Delivery of sustainable supply of non-food biomass to support a "resource-efficient" Bioeconomy in Europe

S2Biom Project Grant Agreement n°608622

Deliverable 7.3
Integrated assessment of biomass supply chains and conversion routes under different scenarios

November 2016

About S2Biom project

The S2Biom project - Delivery of sustainable supply of non-food biomass to support a "resource-efficient" Bioeconomy in Europe - supports the sustainable delivery of non-food biomass feedstock at local, regional and pan European level through developing strategies, and roadmaps that will be informed by a "computerized and easy to use" toolset (and respective databases) with updated harmonized datasets at local, regional, national and pan European level for EU-28, Western Balkans, Moldova, Turkey and Ukraine. Further information about the project and the partners involved are available under www.s2biom.eu.

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About this document

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Executive summary

The S2Biom project aims to support the sustainable delivery of non-food biomass feedstock at local, regional and pan European level through developing strategies and roadmaps. S2Biom Work Package 7 focuses on an integrated assessment of lignocellulosic biomass chains, for energy as well as chemicals and materials. It makes use of the various databases created in earlier WPs of the project, and of ECN's RESolve Biomass model.

The key conclusions from the analyses done in this report are as follows:

- Europe has sufficient amounts of sustainable biomass at its disposal to meet its 2030 ambitions in terms of biobased energy and chemicals. There are, however, clear differences between regions within Europe, and intra-European trade as well as ex-EU imports will be important.
- If new developments, such as additional sustainability criteria, would reduce domestic potentials, there is sufficient remaining (domestic and imported) sustainable biomass available to still meet these ambitions, with relatively modest additional costs.
- The technology mix used for conversion of biomass into the various energy carriers (heat, electricity and fuels) remains remarkably stable in our scenarios. This implies that this mix is relatively robust.
- Heat remains the dominant use of biomass, not only in terms of energy but also in terms of financial turnover. More high-value applications such as chemicals and biofuels can play a role in improving business cases for integrated refinery systems, but profitable sales of heat should not be neglected, nor the relevance of heat-only and CHP options.
- Biomass applications for chemicals create only very modest biomass demand volumes compared to the energy applications, at least towards 2030. As a consequence, this demand does not fundamentally compete against energy applications. Vice versa, the competitiveness of chemical applications can be affected by changes in demand for energy, with exception of chemicals that can be co-produced with energy carriers such as BTX or methanol.
- The competitiveness of biobased chemicals varies strongly between the different reference chemicals studied. Some show consistently lower costs than the fossil reference, while others remain more expensive in all scenarios.
- A development pathway towards more advanced, ligno-based biofuels instead of crop-based biofuels will not come through autonomous developments alone. Important preconditions for such development are:
    - Mobilization of lignocellulosic feedstock for large-scale conversion;
    - Clear objectives for the development of advanced biofuels, e.g. through a specific sub-target for them;
    - A gradual reduction of the (currently 7%) cap on crop-based biofuels.

We realize that policy making is always the craft of reconciling (partly) conflicting interest. From a position of 'honest broker of policy alternatives', we can make the following recommendations:

- If further scientific insights and societal pressure demand so, additional sustainability restrictions to biomass use for energy do not by definition ruin the perspectives for bioenergy and biochemicals. Although much will depend on the level of strictness, and administrative burden to such regulations, biomass availability as such is sufficient to accommodate a reduction of feedstock potential. Such restrictions can, however, induce a change towards more ex-EU imports of biomass and less use of domestic feedstock.
- Active policies to mobilize sustainable feedstocks will be relevant. Particularly for the realization of advanced biofuels, such policies will be necessary, next to policies aimed at technology development and final demand pull. In a policy context with more restrictions on biomass potential, relatively low-impact feedstocks such as manure and perennial lignocellulosic crops will become more important.
- Next to competition issues between biomass applications for energy and chemicals, there can also be significant synergies. This particularly applies to integrated conversion systems that produce both chemicals and energy carriers: in such systems, chemical production routes are less prone to being outcompeted by energy applications. However, given the difference in size between energy and chemical routes, also in terms of financial turnover, there will certainly be room for energy-only applications of biomass.

As with any model exercise, the limitations to the model directly bring limitations, and corresponding recommendations for further research:.

- It should be clear that the demands for biobased energy carriers and biochemicals has been defined exogenously in this project, and are not model outcomes. In a more integrated approach the share of e.g. bioelectricity might be lower, given the recent rapid cost reduction for wind and solar energy.
- The optimization routines of the model have entirely focused on least costs per GJ or tonne. While GHG intensities were available for most (but not all routes), the optimal outcomes from the analyses need not be optimal in GHG terms.
- The scenarios were translated to model inputs in a rather stylized manner. In practice, the sustainability discussion may include more elements, such as the allocation of biomass over heat, biofuels and biobased chemicals.
- Synergies between biobased chemical and biofuel routes were included in a simplified way, merely by joint learning curves. This is worth more detailed analysis.

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1. Introduction

The S2Biom project aims to support the sustainable delivery of non-food biomass feedstock at local, regional and pan European level through developing strategies and roadmaps. These will be supported by a "computerized and easy to use" toolset and databases with updated harmonized datasets at local, regional, national and pan European level for EU-28, Western Balkans, Moldova, Turkey and Ukraine. The 40-month project started mid-2013 and ends in November 2016. In this project, a ~30-party consortium of research institutes and other parties provide a wide array of tools and insights supporting strategies for a sustainable growth of novel applications of lignocellulosic biomass.

S2Biom Work Package 7 focuses on an integrated assessment of lignocellulosic biomass chains, for energy as well as chemicals and materials. It provides answers to questions related to the future costs of biobased options, competition and synergies between energy and chemical-material applications, and overall system implications of the development of a full-blown biobased sector. For this, the ECN model for integrated assessment of biomass chains RESolve-Biomass was further expanded and used. This model has been developed and further improved in an array of EU projects, from the VIEWLS project (2003-2005) through REFUEL (2006-2008), Elobio (2007-2010) and Biomass Futures (2011-2013) to Biomass Policies (2013-2016).

The integrated assessment also builds further on data gathered in earlier WPs of the S2Biom project, on feedstock availability and costs (WP1), conversion technology performance and costs (WP2), and the characteristics of logistical chains (WP3). Within the Work Package, scenarios were developed for the further widening of the analytical scope (Task 7.1 with Deliverable 7.1), and an elaborate survey was made of possible future biomass demand from both the chemicals/materials sector and the various energy sectors (fuels, power, heat): Task 7.2 with Deliverable 7.2.

The structure of this report is as follows:

- In section 2 we present the modelling methodology and key general data
- In section 3 we specify the scenario-dependent assumptions we made and the inputs for some additional analyses
- Section 4 contains key results: general outcomes, key differences found between scenarios, and results of the additional analyses
- Section 5 contains conclusions and recommendations.

2. Modelling methodology

2.1. The RESolve-Biomass model

RESolve-Biomass determines the least-cost configuration of the entire biobased energy chemicals production chain, given demand projections for biofuels, bio-electricity, bioheat and biochemicals[1], biomass potentials and technological progress [1,2]. By doing so the model mimics the competition among these four sectors for the same resources. The RESolve-biomass model includes raw feedstock production, processing, transport and distribution. 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 bioenergy and biochemicals can be approached in a much more realistic way than when each country is evaluated separately.

As compared to the application of RESolve-Biomass as applied in the IEE project Biomass Policies [3] the following modifications have been applied:

- Demand and production routes for chemicals from lignocellulosic biomass have been added to the model
- Nine non-EU countries have been added to the model: Albania, Bosnia and Herzegovina, Moldova, Montenegro, The former Yugoslav Republic of Macedonia, Serbia, Turkey, Ukraine and Kosovo
- Pyrolysis pathways have been added
- Several other technologies have been added, using the database from S2Biom WP2 , see section 2.2.1
- Update of techno-economic data using the database from WP2 of S2Biom, see also section 2.2.1.

Further details on ECN's RESolve-Biomass model can be found in Annex I.

2.2. Supply chain data inputs

For the modelling assignment in S2Biom there have been several updates to the last version of the RESolve-Biomass, as specified in 2.1. This includes an update for the supply chain data. First the newly added and updated conversion technologies are discussed in 2.2.1. Then the cost supply data used in the model is elaborated upon in 2.2.2. Lastly in 2.2.3, the import cost supply curves are given.

