In this respect the RESolve model limits its feedstock use to 10% forestry residues and 5% straw[9].

According to the model outcomes in 2020 around 49 TWhe can be produced through co-firing. This is however, expected to decrease in 2030 to 34 TWhe . An important reason for this trend is the decrease of the EU27 coal capacity from 161 GWe in 2020 to 142 GWe in 2030 according to the PRIMES reference scenario.

Although co-firing has been commercially used and there is rapid progress the current share of biomass utilization in co-firing is small relative to the total amount of biomass used in Europe. It is difficult to estimate the exact utilization figures of biomass in co-firing plants of the EU27 since there are no statistics available on this.

It is important to note that biomass co-firing has been promoted differently in the EU Member States. For instance, Austria, and the Czech Republic support biomass co-firing through a feed-in tariff or a premium. Belgium supports it through green certificates. In the Netherlands co-firing is supported through a fixed premium and there are plans to change this to an obligation for co-firing from 2015 onwards. On the other hand there are objections to subsidizing co-firing as it can serve to the elongated use of the otherwise unprofitable coal power plants. The reason why biomass co-firing is expected to penetrate in some countries where it is almost absent at the moment is due to an increase in the CO_2 price, making combustion of biomass competitive with combustion of coal.

Figure 13: RES-E production [TWhe] per biomass technology category for EU27



[9] Straw is a somewhat challenging fuel for co-combustion, as it has low bulk density and high chlorine and potassium content. Straw-fired boilers have had major operational problems because of rapid deposit accumulation and corrosion rates. Nevertheless, straw been is widely being used for energy

3.1.3 Heat production

As explained in Section 2.2 the heat demand in most countries declines slightly over time, due to efforts on energy savings and increased efficiency, while for a few other countries the demand slightly increases (see Figure 1).

Next to the three demand sectors - residential, industry and service sector - another category is included to the renewable heating options: combined heat and power (CHP), which for the purpose of this modelling exercise has not been allocated to a specific demand sector. Thus, the biomass contributions of the individual sectors might increase slightly due to the heat produced in CHP and sold to the district heating systems in the EU.

Table 6 shows that the overall biomass use for heat remains stable in the period 2020 – 2030. However, the biomass derived heat consumption decreases for residential sector (from a share of 47% in 2010 to 15% by 2030). There are a number of reasons behind this change. First of all, overall heat demand for the residential sector decreases thanks to the energy efficiency and energy saving policies and other renewable energy sources (particularly solar thermal energy). The current high penetration of wood stoves decreases due to phasing out of old equipment: when the lifetime has been reached, old stoves are decommissioned and for a considerable part is not replaced, or it is replaced by more efficient installations.

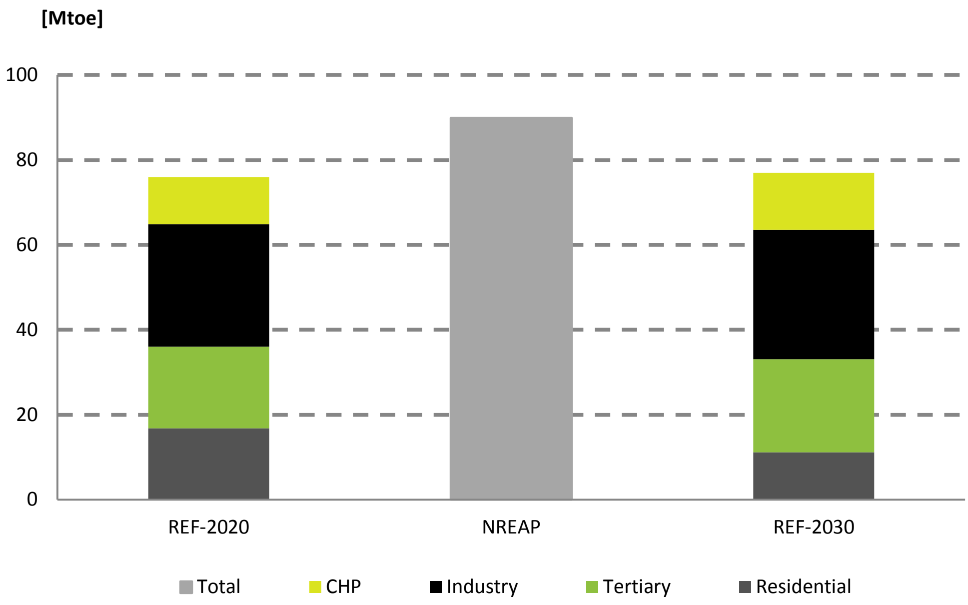
A development in the opposite direction is observed for the industry sector: final heat demand from biomass doubles from 14.6 Mtoe in 2010 to 30.5 Mtoe by 2030, an average annual increase of almost 4% per annum. Biomass is one of the most promising renewable energy sources given the different temperature requirements of industry sector. For industries that require high temperature level heat biomass resources are the most suitable - if not the only - options, followed by deep geothermal. In fact, the RESolve-H model projects around 11% and 12% of the industrial heat demand to be derived from biomass resources for 2020 and 2030, respectively.

Table 6: Final energy consumption in the reference scenario from biomass (various biomass sources: wood and residual steams included). Energy values refer to consumption of heat [Mtoe] from the technology at stake

	2010		2020		2030	
	Mtoe	Share	Mtoe	Share	Mtoe	Share
Residential	24.9	47%	16.8	22%	11.2	15%
Tertiary	7.6	14%	19.2	25%	21.9	28%
Industry	14.6	28%	28.9	38%	30.5	40%
CHP	5.8	11%	11.1	15%	13.4	17%
Total	53.0	100%	76.0	100%	76.9	100%

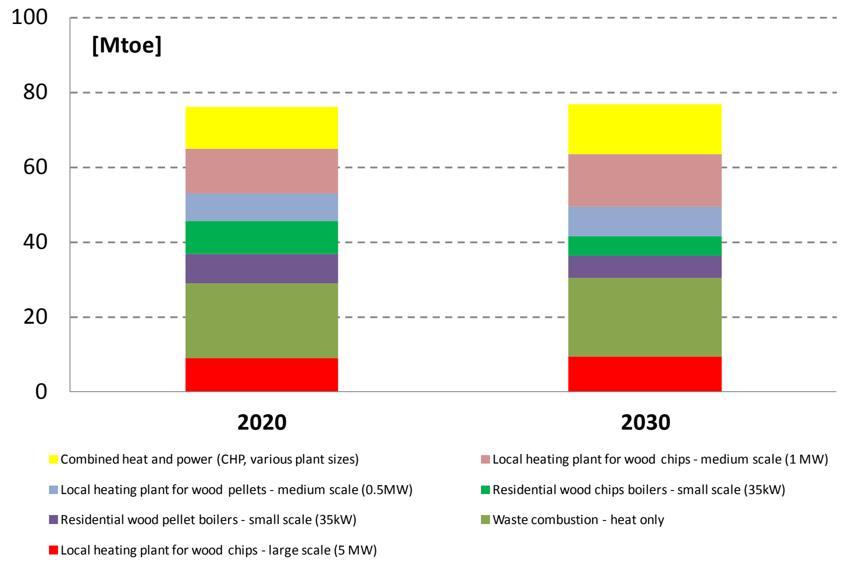
Figure 14 presents the biomass heat penetration in comparison to the NREAP figures. Model results indicate 18% lower final heat demand in 2020 than the NREAPs. It is important to note that RESolve-H does not estimate the contribution from gaseous and liquid biomass resources, unlike the NREAPs.

Figure 14: Penetration of biomass in the reference scenario according to RESolve-H in various cross-sections, with for the year 2020 the NREAP projection as a reference



The figure below presents the biomass heat technology break down. Heat production from large installations (> 500 kW) represents approximately half of the total - which is also in line with the trend that the industrial sector becomes more important in terms of biomass use in comparison to the residential sector, and the decline of biomass use for heat in the residential sector.

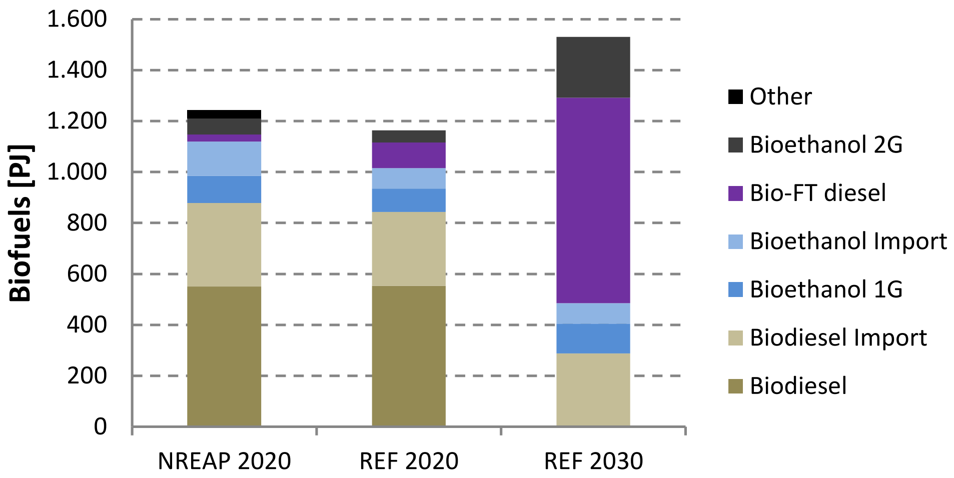
Figure 15: Contributions from various biomass technologies according to RESolve-H (reference scenario)



3.1.4 Production of biofuels

In this scenario the minimal cost allocation along the supply chain has been analysed based on the mandatory 10% renewable energy target for the EU transport sector and the sustainability criteria included in the Renewable Energy Directive. According to the modelling results around 30% of the biofuel demand can be met through imports, of which 25% is biodiesel. Contribution of 2nd generation biofuels is around 13%, amounting to 148 PJ. On the other hand, NREAPs indicate higher import figures (around 37% of the total) and contribution of 2nd generation technologies to be lower (around 7% of the total). The difference between the total energy content of the NREAP biofuel demand and the modelling results for 2020 in Figure 16 is due to the double counting of the second generation. The Renewable Energy Directive considers biofuels produced from waste, residuals, non-food cellulose material and lignocellulosic material to be counted double to the renewable transport target. Model results show a significant growth for the 2nd generation technologies between 2020 and 2030 (see Figure 16).