[1] In this project, the focus was more specifically on chemicals made from lignocellulosic biomass

2.2.1. Conversion technologies

Based on the work in WP 2, which delivered techno-economic parameters on many different biomass conversion technologies, several conversion technologies have been updated or added to ECN's RESolve-Biomass model. The updated conversion technologies are:

- Indirect gasification for synthetic natural gas (SNG) production
- CHP using solid biomass (0.5-10 MW)
- Biomass integrated gasification combined cycle (IGCC)
- Fisher-Tropsch diesel production

Next to this the following conversion technologies were newly added to the RESolve-Biomass model. The added technologies were selected for their promise to become a significant consumer of biomass. The selection was further minimized by picking only those conversion technologies that were significantly different from the existing options in order to reduce runtime of the model. This resulted in the following list:

- CHP using solid biomass (>5 MW_e and <10 MW_{th} (output))
- Small scale wood gasification CHP (<0.25 MW_e and < 0.5 MW_{th} (output))
- Medium scale wood gasification CHP (0.25-5 MW_e and 0.5-10 MW_{th} (output))
- Pyrolysis oil production
- Pyrolysis oil to steam
- Pyrolysis oil to diesel
- Pyrolysis oil to CHP combustion engine

2.2.2. Cost supply data

The reference case for biomass availability is characterized by a policy environment in which the current sustainability policies are in place, and additional sustainability requirements are not limiting the size of feedstock. Therefore, there is no strong competition for resources and biomass feedstocks have low to medium prices.

For the EU-28 countries the required data have been taken from the 'Reference scenario' of the IEE project 'Biomass Policies' [4, 5], in which the current sustainability criteria for biofuels are implemented. Beyond 2020, the 'Reference scenario' is aligned with the 40% GHG reduction targets in 2030. For other countries included in the assessment, but which are not Member States of the European Union, the cost supply data has been taken from a JRC study on RES potentials [6].

The availability of biomass, slightly increasing between 2015 and 2030, is shown in Figure 1. In 2030 the potentials for biomass availability are spread over a wide variety of categories, with largest volumes in straw/stubbles, energy grasses and perennial crops, manure, primary forestry residues, saw mill residues and other wood processing industry residues; see Figure 2. A cost supply curve of these major biomass feedstocks can be seen in Figure 3.

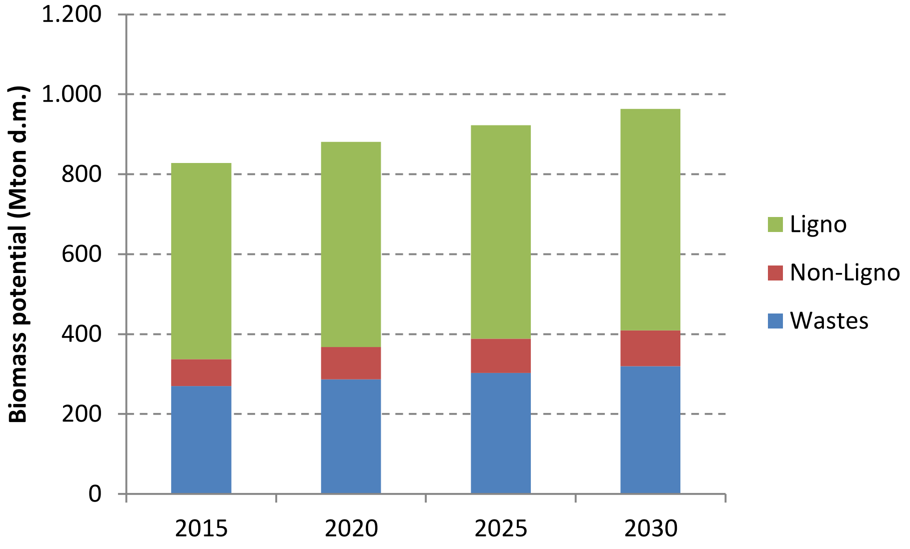


Figure 1 Potential of biomass in the assessed region (in Mton d.m.) per feedstock type.

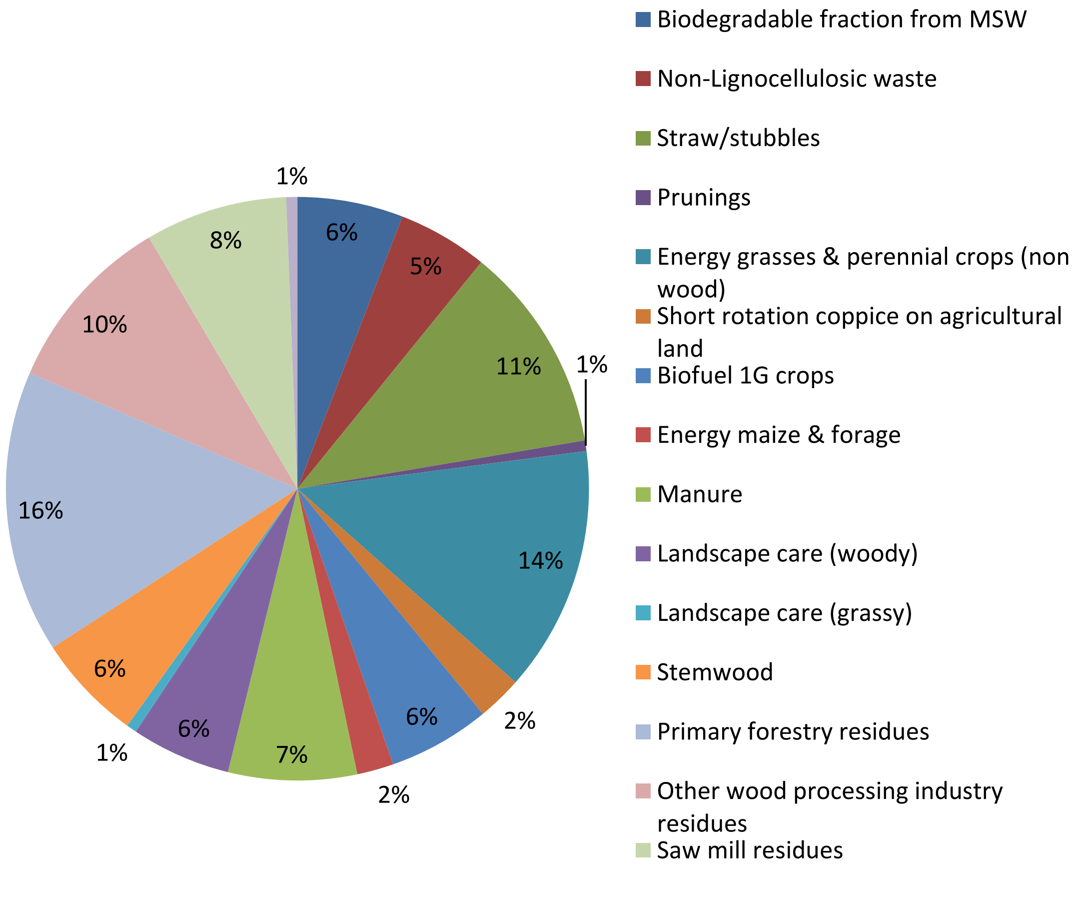


Figure 2 Relative biomass availability in 2030 by biomass type.

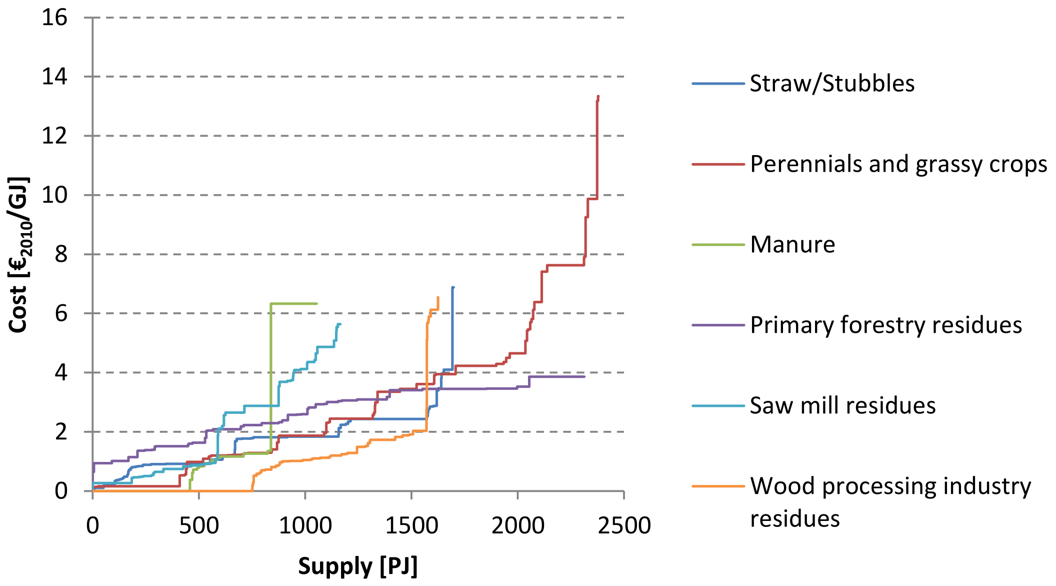


Figure 3 Cost supply curves for 2030 of the biomass feedstocks with the highest availability.