Figure 16: Biofuel distribution [PJ] in 2020 and 2030 for the reference scenario (REF) compared to the 2020 NREAP figures. 1G refers to 1st generation biofuels

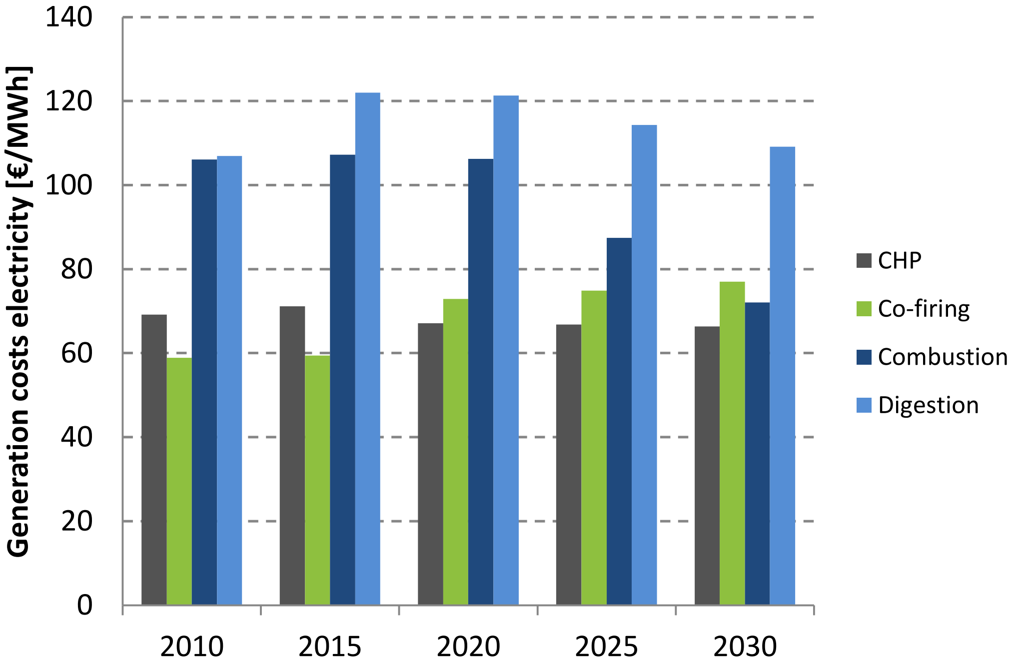


3.1.5 Generation costs

Electricity production

Figure 17 illustrates the (average) bio-electricity generation costs for the timeframe 2010- 2030. CHP is one of the cheapest option due to the heat sold to the markets. The model considers all of the produced heat to be sold in the market. As can be observed the cheapest option, biomass co-firing becomes more expensive after 2015. The main reason for this behaviour is the geographical mismatch in demand of woody biomass for co-firing and the location of the potential (within the EU and globally). Transportation becomes more and more important and to ease transportation woody products are converted into pellets that are more expensive than wood chips and saw dust. Due to the higher share of wood pellets for co-firing in the EU27 from 2010 to 2020 and 2030 the average costs of co-firing increase. The average generation costs of digestion show an interesting behaviour. First there is an increase in costs from 2010 to 2015. Between 2015 and 2020 the costs stay constant and after 2020 there is a decline in costs. This is caused by the variations in feedstock type and their respective prices. Furthermore, each feedstock digestion has its own costs. Up to 2010 the share of digestion of landfill gas and sewage sludge is large. The costs of digesting these two feedstocks is relatively low. However, the share of digestion of these feedstocks drops significantly. After 2010 manure and forage maize are the dominating feedstocks for digestion and it is much more expensive to digest these feedstocks when compared to landfill gas and sewage sludge digestion. After 2015 the share of these feedstocks gets even higher, but the costs of digestion drops due to increased conversion efficiencies and lower investment costs. After 2020 the share of manure digestate stays roughly the same, but the costs drop even more, explaining the further decline in average costs for the EU27.

Figure 17: Generation cost for bio-electricity specified per technology group



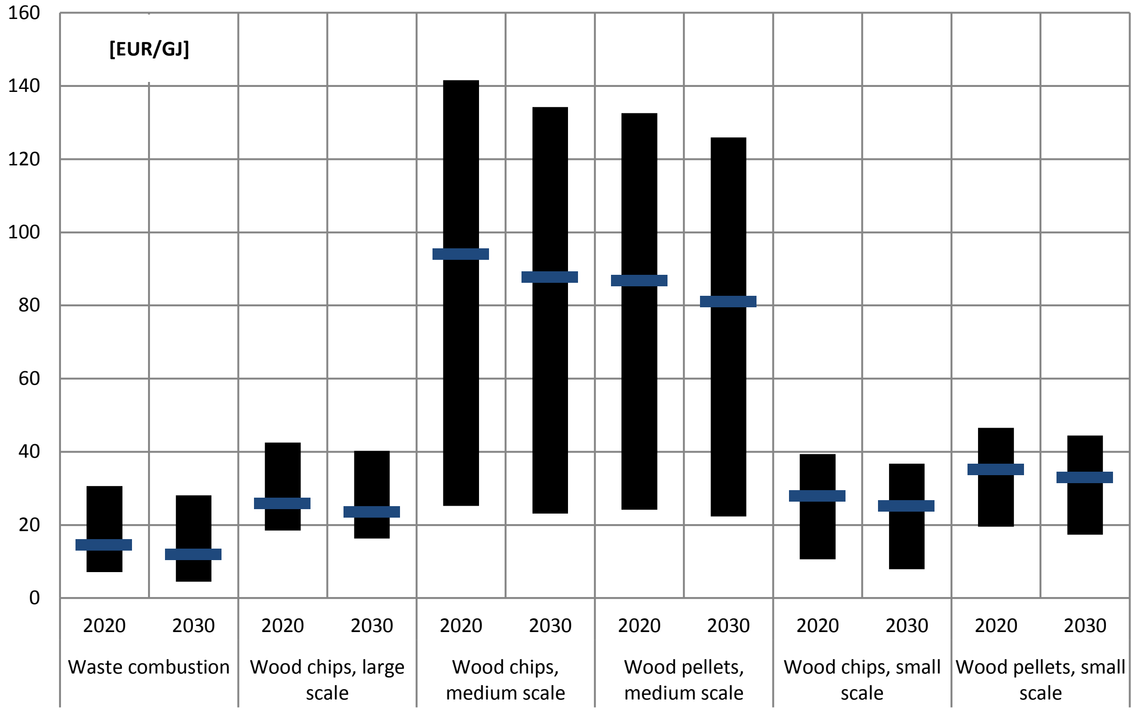
Heat production

The numerous biomass resource streams in this project have been aggregated to three main resources for producing heat: wood chips, wood pellets and waste. Also, three typical installation scales have been considered: small scale (typical household systems), medium scale (hundreds of kW thermal) and large scale (some MW thermal).

Figure 18 highlights the biomass heat price [EUR/GJ] in terms of levelised costs for two target years (2020 and 2030) for the reference scenario. It can be observed that the integral prices are declining slightly from 2020 to 2030, caused by cumulative effects of changes in feedstock prices and technology costs. The data ranges in the graph are a result of the variation of prices in the 27 EU Member States.

It can be observed that the cheapest option is waste combustion, a large scale technology. Large scale wood chip consumption is the second cheapest option. According to the calculations, the medium scale technology is considerably more expensive, whereas the household scale technologies are relatively cheap because of the low technology costs.

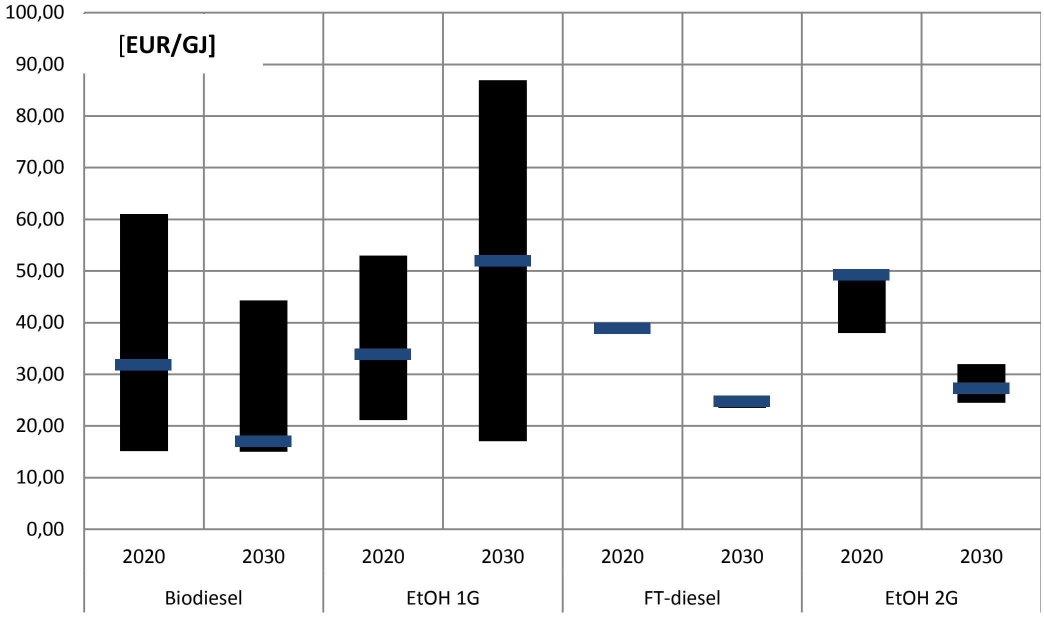
Figure 18: Levelised generation cost of heat from biomass resources



Production of biofuels

The generation costs for biofuels in Figure 19 present the marginal, minimum and average generation costs of biofuels. For the marginal costs the very expensive feedstocks determine the price. When 2nd generation technologies that utilise cheap resources are not available at a substantial scale (so up to 2020), the costs of biofuels will rise. The reason is that more and more expensive feedstocks are needed to generate first generation biofuels. After 2020, when 2nd generation biofuels start to have a more important role the most expensive feedstocks initially demanded for 1st generation biofuels are not needed anymore, resulting in a significant drop in the costs of biofuels. In 2020, the primary feedstock cost for rapeseed is around 20 €/GJ, maise around 25 €/GJ, whereas primary forest residues and wood chips cost 4.5 €/GJ. When the primary feedstock price is assumed to be zero for all technologies, biodiesel and bioethanol production is in the range of 6-8 €/GJ, whereas 2nd generation biofuel production is in the range of 10-15 €/GJ in 2020 and 2030.

Figure 19: Biofuel generation costs in 2020 and 2030



3.1.6 LCA GHG emissions and net avoided GHG emissions

Figure 20 illustrates the LCA GHG emissions of the bioenergy systems, whereas Figure 21 presents the avoided GHG emissions in comparison to the conventional energy system if the NREAP bioenergy targets are met. In line with the significantly higher deployment rate of biomass heat production the total avoided GHG emission from the heat sector is significant. In 2020 GHG emissions can be avoided up to 500 Mton CO_2 eq. On the other hand, specific avoided GHG emissions of biomass electricity is around 7 ton CO_2 eq./toe, whereas it is around 4 ton CO_2 eq./toe for biomass heat and 3 ton CO_2 eq./toe for biofuels. These figures indicate that the utilisation of biomass to produce electricity has larger potentials in terms of GHG emission mitigation.

Figure 20: Total GHG emissions of the bioenergy system [Mton CO_2 eq.] in the EU27 for the reference scenario

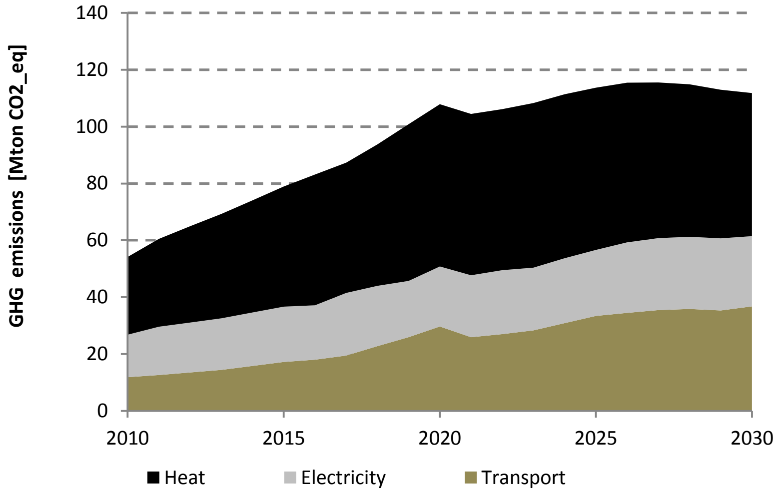
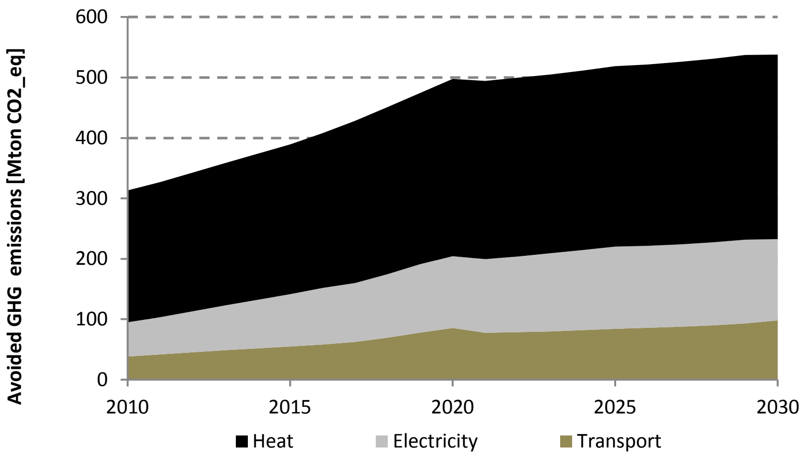


Figure 21: Net avoided GHG emissions [Mton CO_2 eq.] for the EU27 for the reference scenario



3.2 Sustainability scenario

3.2.1 Primary biomass utilisation

Figure 22 and Figure 23 present the sustainability scenario primary feedstock use in comparison to the reference scenario for 2020 and 2030, respectively. Both scenarios consider reaching the NREAP targets through the least cost manner. Significant reduction in primary forestry residue potential due to stringent sustainability criteria applied in this scenario is compensated through larger utilisation of perennial energy crops, more use of the expensive biomass coming from wood processing such as sawmill by-products and higher imports in 2020. On the other hand, in 2030 a significant amount of agricultural residues is utilised. This is related to the straw use to produce 2nd generation biofuels.
In 2020 larger utilisation of prunings and dry manure is observed in the sustainability scenario when compared with the reference scenario. On the other hand there is less use of wet manure in the sustainability scenario. The use of manure is limited by the decrease in feedstocks (such as maize) that is used as co-substrate.

Figure 22: Utilization of EU27 domestic biomass in 2020 for the reference (REF) and sustainability (SUS) scenario

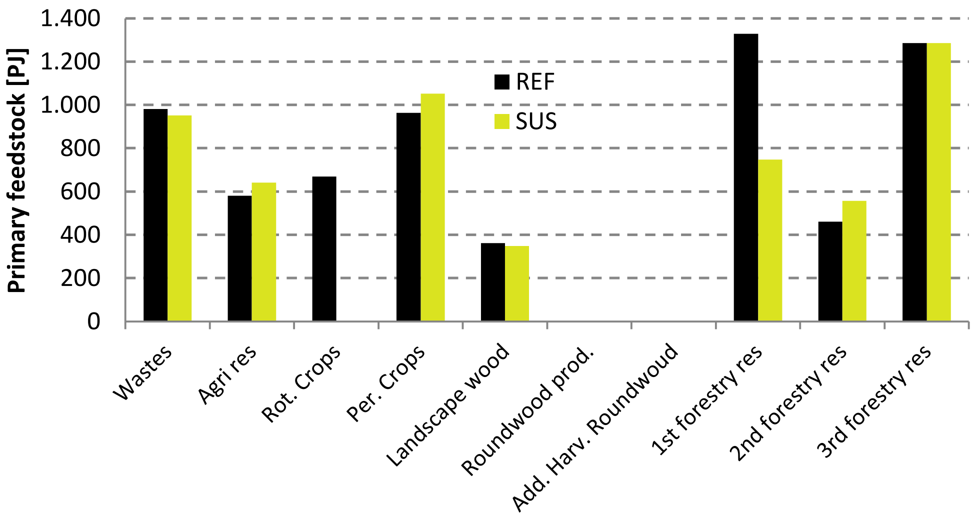
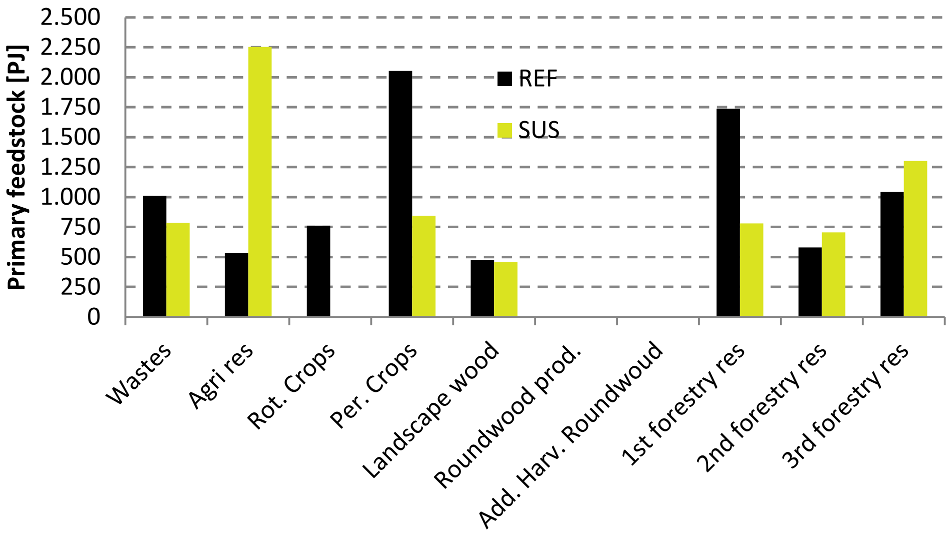
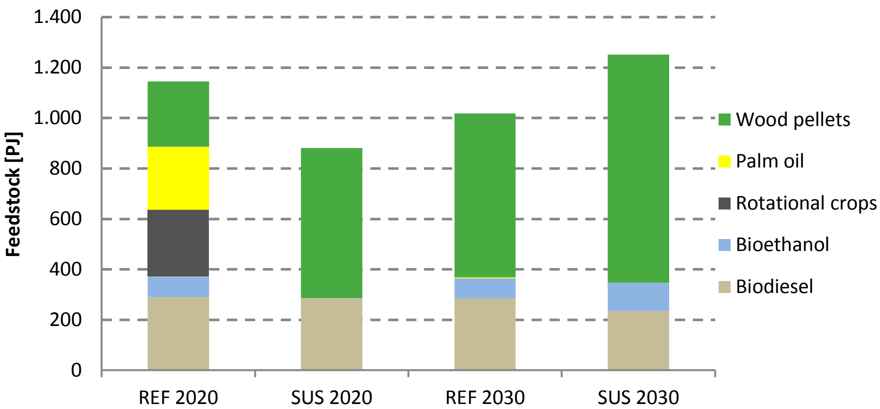


Figure 23: Utilization of EU27 domestic biomass in 2030 for the reference (REF) and sustainability (SUS) scenario



The below figure illustrates the contribution of imported biomass to reach the NREAP targets. Import of palm oil, rotational crops and ethanol disappears in the sustainability scenario in 2020 because of more stringent sustainability criteria that are applied to both biofuels, bio-electricity and bio-heat production. There is, however, still import of wood pellets, bioethanol and biodiesel that are sustainably produced. Besides, in 2030 more expensive sustainable bioethanol is imported. It is important to note that it has been very difficult to define the total amount and the costs of imports that respect the sustainability criteria. Therefore, it is assumed that 10% of the import potential is sustainable.

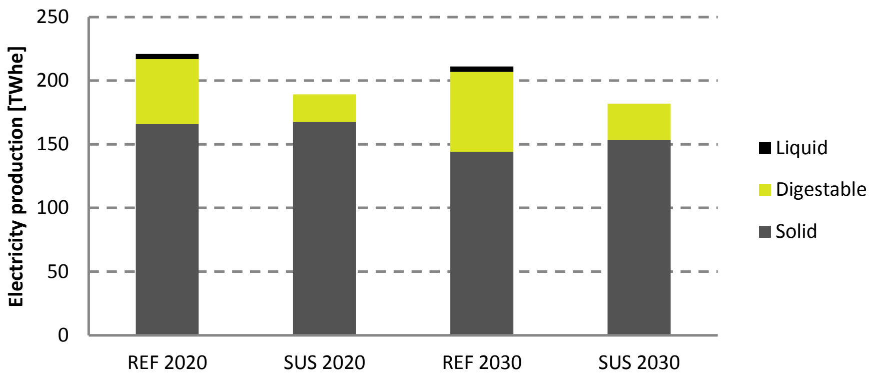
Figure 24: Import of feedstocks for EU27 in 2020 and 2030: reference (REF) versus sustainability (SUS)



3.2.2 Electricity production

Compared to the reference scenario, the production of electricity using biogas is more than halved in the sustainability scenario in both 2020 and 2030. This is in line with the decrease in agricultural residue potentials. The application of liquid biomass for electricity production is completely absent in the sustainability scenario in 2020 and 2030 as the main feedstock for liquid biomass-palm oil- does not comply with the sustainability criteria.