2.2.3. Import cost supply data

ECN's RESolve-Biomass model allows international trade within the assessed region, but also the import of biomass feedstocks from elsewhere in the world. Import cost supply data for first and second generation bioethanol, biodiesel and wood pellets were taken from the IEE project 'Biomass Policies' [7]. Import cost supply data for used fats and oils (UFO) were taken from Spöttle *et al.*[8] and Pelkmans et al. [23] The import potential for palm oil was estimated at 200 PJ[2].

An overview of the import cost supply curves can be found in Figure 4.

Although the S2Biom project has generated import cost supply data in WP1, this data has not been used in the model and thus for the integrated assessment. The main reason for this was the limited number of goods for which import cost supply data was determined (only wood chips, wood pellets, first and second generation bioethanol, and first generation biodiesel). Furthermore, the import data from within S2Biom included the price of transport, while the model needs input data excluding transportation costs, since these are determined within the model based on distance, transportation mode and fossil fuel prices.

Biomass import from outside Europe is assumed to be transported by large Ocean tankers. In the model this biomass can only be transported to the large harbors in Belgium, Germany and the Netherlands. From where it can be further transported to other European countries via other transport modalities. In reality it might well be that, for example, wood pellets from the United States are directly exported to the country

[2] Basis for this assumption: In 2012, a total of 200 PJ palm oil was imported to the EU, about half of which was used for biofuels [24]. We assume that this amount for biofuels can still double up to 2030.

where it will be consumed. However, currently those countries are the largest players in distribution of biomass from outside of Europe. Allowing all countries that are connected to sea to import from outside Europe would result in results which are not in line with current trends.

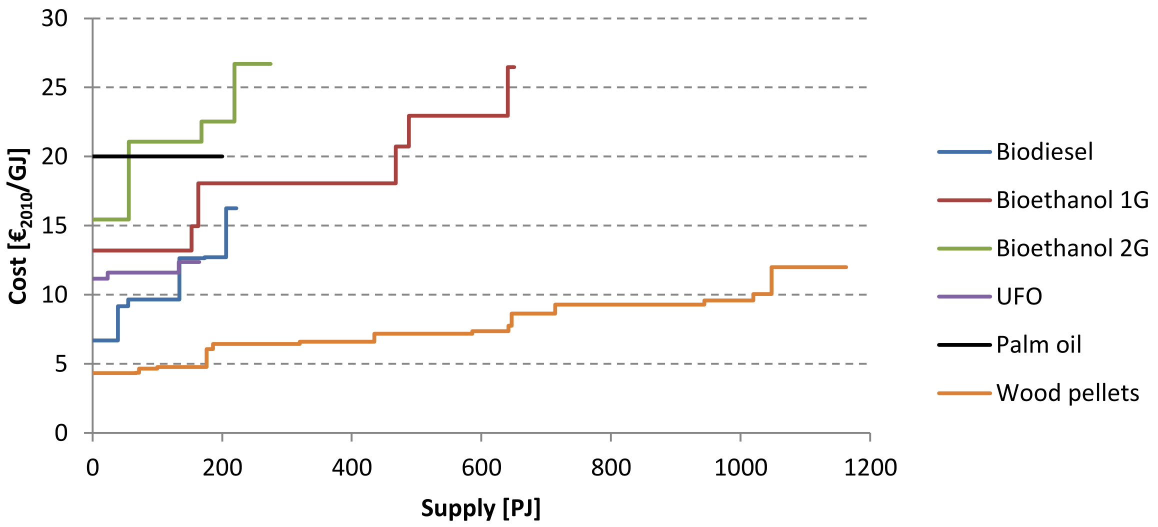


Figure 4 Cost supply curves for the imported feedstocks and biofuels for 2030.

2.3. Demand data for biobased energy and products up to 2030

Next to the biomass supply data the other most important input to ECN's RESolve-Biomass model is the demand for bioenergy and biobased chemicals. In section 2.3.1 the demand for bioenergy as specified per country and per energy carrier (heat[3], electricity or biofuels) is elaborated upon. In section 2.3.2 the overall demand for certain non-energy biobased products is specified.

2.3.1. Markets for bioenergy up to 2030

The demand for bioenergy is specified on a national level for the EU-28 Member States, as well as the other countries included in the analysis: Turkey, Moldova, Ukraine, Serbia, Kosovo, the former Yugoslav Republic of Macedonia, Bosnia and Herzegovina, Albania, and Montenegro. For each country the bioenergy demand is divided into a demand for bioelectricity, bioheat, and biofuels.

Demand projections up to 2030 are mostly taken from the Green-X model as used in the IEE project BETTER (Bringing Europe and Third countries Together through

[3] Cooling is not covered

renewable EneRgies) [9]. For the countries not included in that model their respective National Renewable Energy Action Plans (NREAPs) were used as a basis for demand projections [10]. A detailed description of the market analysis of heat, electricity and (advanced) biofuels is given in the S2Biom Deliverable 7.2a [11], [12].

In Figure 5 the demand projections between 2015 and 2030 are given in five-year increments. The figure shows the total bioenergy demand divided into the three energy carriers heat, electricity and biofuels.

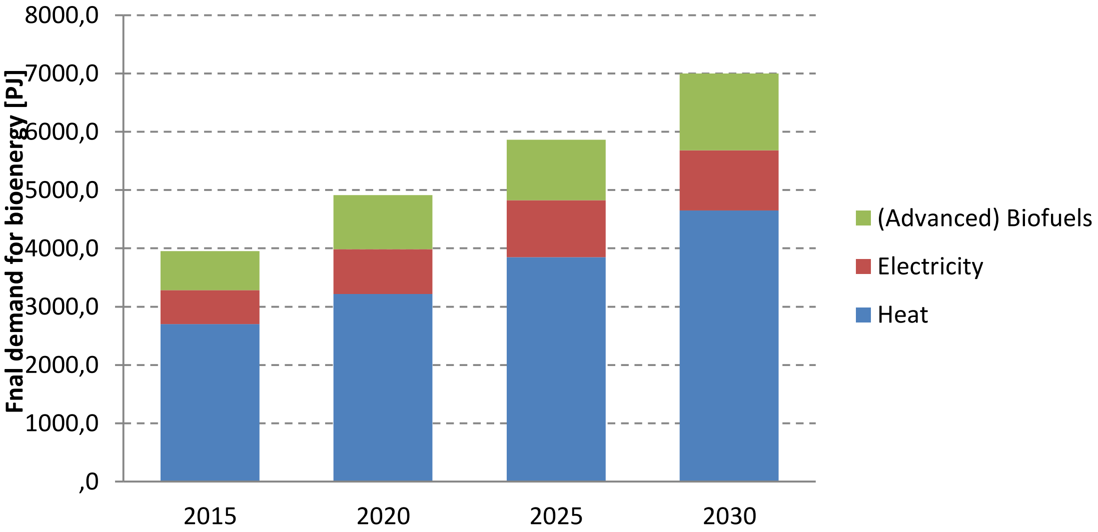


Figure 5 Final demand for bioenergy in the EU-28+ region (in thousands of PJ).

In Figure 6 the bioenergy demand of the EU-28+ region in 2030 is shown per region.

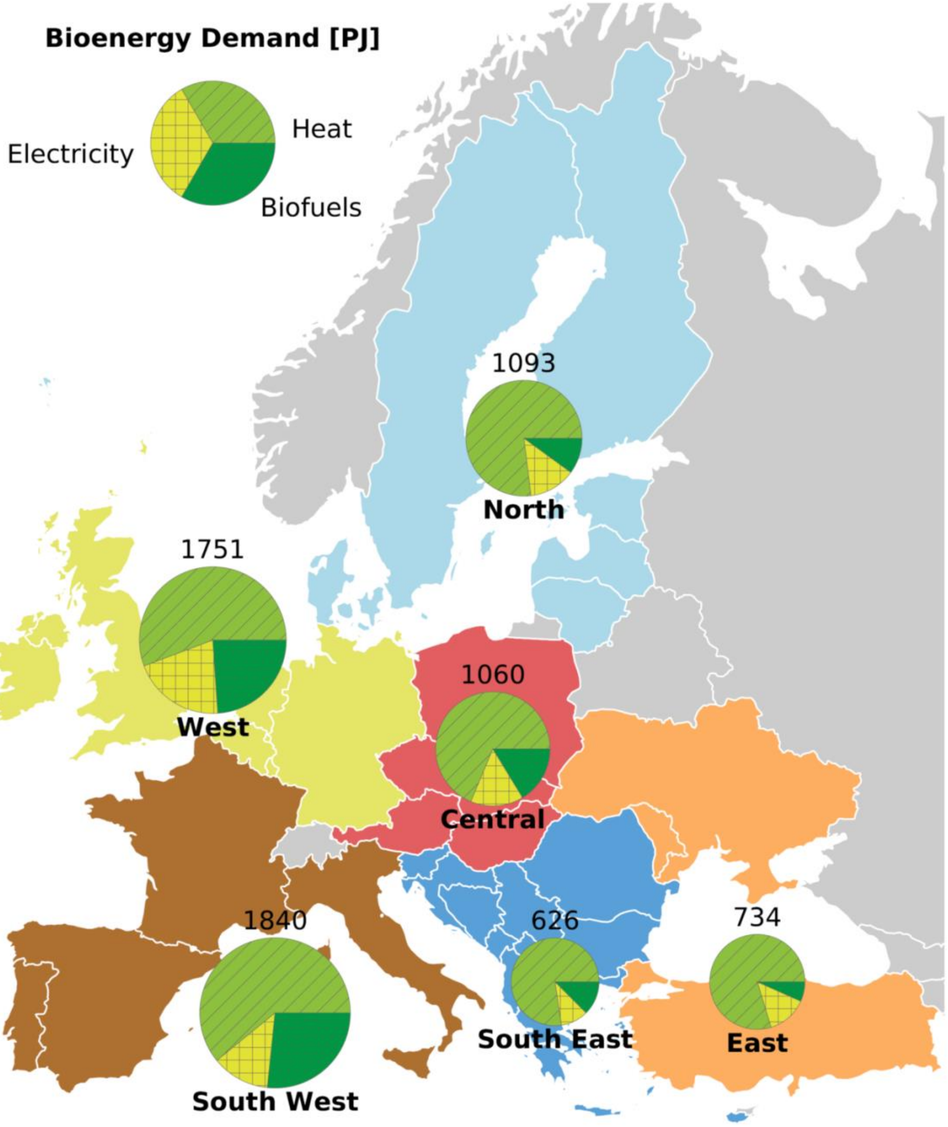


Figure 6 Total demand for bioenergy in PJ in 2030 per region.

2.3.2. Markets for non-energy sectors

The biochemicals that are included in ECN's RESolve-Biomass model are hydrogen, methane, ethylene, BTX (benzene, toluene and xylene), and PLA (polylactic acid) as a proxy for bioplastics. In deliverable 7.2b and 7.2c a detailed description of the market analysis for these biochemical, as well as their potential uses, is given [11], [13], [14].

Figure 7 and Figure 8 show the demand projections up to 2030 in five-year increments for the selection key biochemicals.

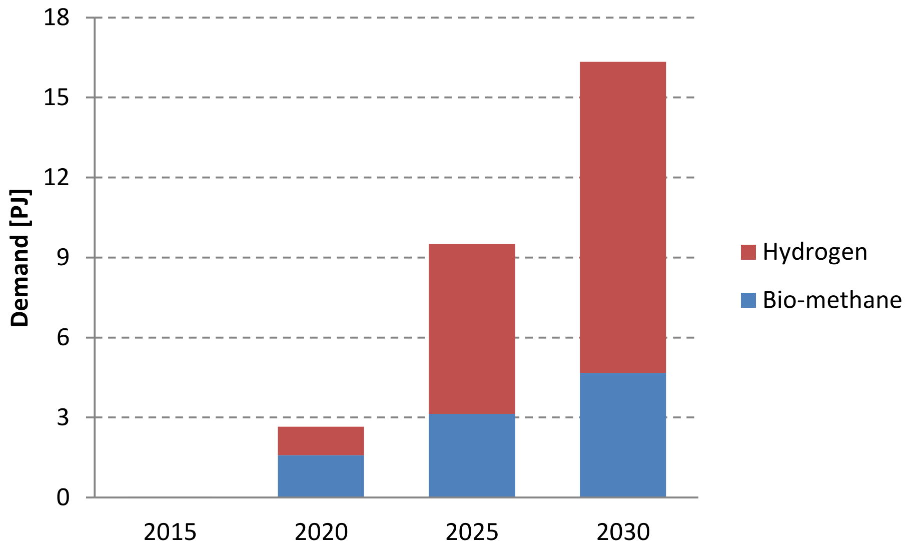


Figure 7 Demand projections for biochemicals hydrogen and methane until 2030 (in PJ).

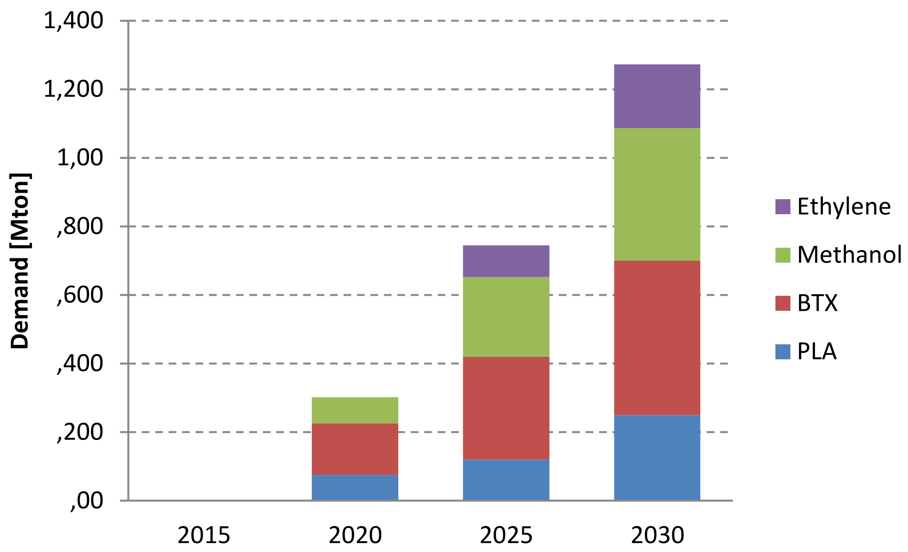


Figure 8 Demand projections for biochemicals ethylene, methanol, BTX and PLA until 2030 (in Mton).

3. Specification of scenario assumptions

Our integrated assessment of the future of lignocellulosic biomass chains includes an analysis of four scenarios. These scenarios were developed in Task 7.1, discussed within the S2Biom consortium in several meetings and were finally consolidated in D7.1. This chapter provides the key characteristics of the four scenarios that were framed along two axes (Section 3.1), and how they were translated into modelling parameters (Sections 3.2 and 3.3). Assumptions taken for several additional analyses are collected in Section 3.4.

3.1. Set-up of the scenarios

S2Biom D7.1 provides the framework of storylines and key determinants of the scenarios that will be analyzed in the project. In a conventional cross of axes, two key uncertainties have been identified (see also Figure 9):

- The availability level of (sustainable) biomass, influenced by the strictness of sustainability criteria and the level of competition for resources.
- The extent to which biobased options will produce in large-scale, centralized conversion systems, or in small-scale, decentralized units.

For the integrated assessment in WP7, these scenario axes need to be translated into (sets of) model parameters. The proposed parameters for the policy/feedstock availability axis are presented in Section 3.2, and the parameters for the central/decentral axis in Section 3.3. These axes then lead to four scenarios:

- A high-centralised scenario (HC), with relatively large feedstock availability and centralized conversion units;
- A restricted-centralised scenario (HD) with more moderate feedstock availability and centralized conversion units;
- A high-decentralised scenario (RD), with relatively large feedstock availability and decentralized conversion units;
- A restricted-decentralised scenario (RD) with more moderate feedstock availability and decentralized conversion units.