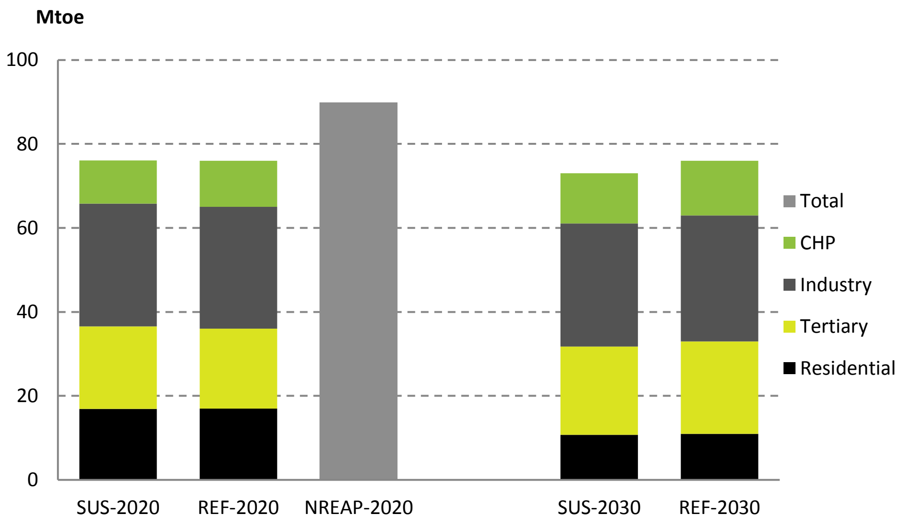
Figure 25: Electricity production in EU27 in 2020 and 2030: reference (REF) versus sustainability (SUS)



3.2.3 Heat production

In comparison with the reference scenario the difference is minimal. For the year 2020 the total biomass penetration is slightly higher (+0.1 Mtoe) than the reference scenario. The most important change lies in the period after 2020: in the year 2030 a reduction can be observed of minus 3.9 Mtoe. The reduction occurs in all demand sectors, but CHP is most affected by the sustainability criteria (-1.5 Mtoe). The reason behind is the sustainability criteria, which impact most significantly on the digestible energy carriers (see Figure 26).

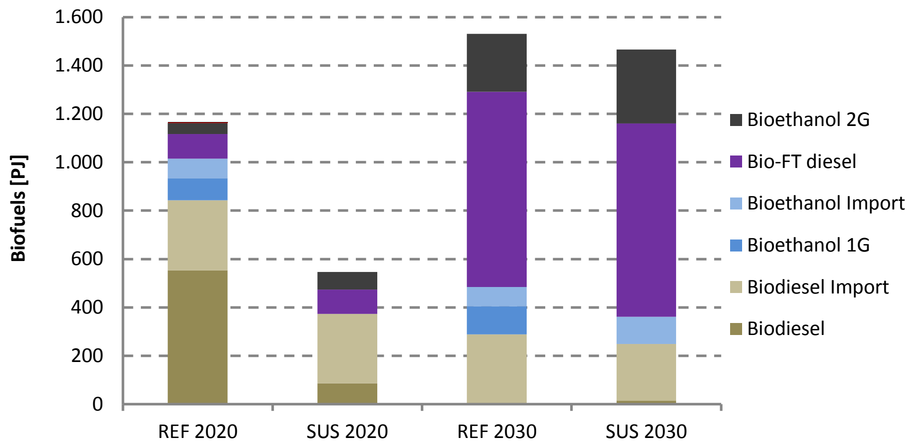
Figure 26: Sustainability scenario heat demand in 2020 and 2030 in comparison to reference scenario



3.2.4 Production of Biofuels

Domestic production of rotational crops for biofuels disappear in the sustainability scenario. This complicates reaching the 10% renewable transport fuel targets. From a modelling point of view this will be compensated through larger quantities of 2nd generation biofuels and/or importing biofuels that are derived from feedstocks grown on degraded land. Already in the reference scenario 12.7 % of the total is assumed to be met through 2nd generation technologies(in absolute terms-without double counting). Thus, given the fact that it is not likely to have larger quantities of 2nd generation biofuels we considered the demand to decrease 45% in 2020. In the following 10 years' time 2nd generation technologies will show a significant growth in both scenarios, being dominant over 1st generation technologies, including import. Bio-FT diesel reaches in both scenarios the same quantity in 2030, however, there is more 2nd generation ethanol in the sustainability scenario than in the reference scenario.

Figure 27: Biofuel distribution [PJ] in 2020 and 2030 in EU27: reference (REF) versus sustainability (SUS)



3.3 High biomass scenario

3.3.1 Primary biomass utilisation

Different than the reference scenario, this scenario considers stronger policy instruments to harness larger amounts of biomass. Electricity and heat demand using solid biomass is assumed to be 25% higher than the NREAP figures.

In total 762 PJ and 492 PJ additional primary domestic biomass is utilized in this scenario in 2020 and 2030, respectively, in comparison to the reference scenario. While certain domestic resources are utilised to reach the targets (agricultural residues (dry manure), primary forestry residues and secondary forestry residues (mainly sawmill by-products)) almost 40%of the required additional biomass is met through imports in 2020. In 2030 this figure is even more than 60%. In 2020, an additional 502 PJ wood pellets is required, increasing to 758 PJ in 2030 (see Figure 29).

Figure 28: Utilization of EU27 domestic biomass for the reference (REF) and high biomass (High) scenario in 2020 and 2030

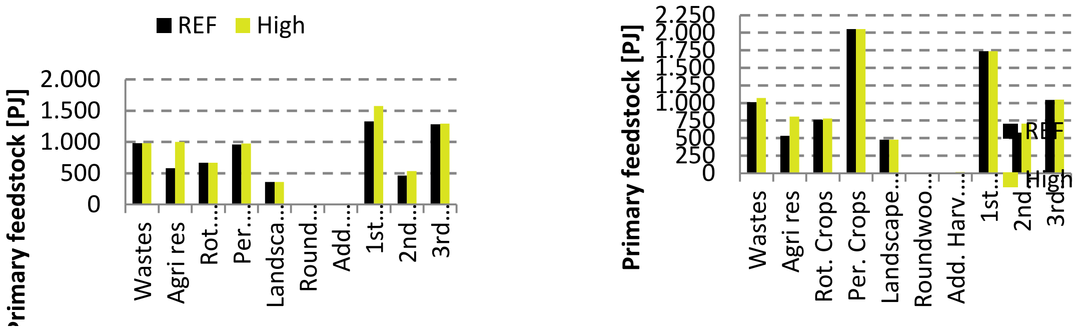
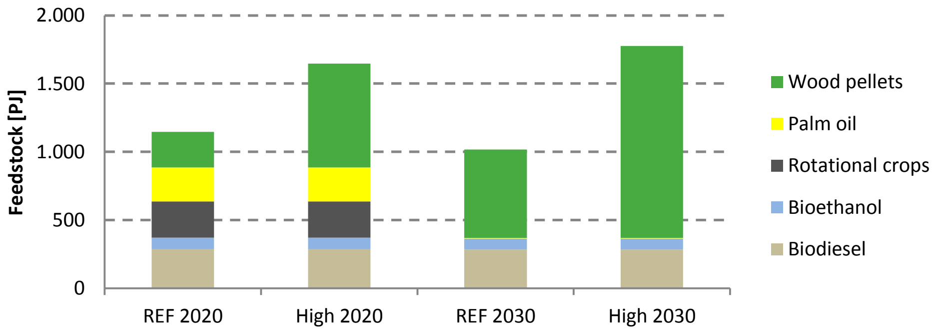


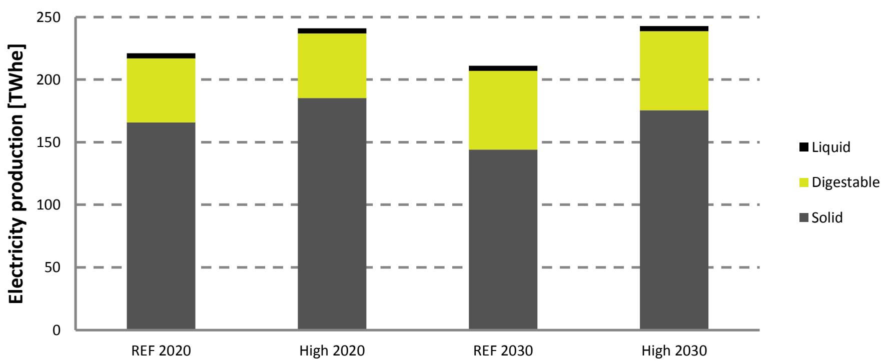
Figure 29: Import of feedstocks for EU27 in 2020 and 2030: reference (REF) versus high biomass (High) scenario



3.3.2 Electricity production

Although the demand for electricity using solid biomass has been increased by 25% for both 2020 and 2030, the RESolve-E, market model projections, indicate that the increase is 11.6% in comparison to the reference scenario in 2020. An increase of 25% seems to be too ambitious, since it would require a very high ramp up in less than 10 years' time. On the other hand, such an increase (25%) can be feasible in 2030 since there is more time to realise that. The RESolve-E projections indicate that the increase of electricity production using solid biomass might be 21.8% in 2030, with respect to the reference scenario. It is worthwhile to mention that the 11.6% increase in electricity production using solid biomass implies that the total bio-electricity production in 2020 will be 3.8% higher than the NREAP 2020 figure.

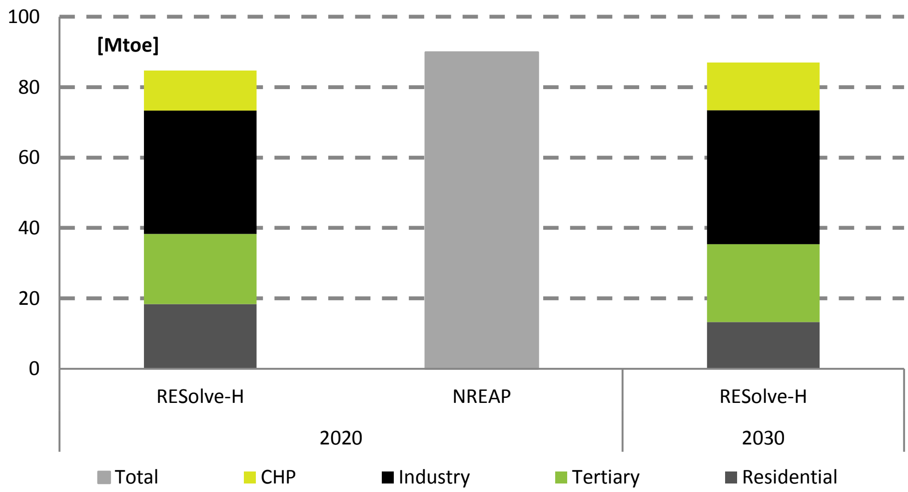
Figure 30: Electricity production in EU27 in 2020 and 2030: reference (REF) versus high biomass (High)



3.3.3 Heat production

In this scenario strengthened policy measures (increased conventional heat prices (+20%)) result in a competitive advantage for the renewable energy technologies (biomass but also geothermal and solar thermal), with higher penetrations as a result. The results are displayed in Figure 31. For the year 2020 the total biomass penetration is considerably higher (+8.8 Mtoe, +12%) than the reference scenario. The change in the period after 2020 is comparable: in the year 2030 an increase can be observed of plus 10.1 Mtoe (+13.1%). The uptake is most important in the residential sector and in industry (+2.1 Mtoe and +7.6 Mtoe respectively in 2030).