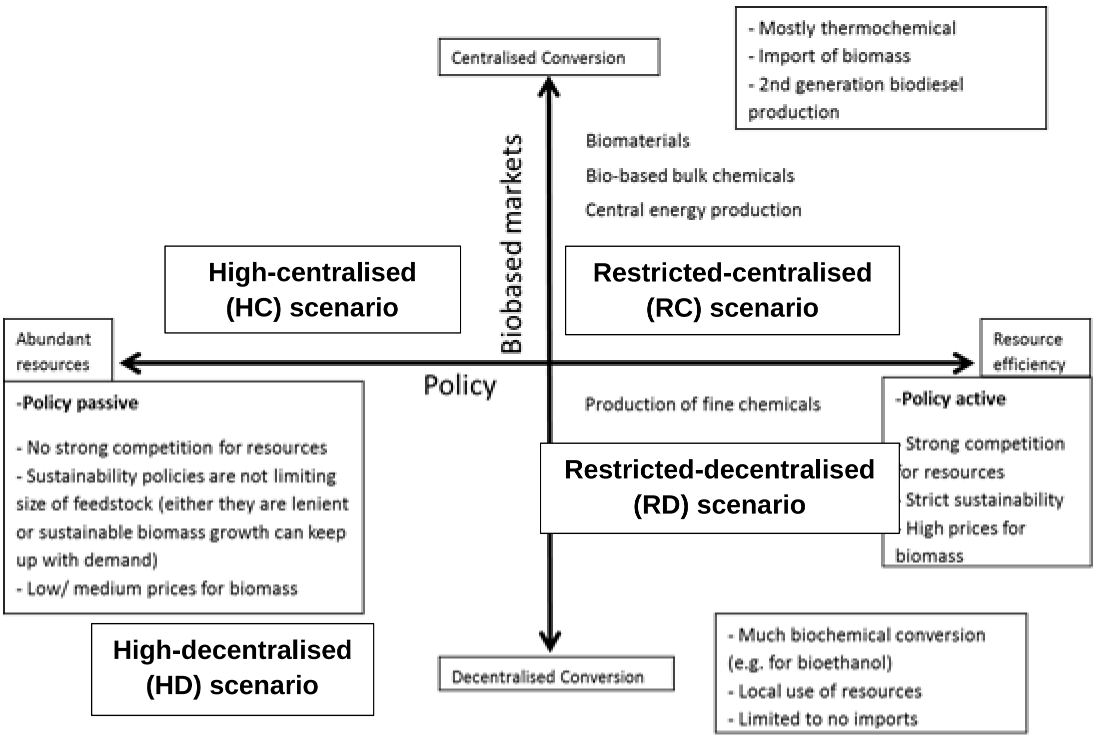


Figure 9 Scenario definitions in S2Biom D7.1.

3.2. Translation of the resource availability axis into model input

The horizontal axis in Figure 9 is determined by the policies governing biomass sustainability. On the left, in the policy passive scenario, the resource availability is assumed not to be limited by any additional policy measures and therefore to be equal to the potentials in 2.2.2. For the right-hand side of Figure 9, a coherent set of assumptions is needed on a more limited availability of feedstock. For scenarios related to this part of the figure, an active policy environment results in sustainability criteria that are stricter than today's, and corresponding restricted availability of biomass. In principle, this will result in stronger competition for resources, and corresponding higher biomass costs for meeting a given target.

For the 'resource efficiency' dataset, distinction has been made between primary biomass and primary, secondary and tertiary residues, as often defined in bioenergy feedstock reviews (see Figure 10). In this classification, the S2Biom/RESolve-Biomass types of feedstock can be grouped, as can be seen in the table in Annex III.

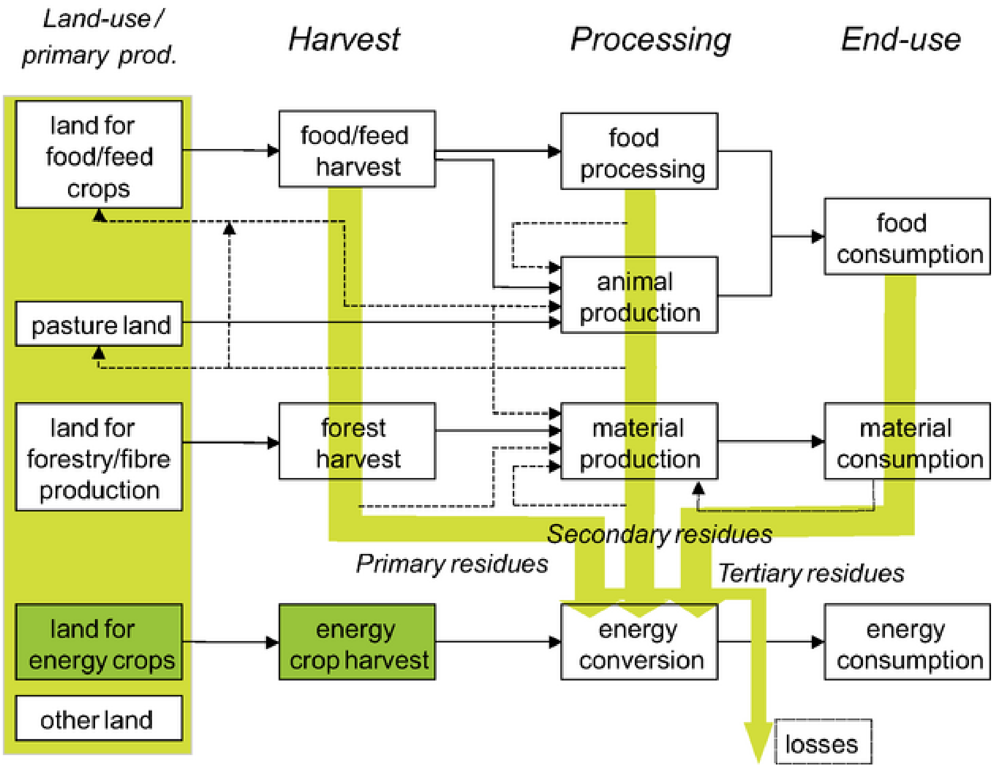


Figure 10: Biomass material flows, and identification of primary, secondary and tertiary residues [15].

For each the primary considerations for restricting availability are:

- **Primary products** are dedicated crops and other feedstocks that are cultivated for energy and/or other purposes. They have an element of direct and indirect land use change to them, and are often part of the food versus fuel debate.

- **Primary residues and side-streams** are materials that become available during harvest: think of straw, tree tops and branches, that can be left on the land and/or be collected for energy and/or other purposes. The critical question for these feedstock is how much of the residues can be extracted from the land without jeopardizing soil quality and stability (e.g. straw), and possibly carbon balance (forestry residues). This harvestable fraction is typically below 70% in forestry.
- **Secondary residues and side-streams** become available during biomass processing: think of oil seed meals, DDGS, sawdust, black liquor, bark, etc. Their availability is not directly linked to sustainability policies, but changes in demand for the prime product, and more efficient processes can affect the potential for these residues.
- **Tertiary residues and side-streams** are generated after consumption of food, feed and/or materials. Typical examples are organic wastes, the biogenic fraction of MSW, manure and demolition wood and other post-consumer wood. Also these are not directly linked to sustainability issues, but more attention for circularity and recycling, and changes in consumption patterns can influence their availability.

On the basis of the considerations above, the following ratios between the 'constrained' and 'reference' scenarios for S2Biom were determined, see Table 1. General line of reasoning behind this table is:

- Further down the production chain, sustainability issues related to biomass supply are considered less strong. Therefore, the ratio increases downward.
- Forestry-based feedstocks generally have less sustainability concerns than those related to agricultural production. Therefore, the ratios are slightly higher in the right-had column than in the left hand column.

Table 1: Proposed ratios between 'constrained' and 'reference' S2Biom scenarios, for various feedstock types.

Type of feedstock	Agricultural	Forestry/lignocellulose-based
Primary products	Annual crops: 0 Perennial crops: 0.6	0.7
Primary residues	0.7	0.8
Secondary residues	0.8	0.9
Tertiary residues	0.9	1

For more information on the considerations taken into account, see D.7.1 [16].

3.3. Translation of the (de)centralized scenario axis into model input

The vertical axis in Figure 9 distinguishes futures in with the focus of biomass conversion technologies either is on large-scale centralized units or on more decentralized units of moderate scale. This axis thereby describes the ongoing debate whether the benefits of larger conversion plants that reap economies of scale outweigh the disadvantage of longer transportation distances of the biomass feedstock needed. Therefore, two underlying data were split to create these axis extremes:

- The dynamics of technological learning
- Fossil fuel prices, as a proxy for logistics costs.

3.3.1 Technological learning

The speed of cost reductions realized due to technological learning is inherently uncertain, and this has been used to distinguish among the axis of the scenarios. Technological learning in ECN's RESolve-Biomass model is based upon technological learning as described in De Wit et al. [17]. It was already present in the model for the conversion technologies described the same article. For the purpose of using the RESolve-Biomass model for the S2Biom project this feature of technological learning has been reinstated in the model and expanded to several other conversion technologies, which include large-scale, advanced bioenergy conversion technologies, and processes for biochemical production. A list of technologies selected for technological learning can be found in Table 2.

In RESolve-Biomass two types of technological learning have been implemented:

- The market-driven learning (or experience) curve is an empirical causality that expresses the decline in cost per unit as cumulative production grows. This empirical rule usually includes all factors causing cost reduction: scale effects, risk reductions, other efficiency improvements, etc. The progress ratio is the rate of cost decline for every doubling of cumulative production. The market driven learning is parameterized by the progress ratio.
- Purely scale-dependent learning focuses only on technologies' ability to grow in scale and thus benefit from economies of scale. The scale factor is used to describe the relationship between the ratio of future to current scale versus future to current cost. A minimum doubling time of cumulative production is used to distinguish between scenarios.

For technologies that are already in the market for considerable time, i.e. conventional 'first generation' routes to ethanol and biodiesel, a learning curve approach was used, with empirical progress ratios. For relatively novel technologies that only have small volumes in the market, learning effects were primarily calculated through scale effects with corresponding scale factors. For full details see De Wit et al. [17].

Faster technological learning has been allowed for the two scenarios that favour central biomass use, such that the large-scale scenarios will see cost reductions faster in this scenario. A higher rate of technological learning is characterized by lower progress ratios and a lower minimum doubling time. On the other hand, in the decentral scenarios the slower possible cost reductions in the large-scale, advanced technologies will favour more local solutions to biomass use. This end of the axis is characterized by higher progress ratios and longer minimum doubling time of cumulative production.

Table 2 List of processes included with technological learning feature. The newly added conversion technologies are in italics.

Conversion processes	Market-driven learning	Scale-driven learning
Biomass IGCC	X	X
Cellulose-EtOH	X	X
DME production	X	
Ethanol+PLA production	X	X
FT production	X	X
Gasification for BTX and SNG production	X	
Gasification for hydrogen production	X	
Gasification for methanol production	X	
HEFA-HRD	X	
HEFA-HRD using UFO	X	
HTL-D	X	X
Indirect gasification for SNG production (transp.)	X	
Pre-tr. (TOP)	X	X
Starch-EtOH	X	
Sugar-EtOH	X	
Transesterif-oil seed	X	
Transesterif-palm oil	X	
Transesterif-used-fat	X	
Upgrading of biogas for Transport	X	

Technological learning was added to the model for different conversion technologies. For bioenergy purposes (excl. biojet-related fuels) the added technologies are biomass IGCC, Fischer-Tropsch fuel (FT) production, and indirect gasification. Indirect gasification was assumed to experience similar growth to the other gasification conversion processes, which experience their scale-driven cost reduction through the growth of torrefaction. Biomass IGCC and FT were assumed to be similar to dimethyl ether (DME) production. Also biofuels created using HEFA (hydro processed esters and fatty acids) and HTL (hydrothermal liquefaction) were added.

The biochemical conversion route that was added to the technological learning procedure is ethanol+PLA production, as the gasification routes were already included and ethylene from ethanol conversion is a mature technology, such that little technological learning is expected. The same parameters were assumed for ethanol+PLA production as for FT production. In Table 2 the list of conversion processes that experience technological learning is included, with the newly added conversion technologies in italics.

3.3.2 Fossil fuel, CO_2 and electricity prices

As a proxy for the counter-effect to scale effects, i.e. the increasing costs of biomass logistics[4], fossil fuel prices were varied between the scenarios as well. As transportation costs for all transport modes in the model are dependent on these prices, this parameter directly affects logistics costs[5].

Fossil energy prices for the decentralized and centralized scenarios are given in Figure 11.

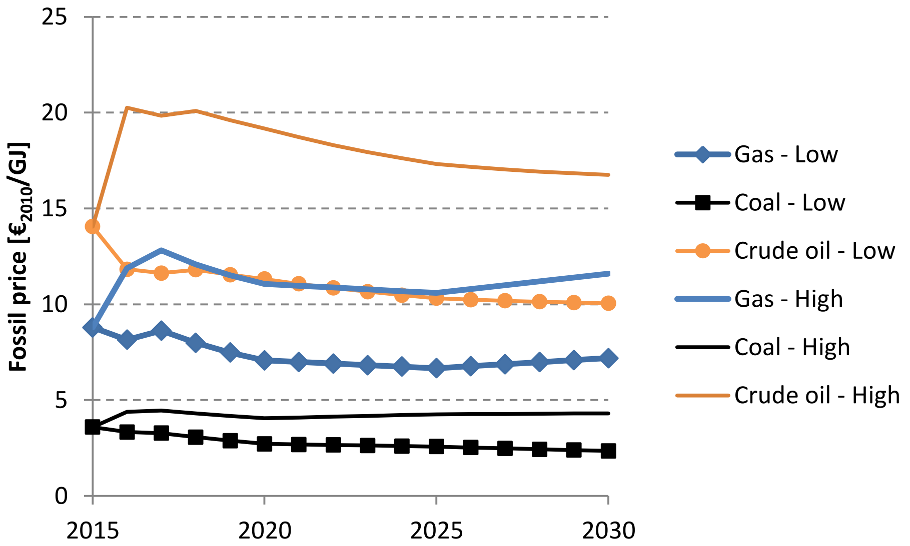


Figure 11: Assumed fossil fuel prices in the centralized (low prices) and decentralized (high prices) scenarios.

The prices of the fossil fuel energy carriers are determined by taking the values from PRIMES Reference scenario 2013 [18] as central values. To determine the high and

[4] As biomass needs to be sourced from a larger area in case of larger scale installations

[5]: Note that changes in fossil energy prices also directly affect the competitive edge of biobased energy and material options in general, as they have to compete against reference technologies mostly based on fossil oil and gas. This dynamic was not taken into account here; fossil energy price changes were merely taken as an easy-to-implement parameter in the model to coherently change logistics costs.

low values, upper and lower band widths have been applied. Those band widths are taken from Dutch National Energy Outlook 2015 [19] and are based on different scenario from the World Energy Outlook 2014 [20][6].

A bandwidth was not applied to CO_2 prices since it does not fit well with the rationale of the scenario axes. CO_2 prices have been taken from the impact assessment [21].

Country specific wholesale electricity prices have also been used as an exogenous input to the RESolve-biomass model. Values have been calculated using the electricity market model COMPETES [22]. For electricity high and low values have been calculated using the fossil energy prices as given in Figure 11. The CO_2 prices as decribed above were used in COMPETES.

3.4 Additional analyses

Next to the scenario assessment, several other variants and questions were put up for additional analysis with the model. These were:

1. 'Lock-in analysis': what is the effect of the fact that standing capacity competes on variable costs basis against new investments that calculate with full costs? In this variant, standing capacity costs were also set at full costs. Furthermore, a constraint on the rate with which standing capacity can be phased was relaxed, meaning that, in principle, standing capacity can be phased out directly.
2. The effect of biochemical options on biomass marginal costs: to what extent does demand for biobased chemicals affect the marginal costs of various biomass feedstocks? To this end, a run was made without demand for biobased chemicals.
3. The effect of bioenergy demand on biomass marginal costs: comparably, a run was done in which bioenergy demand was set to 50% of default values.
4. The impact of earlier introduction of advanced biofuel technologies on technology deployment and costs: to this end, we made a run with a three years earlier introduction year for advanced biofuel routes.
5. Effect of improved mobilization of biomass. In the default runs, the growth of feedstock use is constrained by specific boundary pathways (see Figure 12). In an 'improved mobilization of biomass' variant, the constraints for feedstock deployment were released, mimicking a situation with very active biomass mobilization policies.
6. A combination of 1 and 3: lower bioenergy demand and less lock-in effects.