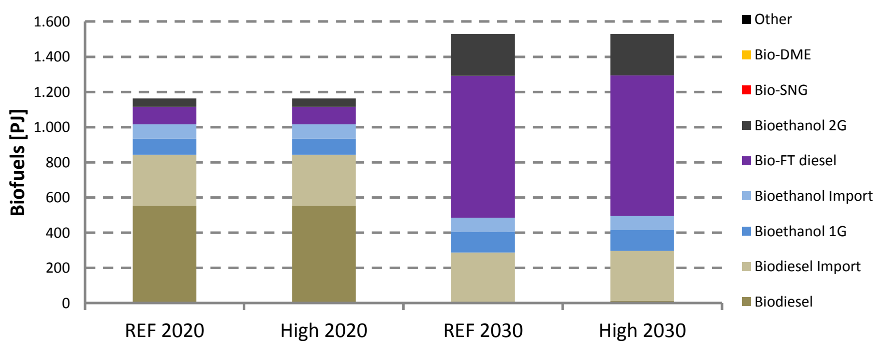
Figure 31: Penetration of biomass in the high biomass scenario according to RESolve-H in various cross-sections, with for the year 2020 the NREAP projection as a reference



3.3.4 Production of Biofuels

Since the reference scenario and the high biomass scenario only differ in the demand of solid biomass for electricity and heat production, the difference in biofuel distribution is marginal, see Figure 32.

Figure 32: Biofuel distribution [PJ] in 2020 and 2030 in EU27: reference (REF) versus high biomass (High)



3.4 Country results

In this section reference scenario results are presented per Member States level for the electricity and heat sector.

3.4.1 Electricity production

At the EU27 level the discrepancy with the NREAP figures for 2020 is only 4.7%, however, on a country by country level the discrepancies are much larger - also for the type of biomass, solid, digestible or liquid biomass. Figure 33 and Figure 34 present the bio-electricity production per Member States in comparison to their commitments in their NREAPs. Countries with a realization at least 15% larger than the NREAP figures are Austria, Finland, Hungary and Romania.

Figure 33: Comparison of bio-electricity production in 2020 as predicted by NREAP and RESolve-E. S=solid biomass, G=digestible biomass (biogas) and L=liquid biomass. Only countries with a total production in 2020 of more than 8 ™he are shown

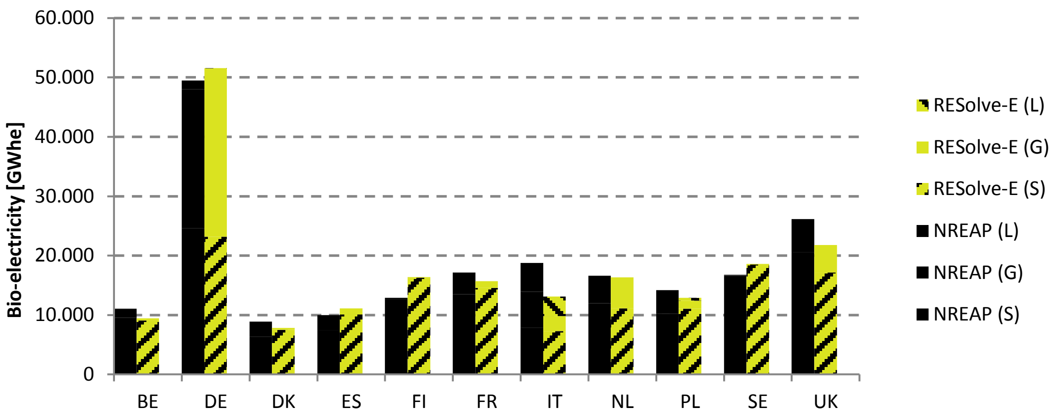


Figure 34: Comparison of bio-electricity production in 2020 as predicted by NREAP and RESolve-E. Only countries with a total production in 2030 of < 10 TWhe. are shown. S=solid biomass, G=digestible biomass and L=liquid biomass

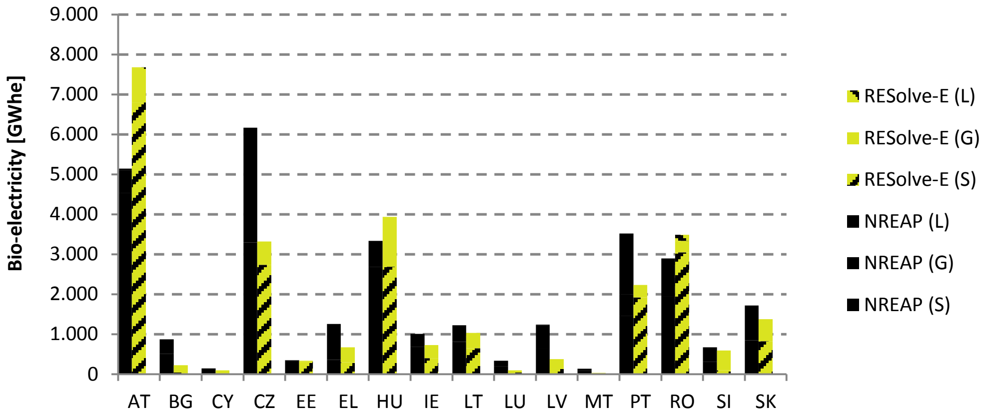


Table 7 illustrates the countries for which the deficit, as compared to the NREAP figures, for bio-electricity are larger than 15%. The table distinguishes the main reasons behind the discrepancies as the insufficient level of support schemes indicated in their NREAPs and the unrealistic growth rates (from a modelling perspective). The growth rates are further analysed in the sensitivity section.

Table 7: Countries for which a deficit of more than 15% in 2020 as compared to the NREAP figures. S=solid biomass, G=digestable biomass and L=liquid biomass RESolve-H technologies

Country	Deficit compared to NREAP [%]	Type of biomass	Deficit related to support levels/prices of biomass	Decline related to the growth rate/NREAP ambitions
BG	74%	S,G		
CY	35%	G		
CZ	46%	G		
EL	47%	S,G		
IE	28%	S		
IT	30%	G,L		
LT	16%	S		
LU	71%	S,G		
LV	70%	S,G		
MT	76%	S,G		
PT	37%	L		
SK	20%	G		
UK	17%	S		

According to the model results there is a decline in bio-electricity production after 2025. The decline for Austria, Finland and Sweden is related to the reduction in the black liquor potential. For Germany the predicted reduction in the use of digestible biomass for electricity production is caused by a reduction of the forage maize potential. In Both Spain and France the capacity of coal fired power plants is declining, this results in a decline of co-firing of biomass. Furthermore the Spanish potential of prunings declines after 2020. For Belgium, Italy and the UK, all are modelled assuming a quota obligation system, bio-electricity declines due to competition with other RES-E options. According to our analysis the use of biomass for electricity in Luxembourg, the Netherlands and Slovakia will decline because biomass prices will increase towards 2030. Table 8 presents the countries with a bio-electricity decline of more than 5% in 2030 compared to 2025, with the reasons behind.

Table 8: Countries for which a decline of more than 5% is predicted in electricity production using biomass in 2030 compared to 2025. S=solid biomass, G=digestible biomass and L=liquid biomass

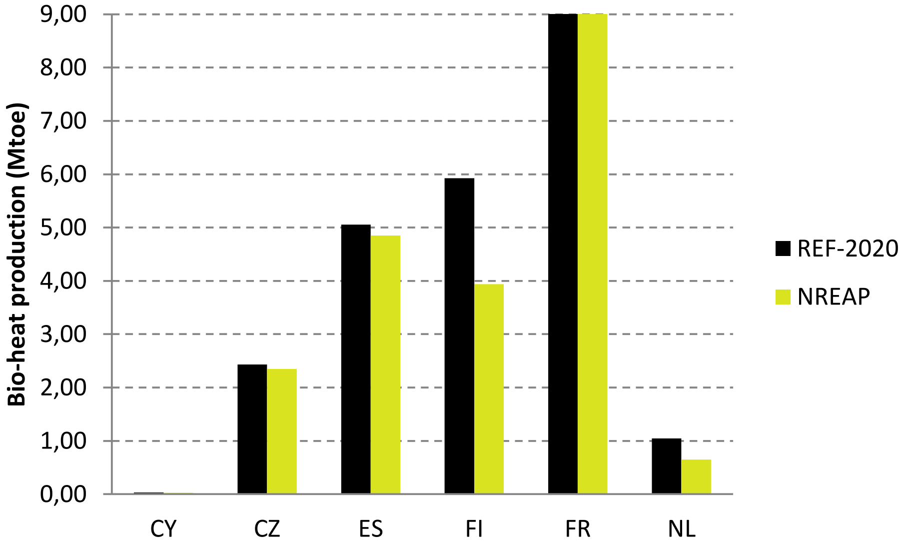
Country	Decline [%]	Type of biomass	Decline related to support levels/prices of biomass	Decline related to the potential
AT	10%	S		
BE	33%	S		
DE	7%	G		
ES	29%	S		
FI	15%	S		
FR	9%	S		
IT	24%	S		
LU	32%	G		
NL	14%	S		
SE	12%	S		
SK	13%	S		
UK	6%	S		

3.4.2 Heat production

While on the EU27 level the discrepancy between the RESolve-H model results and the NREAPs is approximately 16%, the difference in individual Member States increases up to 70%. Figure 35 presents the Member States with a deviation larger than 15% in comparison to the NREAPs.

A few countries (Finland, France, Spain, Slovenia and Slovakia) are observed to overshoot their NREAP targets. For countries with a relative small projected NREAP biomass contribution the increase may be important in relative terms, but not in absolute terms: for most cases it does not exceed 1 Mtoe.

Figure 35: Comparison of the Member States level bio-heat deployment in 2020. Only Member states with a deviation of - 15% are presented.



3.5 Sensitivity runs

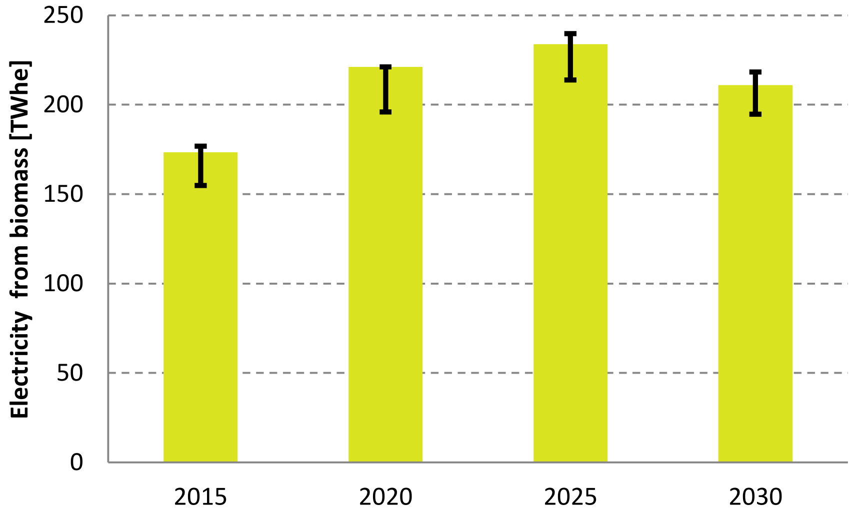
In this section the effects of feedstock prices and the growth rates included in the RESolve-E model are analysed.

3.5.1 Biomass feedstock prices

Since biomass prices are an important component of the costs of electricity generation using biomass, but there is quite some uncertainty about the future biomass price, it seems sensible to see how robust the outcomes of the RESolve-E model are towards changes in biomass prices. For that purpose two additional sensitivity runs were performed: one with biomass prices which are 25% higher than the default reference scenario and one where these prices are 25% lower. The negative effect of an increase in biomass prices is higher than the positive effect of a lowering in biomass prices. This is partially related to the bio-electricity figures for some countries already being quite optimistic: an even faster penetration of biomass seems infeasible for some countries. A good example of this is Ireland. According to Table 7 Ireland is one of the countries where the growth rate of bio-electricity is a bottleneck. Lowering the biomass prices has a modest effect on the bio-electricity figures of Ireland in 2020: an increase of 20%. The negative effect of increasing the prices is larger: a decline of 48%. Since the growth rate is already high the modest effect of lowering the biomass prices indicates that the growth figures are at its limits for Ireland[10]. The opposite effect, a slower increase, which will happen with higher prices, is of course not hindered by this limit and therefore has more effect.

[10] Note that an increase of 20% with 25% lower prices can't of course be neglected. In Ireland part of the feedstock, technology combinations already reaches its limits, however, there are certain feedstock, technology combinations which still have room for growth. These applications are the major drivers for the 20% increase.

Figure 36: Sensitivity of bio-electricity projections with respect to variations in biomass prices (indicated by the error bars) for the EU27 according to the reference scenario



Germany, Ireland, the Netherlands, Romania and the UK show a large sensitivity to higher biomass prices. For Romania and the UK this seems sensible since both countries have been modelled assuming a quota obligation system, hence higher biomass prices imply a better position of other RES-E options. According to the RESolve-E modelling the digestion of forage maize[11] is a large contributor to the bio-electricity figures of Germany. Therefore, a 25% increase in the feedstock price has a large effect on the levelized production costs of electricity (LPC). Digestion of forage maize becomes very unattractive, unless the incentives would be increased significantly. For both Ireland and the Netherlands the main decline in bio-electricity production due to co-firing of wood pellets. Co-firing of wood pellets becomes too expensive, unless the incentive levels are increased significantly. Figure 37 and Figure 38 illustrate the effects of feedstock price variations on the electricity production using biomass.

[11] The price of forage maize contributes much more to the levelized production cost than the investment costs and O&M costs.

Figure 37: Sensitivity of bio-electricity 2020 projection with respect to variations in biomass prices. Only countries with a total production in 2020 of more than 8 TWhe are shown

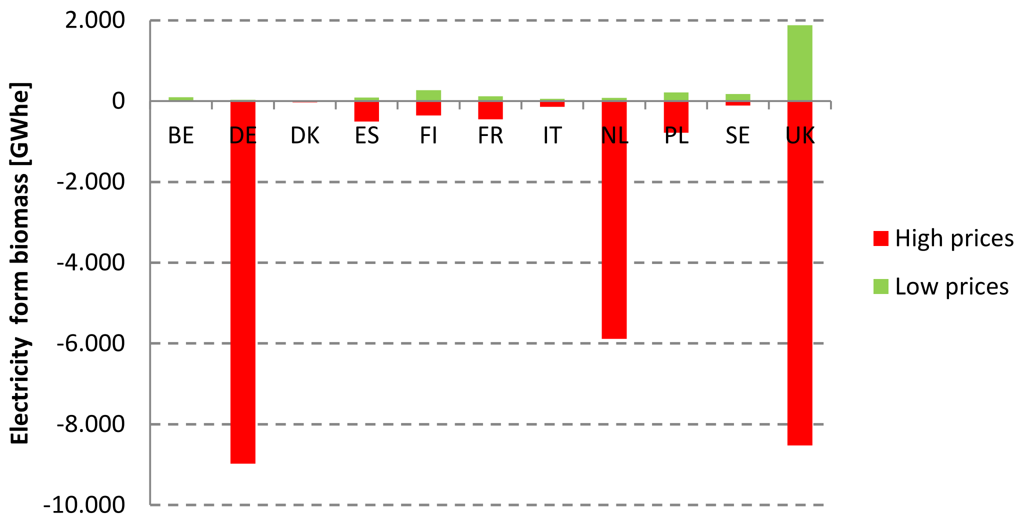
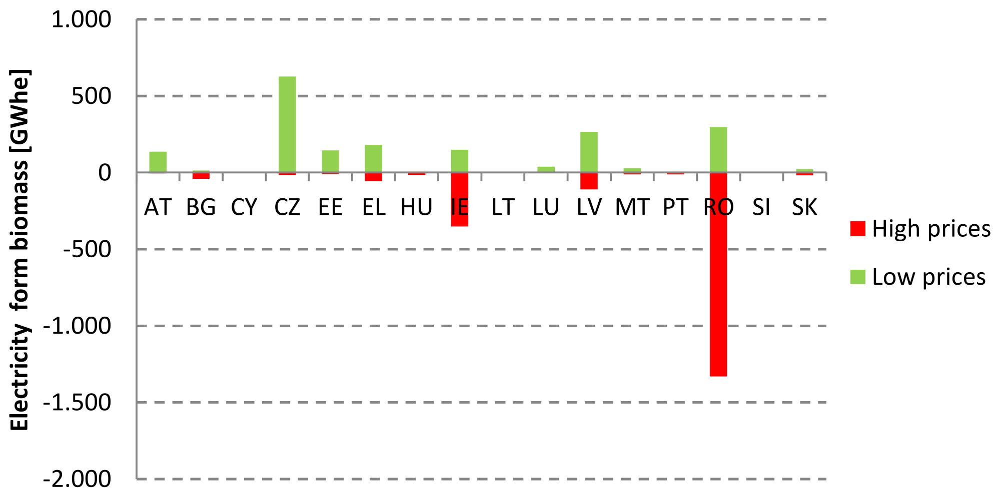


Figure 38: Sensitivity of bio-electricity 2020 projection with respect to variations in biomass prices. Only countries with a total production in 2030 of less than 10 TWhe are shown



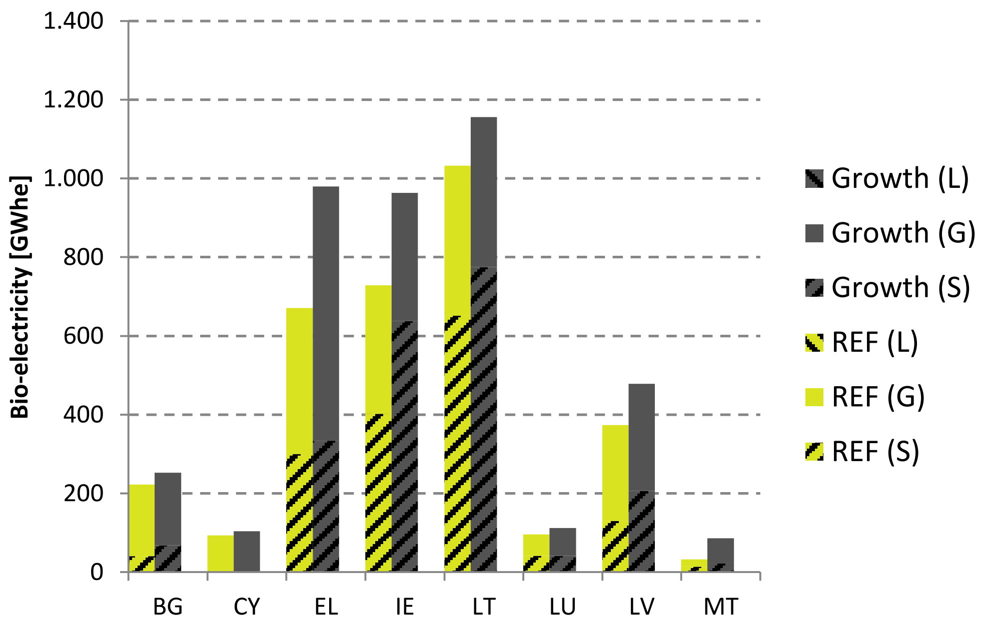
3.5.2 Growth rates

One of the main reasons behind the large discrepancies of the modelling results in comparison to the NREAP targets are observed to be the growth rates or penetration rates of bio-electricity technologies. According to the RESolve-E model the pace bio-electricity technologies will diffuse in a country depends on how quickly the biomass potential can be realized. To model this various limitations are taken into account. Examples are the limited production capacity of the capital goods industry, the limited speed of opening up the available biomass resources, the limited amount of potential that enters exploratory courses (pipeline potential) and the limited amount of investment plans passing these courses and the accompanying legal procedures successfully. These factors have been formalized in the model via certain parameters 'growth rates', each with its own value. It appeared that for countries for which these growth rates formed a bottleneck, the uptake of biomass resources was the main barrier. In other words there is (enough) biomass potential available but there are problems in harvesting this biomass and applying it for energy purposes.

The countries for which this applies are: BG, CY, CZ, EL, IE, IT, LT, LU, LV and MT as can be found in Table 7 (the last column is colored in this case). The reason why this effect was observed for these countries might be twofold: Firstly it might be that the NREAP figures are too ambitious. Secondly it might be that it was not possible to calibrate the model properly for these countries, since bio-electricity in the period 2005 -2010 is still at a modest level of development compared to NREAP ambitions. If a country has marginal figures in this period it is difficult to calibrate. Low figures in this period are especially the case for BG, CY, EL, LT, LV and MT.

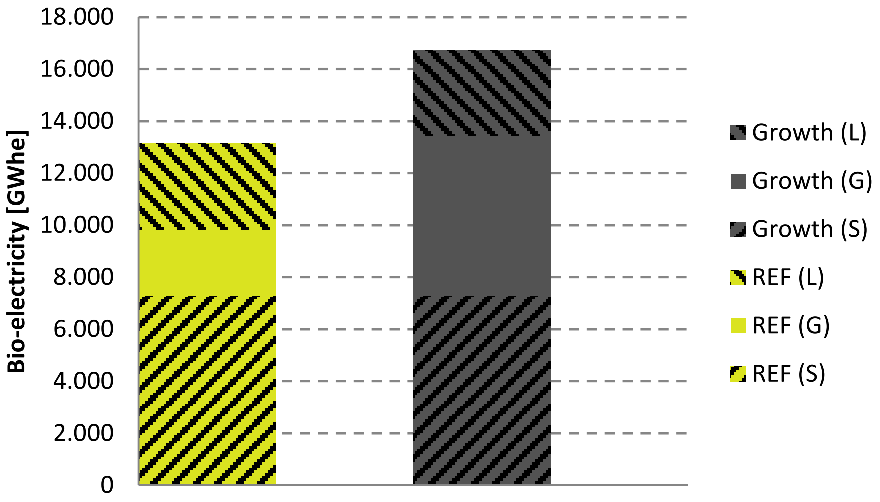
Figure 39 and Figure 40 illustrate the impacts of improved growth rates for these countries. When the parameter related to the uptake of biomass is increased in the RESolve-E model an increase in bio-electricity production is seen. However, still none of these countries can reach their bio-electricity NREAP figure. This leads to the conclusion that for these countries the NREAP figures seem too ambitious.