[6] Although S2Biom is an European project, band widths for fossil fuel prices have been taken from the *Dutch* National Energy Outlook because this appeared to be a deliberate and consistent band width to the authors, based on international best-in-class source material.

7. Capital cost analysis: what happens if we use a lower weighted average costs of capital in the model (4% versus the normal 7-8%)
8. What if food-crop based biofuels are forced to be phased out or significantly reduced by 2030? This option, currently also under discussion in Brussels, shows quite different technology development and system costs.

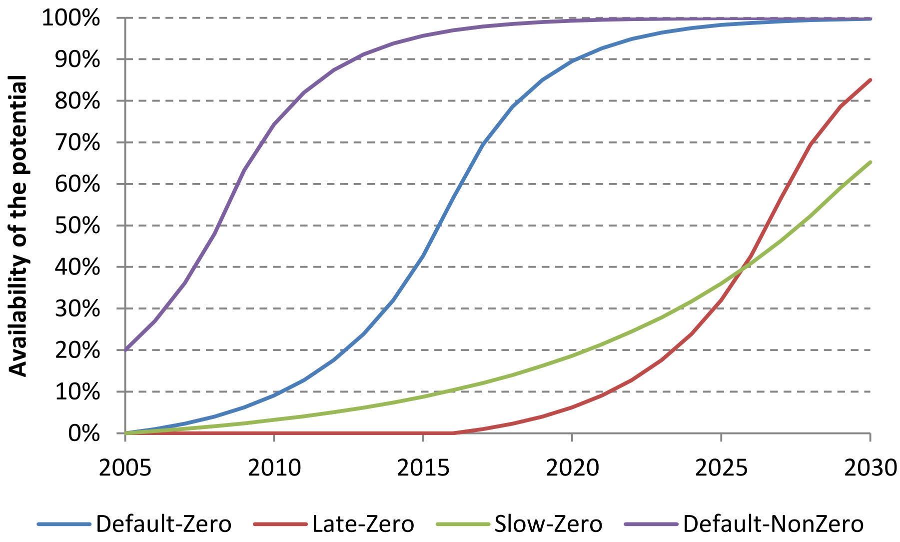


Figure 12: Various variants of potential constraints, applied to feedstock availability EU-domestic and imports, conversion capacity and no of adapted engines.

4. Results and discussion

This section provides the key outcomes of the assessment. It consists of:

- Key general outcomes that are consistent throughout the scenarios (4.1)
- Insights from comparing the high and restricted feedstock scenarios (4.2)
- Insights from comparing the centralized and decentralized scenarios (4.3)
- Further insights from additional analyses (4.4)

4.1. Common outcomes across all scenarios

Regarding feedstock consumption and imports, general observations are:

- The effect of feedstock restrictions and the dynamics of technological learning and the fossil fuel prices introduced in different scenarios is very limited on the amount and the mix of primary biomass feedstock consumed.
- Among the feedstocks, SRC on arable land and manure are the two feedstocks most affected when the restrictions are introduced to the biomass potentials. Next to that high transport costs in decentralized scenarios result in more use of these feedstocks for instance for local heating in industry.
- Restricted scenarios, indicated by capital R, result in more import in both absolute and relative terms: R scenarios importing around 1700 PJ, contributing to around 19% of the total feedstock consumption and High scenarios, indicated by capital H, importing around 1200 PJ, contributing to around 12-13% of total biomass consumption.
- The unused potentials are large in all scenarios indicating the vast availability of domestic resources.

Regarding technology diffusion, key points are:

- Results show no fundamental impact on the technology diffusion between Central or Decentral and High or Restricted biomass scenarios. Partly, this is due to high sunk costs in each sector and thus the technology lock in effect (see also Section 4.4.1).
- Biomass co-firing in coal fired power plants becomes less attractive in decentralized scenarios as higher fossil fuel prices increase the wood pellet transport costs. As a result, wood pellets are used more in CHP or local heat boilers.

On the point of Intra-EU trade:

- The effect of central vs decentral scenarios on intra-EU trade is relatively small. In the Restricted scenarios smaller trade volumes of wood pellets can be observes as each region needs more of its own potential.

Regarding total system costs:

- Both restricted and decentralized scenarios result in marginal costs that are in general around 10% higher than Central and High scenarios. Only wood chips, biomethanol & biohydrogen (both for chemical sector) show higher than 35% marginal cost increase when Restricted (Central) scenario is compared with the High (Central) scenario.
- Overall system costs is the lowest in the HC scenario and the highest in RD scenario. Though the difference between the two extremes is only 10%.

Regarding the role of biobased chemicals:

- The impact of the demand from chemicals for lignocellulosic biomass on bioenergy sector is small. The total additional amount of biomass needed to fulfill the demand for biochemicals is only 1-1.5% of the amount needed for the bioenergy demand. As such the effect on marginal costs of bioenergy, wood chips and pellets is also small.
- While the demand from the chemical sector for lignocellulosic biomass has limited/negligible effects on bioenergy, we can't conclude the other way around.
- In general, the cost competitiveness of biochemical is more determined by the price of fossil energy carriers than by the competing demand for biomass from the bioenergy sector, but both effects add up. Results indicate that marginal cost of PLA, methane, hydrogen and ethylene can decrease if bioenergy demand is lowered. PLA could be cost competitive also with a high demand for bioenergy in case of a high fossil energy price (see Figure 11). With a low demand for bioenergy its prospects are better.

Regarding biofuels:

- Market roll out of advanced biofuels up to 2030 is very limited: at most a 7% share in the total biofuel mix in 2030 in the HC scenario. In absolute terms around 90 PJ.
- Even when they are introduced three years earlier than in the reference situation, the market roll out is not affected (see Section 4.4.4).
- It is very unlikely to abandon food based biofuels without scarifying biofuel ambitions even on the basis of our assumptions regarding e.g. maximum deployment of new technologies and feedstocks.
- It is possible to limit the amount of food-crop based biofuels; in our analysis, still 1.5% of crop-based biofuels would be needed by 2030 (as a share of the total demand for fuels for road transport).

4.2. Comparing the high and restricted feedstock scenarios

This section analyses the modelling results of the high and restricted feedstock scenarios. The analysis consists of the comparison of the two scenarios in respect to:

- Resource exhaustion and the role of imports;
- The technology diffusion;
- System costs aspects.

We focus on the centralized variant to enable consistent comparison throughout the section.

4.2.1. Resource exhaustion and the role of imports

Figure 13 presents the modeling results of the biomass consumption in comparison to the total biomass potentials for the High Central (HC) and the Restricted Central (RC) scenarios. The results are illustrated for different regions (See Annex II for an overview of country grouping in regions).

- Among the regions East (mainly in Ukraine), South West (i.e. countries like Spain and France) followed by North (i.e. Finland and Sweden) hold the highest lignocellulosic biomass potential.
- In contrast to the very high potential, the East region has the lowest consumption of lignocellulosic biomass feedstocks when compared with the other regions. In 2030 only 26% of the potential is consumed in the HC scenario; it is 45% in the RC scenario. This low utilization rate relates to the relatively low bioenergy policy ambitions in the region.
- The highest biomass consumption occurs in the North region, both in absolute and relative terms. While the lignocellulosic biomass consumption in the HC scenario is 72% of the region potential, it increases to 84% in the RC scenario. This illustrates both the large resource base in this region and the strong ambitions to use it for sustainable energy purposes.
- For the other regions the utilization rate is between 58%-65% in the HC scenario, increasing to 67%-75% in the RC scenario in 2030.