Figure 39: Comparison of default reference (REF) and run with improved growth rates (Growth) for countries for which this seems a bottleneck up to 2020. S=solid biomass, G=digestible biomass and L=liquid biomass



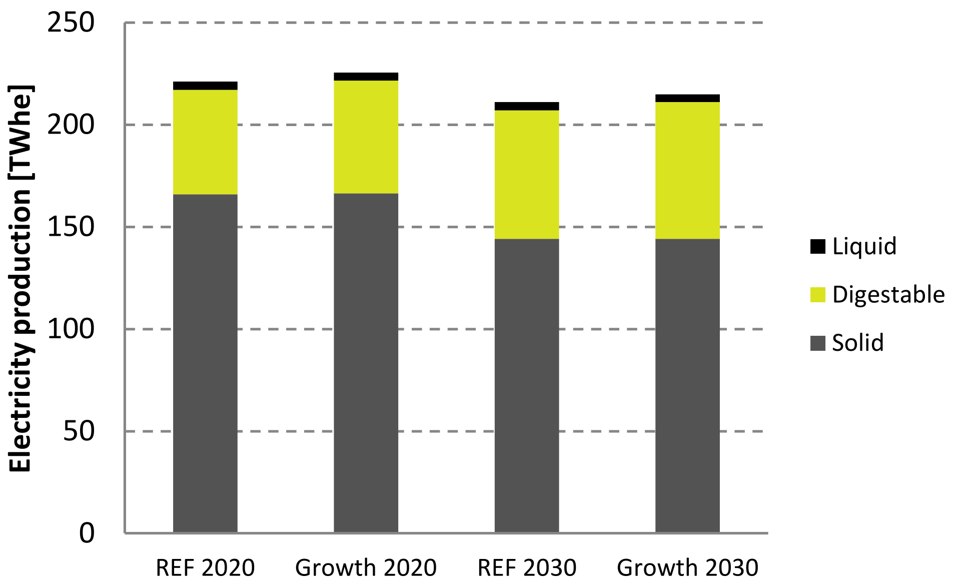
Italy country results are presented separately for practical reasons as the much higher figures of Italy would otherwise avoid seeing the results of the other countries clearly.

Figure 40: Comparison of default reference (REF) and run with improved growth rates (Growth) for Italy in 2020



The aggregated effect on the EU27 that the increased growth rates for the above mentioned countries have is modest. The increase in electricity production from biomass is 4.5 TWhe in 2020 and 3.9 TWhe in 2030. This means that this increase is not sufficient to resolve entirely the gap between the figures of the NREAPs and the RESolve-E projection. The mismatch is 2.9% in 2020.

Figure 41: Comparison of default reference (REF) and run with improved growth rates (Growth) for countries for which this seems a bottleneck up to 2020



4
Conclusions and recommendations

In this study three scenarios have been developed to model the implications and impacts of sustainability criteria and policy measures on future bioenergy demand. Each scenario included a comprehensive set of policy measures. These measures were derived from the NREAPs. Sustainability criteria, in line with the Renewable Energy Directive, have been applied to biofuels for the transport sector for the reference scenario, whereas it has been expanded to heat and electricity sector in the sustainability scenario. Moreover, the sustainability scenario attempted to include the indirect land use change effects through crop-specific iLUC factors. The high biomass scenario included stronger policy instruments to harness further utilisation of domestic biomass resources.

Results show that **EU biomass resources are quite significant in size even when more stringent sustainability criteria are considered. However, only around 40-50% of the total can economically and technically be utilised for energy**. The main reasons are first that an important fraction of the total potential is from roundwood and additional harvestable roundwood, which is very expensive to use directly for energy purposes. Secondly, some of the agricultural potential (i.e. straw, manure) faces technical difficulties and it is more expensive to produce energy from. The agricultural biomass feedstock potential is significant. However, model results show that only a limited amount of this potential can actually be utilised (around 30%). For feedstocks such as straw and prunings sufficient incentives are required to overcome the techno-economic challenges for supply and final conversion. Another important agricultural feedstock, manure, requires policy actions that would support biogas production from manure. For co-digestion with other crops and residues, further research is required to define the best combinations that yield larger methane production.

NREAP targets for biomass based heat, electricity and transport will not be reached under the present regional and national policy/support schemes and market developments in most of the EU countries. While the level of support schemes play an important role they will not immediately lead to enough growth to meet the targets. Many other factors (such as administrative and regulatory conditions, permitting procedures, the maturity of the industry etc.) slow down such developments. In this respect, the time frame up to 2020 might be too tight to achieve the ambitious NREAP bioenergy targets in Member States level.

The current Member States support schemes to produce renewable electricity and heat are very different with respects to their type (such as feed-in tariff, feed-in premium, quota obligation, investment grants, etc.), level of support, and the type of technology (for instance only for CHP) or feedstock they target. This could pose a risk that biomass is not used in areas where it is most cost-efficient.

On the other hand, a less fragmented policy approach **- implementing co-operation mechanisms** that are included in the Renewable Energy Directive – **could help Member States reach their targets and increase the cost-efficiency for bioenergy.**

While the sustainability criteria, particularly the criterion on iLUC, do not substantially affect the solid biomass potential they do influence the potential for digestible biomass and the rotational crops. In return, electricity and heat production from these digestible biomass sources and, more importantly, biofuel production is influenced. Such a pressure on conventional biofuels makes it hard to reach the 10% renewable energy in transport fuels.

Not only liquid biofuel imports but also the import of wood pellets will play an important role in the European bioenergy future. The modelling results indicate that around 259-761 PJ[12] wood pellets will be imported from outside the EU to reach the 2020 targets. Importing such large quantities, particularly from developing countries, however, brings in the concerns on the sustainability of biomass feedstock supply. While expanding the sustainability criteria from biofuels to biomass for energy will help decreasing their likely negative impacts the social and economic impacts on local communities, such as food security, local energy security and land access are open and difficult issues to tackle with.

If and when the NREAP bioenergy targets are achieved **around 500 Mton CO_2 eq. can be avoided in comparison to the conventional energy systems, corresponding to 11 % of the total volume of GHG emissions in EU-27 in 2010[13]. This underpins the importance of bioenergy for meeting EU's future GHG reduction targets.**

[12] 259 PJ for the reference scenario 761 PJ for the high biomass scenario

[13] EU27 total GHG emissions in 2010 is indicated as 4 724.1 Mton CO_2 eq. by the EEA (2011)

5

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Annex 1

Table 9: ECN techno-economic data

Technology name	Covers sector	Efficiency 1st main product			Lifetime [a]	Investment cost (€2010/kW)			Fixed O&M costs (€2010/(kW*yr)			Power / Size
		2010	2020	2030		2010	2020	2030	2010	2020	2030	MW out
Direct co-firing coal process	E	37,5%	41,8%	46,0%	12	220	220	220				100
MSW combustion	E	28,5%			15	2550			-	-	-	20-30
MSW-CHP	E,H	20,0%			15	2550			-	-	-	20-30
Solid combustion (electricity only)	E	27,0%			12	3725			270			~10
Liquid combustion (electricity only)	E	45,0%			12	1400			155			~10
CHP-liquid	E,H	39,0%	40%	41%	12	1600	1600	1600	175	175	175	~10
CHP-solid	E,H	27,5%	28,5%	30,0%	12	4018	3900	3800	298	298	298	~10
Waste digestion CHP	E,H	35,0%	35,5%	36,0%	12	2285	2255	2210	230	230	230	0,3
Biogas digestion CHP	E,H	39,0%	39,5%	40,0%	12	585			62,0			1.1-3.0
Waste combustion - heat only *	H	85,0%			10	12,67						
Residential-Pellet boiler	H	85,0%	86,0%	87,0%	17	671	650	629	25	25	25	
Local heating plant for wood pellets-small scale (0.5MW)	H	89,0%			15	704			21,243			
Local heating plants for processed energy crops i.e. miscantus)	H	86,0%			15	513			22,361			
Local heating plant for straw	H	90,0%			17	685			102,000			

Technology name	Covers sector	Efficiency 1st main product			Lifetime [a]	Investment cost (€2010/kW)			Fixed O&M costs (€2010/(kW*yr)			Power / Size
wood chip boilers-medium size	H	80,0%	81,0%	82,0%	17	585	552	544	21,50	21,50	21,50	
local heating plant	H	86,0%			20	505	485		19,700			
Co-firing in a coal fired CHP plant	E,H	30,0%			25	224			137,517			
Cellulose EtOH	T	39,0%			20	3673	learning	learning	363	learning	learning	190 kton_output/yr
DME production	T	56,0%			20	1937	learning	learning	116	learning	learning	110
FT production	T	52,5%			20	2429	learning	learning	146	learning	learning	100
Oil extraction		39,0%			20	274	274	274	116	71	71	500 kton_output/yr
Starch EtOH	T	54,5%			20	1060	learning	learning	433	learning	learning	100 kton_output/yr
Sugar EtOH	T	44,7%			20	659	learning	learning	272	learning	learning	100 kton_output/yr
Transesterification of vegetable oil (no palm oil)	T	98,9%			20	201	learning	learning	81	learning	learning	100 kton_output/yr
Transesterification of used fats/oils and palm oil	T	99,7%			20	302	learning	learning	89	learning	learning	50 kton_output/yr
* : €2010/GJinput/yr												

Table 10: NTUA techno-economic data

Technology name	Output products of technologies	Covers sector	Output/Feedstock Ratio [%]			Lifetime [a]	Investment cost (€2010/KW)			Fixed O&M costs (€2010/KW)		
			2010	2020	2030		2010	2020	2030	2010	2020	2030
Fermentation of Starch (Starch Et-OH)	Bioethanol	T	27%	29%	29%	25	539	484	480	26	24	23
Fermentation of Sugar (Sugar-EtOH)	Bioethanol	T	28%	29%	30%	20	1045	836	829	13	10	10
Enzymatic Hydrolysis and Fermentation (Cellulose Et-OH)	Bioethanol	T	24%	26%	27%	25	2364	1856	1348	16	14	12
Enzymatic Hydrolysis and Fermentation & Catalytic Upgrading	Biogasoline	T	14%	15%	17%	25	3205	2557	1909	41	33	24
Enzymatic Hydrolysis and Fermentation & Hydro Deoxygenation	Biogasoline	T	14%	15%	17%	25	3416	2732	2049	47	37	28
Gasification & F-T Synthesis	Biogasoline	T										
Gasification & F-T Synthesis & Naphtha Upgrading	Biogasoline	T	15%	17%	19%	25	3330	2883	2647	237	184	156
Black Liquor Gasification & F-T Synthesis & Naphtha Upgrading	Biogasoline	T	11%	13%	14%	25	3330	2883	2647	237	184	156
HTU & Hydro Deoxygenation & Naphtha Upgrading	Biogasoline	T	14%	14%	15%	25	3234	2706	2179	100	76	53

Technology name	Output products of technologies	Covers sector	Output/Feedstock Ratio [%]			Lifetime [a]	Investment cost (€2010/KW)			Fixed O&M costs (€2010/KW)		
Pyrolysis & Hydro- deoxygenation & Naphtha Upgrading	Biogasoline	T	12%	13%	14%	20	2462	2218	1974	82	73	63
Pyrolysis & Gasification Oil & F-T Synthesis & Naphtha Upgrading	Biogasoline	T	7%	8%	9%	20	3041	2833	2706	145	132	124
Transesterification of vegetable oil (not palm oil)	Biodiesel	T	50%	55%	56%	20	270	213	183	11	10	9
Transesterification of used fats/oils and palm oil	Biodiesel	T	85%	88%	90%	20	270	213	183	11	10	9
Enzymatic Hydrolysis of sugar & Hydro-deoxygenation	Biodiesel	T	16%	17%	18%	25	2185	1943	1700	34	26	18
Hydrolysis of starch & Enzymatic Hydrolysis & Hydro-deoxygenation	Biodiesel	T	15%	16%	17%	25	2713	2310	1908	37	28	20
Hydro-deoxygenation of vegetable oil	Pure Diesel	T	65%	66%	67%	25	1261	1051	841	32	24	16
Gasification and F-T synthesis (F-T Diesel)	Pure Diesel	T	16%	18%	20%	25	3250	2805	2571	232	178	151
Black Liquor Gasification & F-T Synthesis	Pure Diesel	T	12%	14%	15%	25	3250	2805	2571	232	178	151
HTU & Hydro Deoxygenation	Pure Diesel	T	15%	15%	16%	25	3154	2628	2103	95	71	47
Pyrolysis & Hydro-deoxygenation	Pure Diesel	T	13%	14%	15%	20	2382	2140	1898	76	67	58

Technology name	Output products of technologies	Covers sector	Output/Feedstock Ratio [%]			Lifetime [a]	Investment cost (€2010/KW)			Fixed O&M costs (€2010/KW)		
Pyrolysis & Gasification Oil & F-T Synthesis	Pure Diesel	T	7%	8%	10%	20	2961	2755	2630	139	126	119
Gasification & F-T Synthesis	Biokerosene	T	16%	18%	20%	25	3250	2805	2571	232	178	151
HTU & Hydro-deoxygenation	Biokerosene	T	15%	15%	16%	25	3154	2628	2103	95	71	47
Pyrolysis & Hydro-deoxygenation	Biokerosene	T	13%	14%	15%	20	2382	2140	1898	76	67	58
Pyrolysis & Gasification Oil & F-T synthesis	Biokerosene	T	7%	8%	10%	20	2961	2755	2630	139	126	119
Gasification & Methanol Synthesis	Methanol	T	28%	30%	31%	15	2566	2174	1971	172	123	98
Gasification of Black Liquor & SynGas to Biogas	Biogas	H/E	29%	31%	32%	25	2599	2131	1888	174	127	104
Anaerobic Digestion	Biogas	H/E	56%	67%	67%	15	490	443	440	17	15	15
Gasification of Biogas & SynGas to biogas	Biogas	H/E	37%	38%	39%	25	1424	1134	985	45	37	34
Enzymatic hydrolysis	Biogas	H/E	29%	32%	34%	25	924	831	739	3	2	2
Catalytic Hydrothermal Gasification of wood & SynGas to biogas	Biogas	H/E	37%	39%	40%	25	899	696	593	17	19	20
Catalytic Hydrothermal Gasification of wet feedstock & SynGas to biogas	Biogas	H/E	22%	32%	40%	25	849	459	263	18	20	21
Gasification of Black Liquor & SynGas to Biogas & Biogas to Biomethane	Biomethane	T/H/E	14%	15%	16%	15	2807	2328	2076	178	131	108

Technology name	Output products of technologies	Covers sector	Output/Feedstock Ratio [%]			Lifetime [a]	Investment cost (€2010/KW)			Fixed O&M costs (€2010/KW)		
Anaerobic Digestion & Biogas to Biomethane	Biomethane	T/H/E	28%	34%	34%	15	698	641	627	21	19	19
Gasification of Biogas & SynGas to biogas & Biogas to Biomethane	Biomethane	T/H/E	19%	19%	20%	15	1632	1332	1172	49	41	37
Enzymatic hydrolysis & Biogas to Biomethane	Biomethane	T/H/E	15%	16%	18%	15	1132	1029	926	7	6	6
Catalytic Hydrothermal Gasification of wood & SynGas to biogas & Biogas to Biomethane	Biomethane	T/H/E	19%	20%	20%	15	1107	894	780	21	23	24
Catalytic Hydrothermal Gasification of wet feedstock & SynGas to biogas & Biogas to Biomethane	Biomethane	T/H/E	11%	16%	20%	15	1057	657	450	22	24	24
HTU process	Bio heavy fuel oil	T/H/E	22%	23%	24%	25	1892	1577	1261	63	47	32
Pyrolysis of woody biomass	Bio heavy fuel oil	T/H/E	19%	21%	22%	20	1121	1089	1057	45	44	42
Catalytic Upgrading of Black Liquor	Bio heavy fuel oil	T/H/E	18%	19%	20%	25	1682	1402	1122	25	19	13
Landfill	Waste gas	H/E	100%	100%	100%	15	440	418	414	13	12	12
Anaerobic digestion	Waste gas	H/E	56%	67%	67%	15	490	443	440	17	15	15
RDF	Waste solid	H/E	82%	85%	85%	15	79	78	77	8	5	5

Technology name	Output products of technologies	Covers sector	Output/Feedstock Ratio [%]			Lifetime [a]	Investment cost (€2010/KW)			Fixed O&M costs (€2010/KW)		
Small scale solid	Small scale solid	H/E	85%	85%	85%	15	182	137	136	18	14	14
Large scale solid from wood biomass	Large scale solid	H/E	90%	90%	91%	15	91	85	84	4	3	3
Note on production processes												
1 The pretreatment cost of feedstock is excluded in all production pathways costs												
2 Starch EtOH production pathway in PRIMES Biomass model is considered to use as feedstock crops such as maize, wheat, barley etc. An average of these crops has been used. The costs presented don't include pretreatment costs, which amounts to approximately 300 €/KW												
3 Sugar feedstock is considered to be preprocessed when entering the conversion pathway												

Table 11: Oeko Institute techno-economic data

	Description		Technology data				Costs data						
Technology name	Technology description	Covers sector	Efficiency 1st main product [%]			Lifetime [a]	Investment cost (€2010/kW)			Fixed O&M costs (€2010/kW)			Power/Size
			2010	2020	2030		2010	2020	2030	2010	2020	2030	MW out
Direct co-firing coal	wood chips co-fired in new large ST plant	E	45,3	47	51	30	168,5	168,5	168,5	39,3	39,3	39,3	70
CHP electricity - liquid	diesel enginge	E, H	39	40	41	15	1000	1000	1000	30	30	30	1
CHP electricity - solid	ST BP	E, H	27,5	28,5	30	25	2000	1950	1900	40	40	40	20
Waste digestion CHP	gas engine	E, H	39	39,5	40	15	775	765	750	50	50	50	0,5
Biogas digestion CHP	gas engine	E, H	39	39,5	40	15	775	765	750	50	50	50	0,5

	Description		Technology data				Costs data						
Technology name	Technology description	Covers sector	Efficiency 1st main product [%]			Lifetime [a]	Investment cost (€2010/kW)			Fixed O&M costs (€2010/kW)			Power/Size
			2010	2020	2030		2010	2020	2030	2010	2020	2030	MW out
SNG from solids	syngas from CFB gasifier + steam reforming	intermediate		65	65	15		1125	1070		29	27	167
heat, wood chips boiler	small-scale system	H	85	86	87	15	687	647	637	21	21	21	0,01
heat, pellets boiler	small-scale system	H	86	87	88	15	860	836	812	26	26	26	0,01
2G EtOH from straw	assuming internal use of lignin	T		50	55	15		450	395		10	5	100
FT from solids	assuming no H2 input	T		45	45	20		2025	1875		85	54	500
Plant oil extraction (milling)	assuming rapeseedoil input	intermediate	66,25	66,25	66,25								12,5
wheat 1G EtOH	no internal biogas	T	58	58	58		860	775	730	20	17,5	15	96
Sugarcane 1G EtOH	data for Brazil	T	20,7	21	21	15	337	321	320	8,5	5,5	5	150

	Description		Technology data				Costs data						
Technology name	Technology description	Covers sector	Efficiency 1st main product [%]			Lifetime [a]	Investment cost (€2010/kW)			Fixed O&M costs (€2010/kW)			Power/Size
			2010	2020	2030		2010	2020	2030	2010	2020	2030	MW out
FAME from plant oil	assuming rapeoil input	T	99	99	99				15				12,5
FAME from used oil	assuming waste oil input	T	92,4	92,5	93				15				12,5

Table 12: IIASA techno-economic data

	Description		Technology data			Costs data						
Technology name	Technology description	Covers sector	Efficiency 1st main product [%]			Investment cost (€/GJ)			Fixed O&M costs			Unit
			2010	2020	2030	2000 Min	2000 Max	2030	2000	2020	2030	
Biogas LT-gasification CHP	Gasification of wood	T, H	0,45			24,62	34,55	-	80,47			€/ha
	Gasification of wood from short rotation plantings	T, H	0,45			22,92	32,17	-	5,47	-	-	€/GJ
BIGCC	Combustion of wood	H, E	0,60			3,09	9,45	-	80,47			€/ha
	Combustion of wood from short rotation plantings	H, E	0,60			2,87	8,80	-	4,10	-	-	€/GJ
Wood cumbustion - heat only												
Waste combustion - heat only												
Direct firing - heat	direct biomass use for	H	1,00									

	Description		Technology data			Costs data						
Technology name	Technology description	Covers sector	Efficiency 1st main product [%]			Investment cost (€/GJ)			Fixed O&M costs			Unit
			2010	2020	2030	2000 Min	2000 Max	2030	2000	2020	2030	
	cooking											
Liquid combustion - heat												
LT-gasification (SNG production)												
Cellulose Et-OH	Fermentation of wood	T, H, E	0,29			15,16	21,27	-	80,47	-	-	€/ha harvested area
	Fermentation of wood from short rotation planting	T, H, E	0,29			14,11	19,81	-	8,48	-	-	€/GJ
DME production												
FT production												
Oil extraction												

	Description		Technology data			Costs data						
Technology name	Technology description	Covers sector	Efficiency 1st main product [%]			Investment cost (€/GJ)			Fixed O&M costs			Unit
			2010	2020	2030	2000 Min	2000 Max	2030	2000	2020	2030	
Pretreatment for gasification (torrefaction, pelletisation)												
Starch EtOH	Corn to Ethanol	T	0,57			16,57	23,26	-	13,19	-	-	€/GJ
	Wheat to Ethanol	T	0,53			21,20	29,76	-	13,16	-	-	€/GJ
Sugar-EtOH	Sugar cane to Ethanol	T	0,32			3,02	4,24					
Transesterification of vegetable oil (no palm oil)	Rape to FAME	T	1,09			19,86	27,87	-	11,36	-	-	€/GJ
	soya to FAME	T	0,41			23,48	32,96	-	29,43	-	-	€/GJ
Transesterification of used fats/oils and palm oil	Palm oil to FAME	T	0,30			35,67	50,07	-				