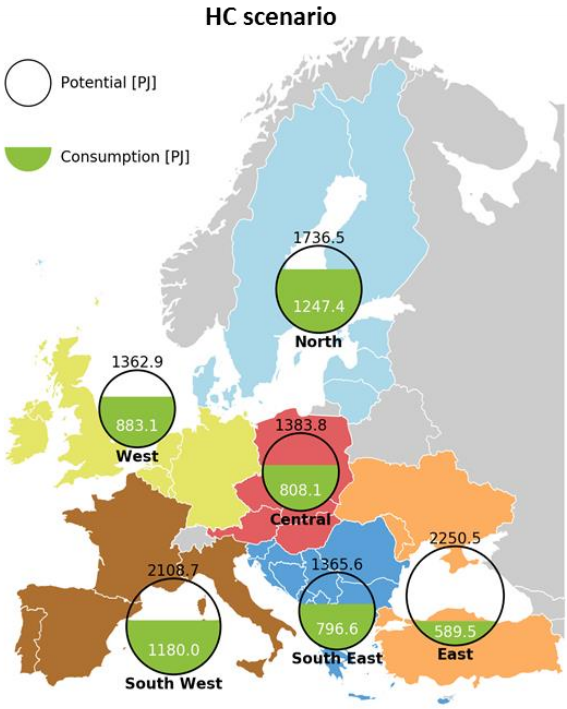


Figure 13 Lignocellulosic primary domestic biomass potential and the consumption amounts (including trade) for the HC and RC for the 6 regions in Europe.

Biomass and biofuel import

Modelling results indicate that in total slightly more than 9 EJ of primary biomass is used in 2030 in the HC scenario. This amount is only 2% lower in the RC scenario. In absolute terms the HC scenario consumes approximately 200 PJ more primary biomass than the RC. This illustrates that a limitation of feedstock availability does not induce a shift towards more biomass-efficient chains. Obviously, this relates to cost aspects as well, see section 4.2.3.

Figure 14 illustrates the breakdown of the primary biomass consumption into domestic and imported biomass in 2020 and 2030 in the HC and the RC scenarios. As can be seen the figures are quite comparable in 2020. However, in 2030 restrictions in feedstock potentials result in more import of wood pellets and biofuels rather than further utilization of domestic feedstocks

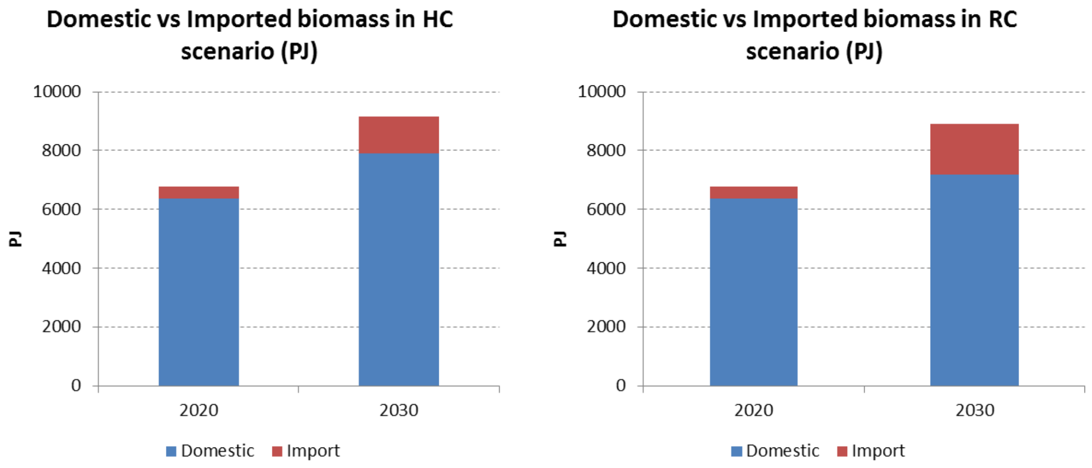


Figure 14 Consumption of domestic biomass in Europe and imported biomass from outside of Europe for the HC and the RC Scenarios

Figure 15 shows the changes in imports between both scenarios in more detail.

- One of the differences between the HC and RC scenario relates to higher bioethanol import (in the RC scenario 40% higher import of bioethanol is observed when compared to the HC). This is due to the restrictions introduced in the RC scenario. In this scenario land based biomass feedstocks are reduced to zero.
- Another difference is the amount of wood pellet imports. While palm oil and the UFO imports are equal in both scenarios, the wood pellet import in the RC scenario is two times the HC scenario.

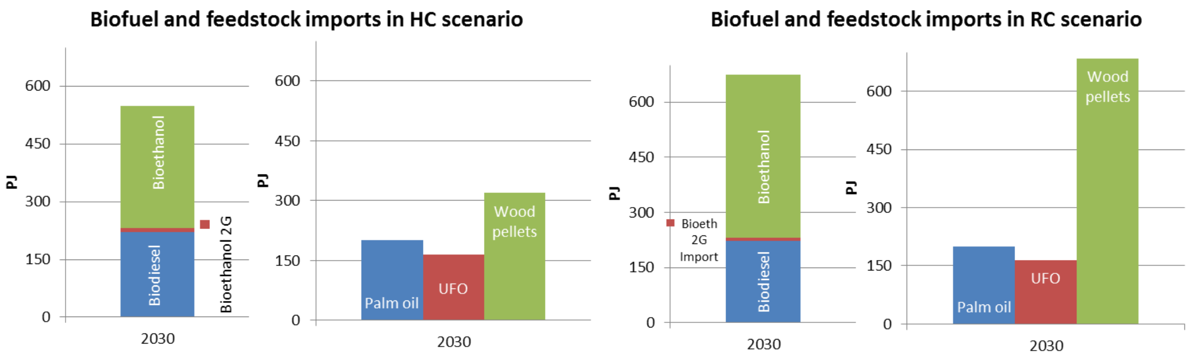


Figure 15 Imported biomass and biofuel consumption in the HC and RC scenarios

Figure 16 and Figure 17 illustrate the wood pellet and wood chip imports to the EU and the net trade within the EU regions.

- In terms of intra-European trade, the RC scenario generally shows smaller trade flows between the European regions, as illustrated in Figure 16 for wood pellets. This is because each region needs more of its own potential to meet the given objectives.

- The volume of wood chips trade among the regions is relatively small compared to the wood pellets and the RC scenario generally shows smaller trade flows between the regions (see Figure 17).
- The North region is the main net supplier of wood pellets and chips to the other regions: a large amount of wood pellets going to the West and a large amount of wood chips going to the Central region.

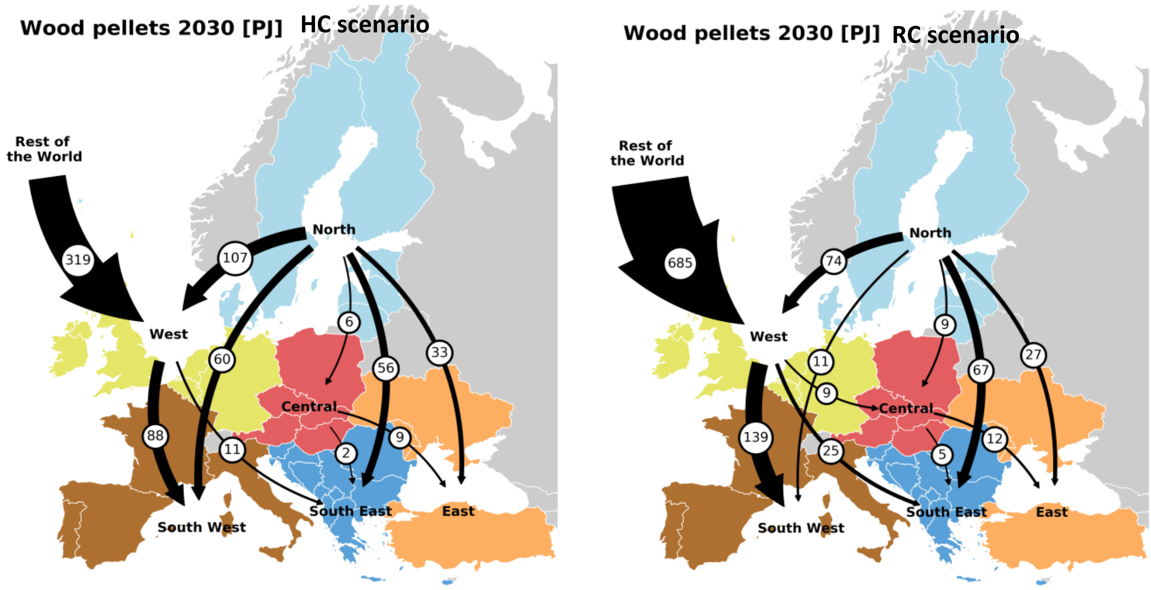


Figure 16 Wood pellet imports to EU and net trade among the regions

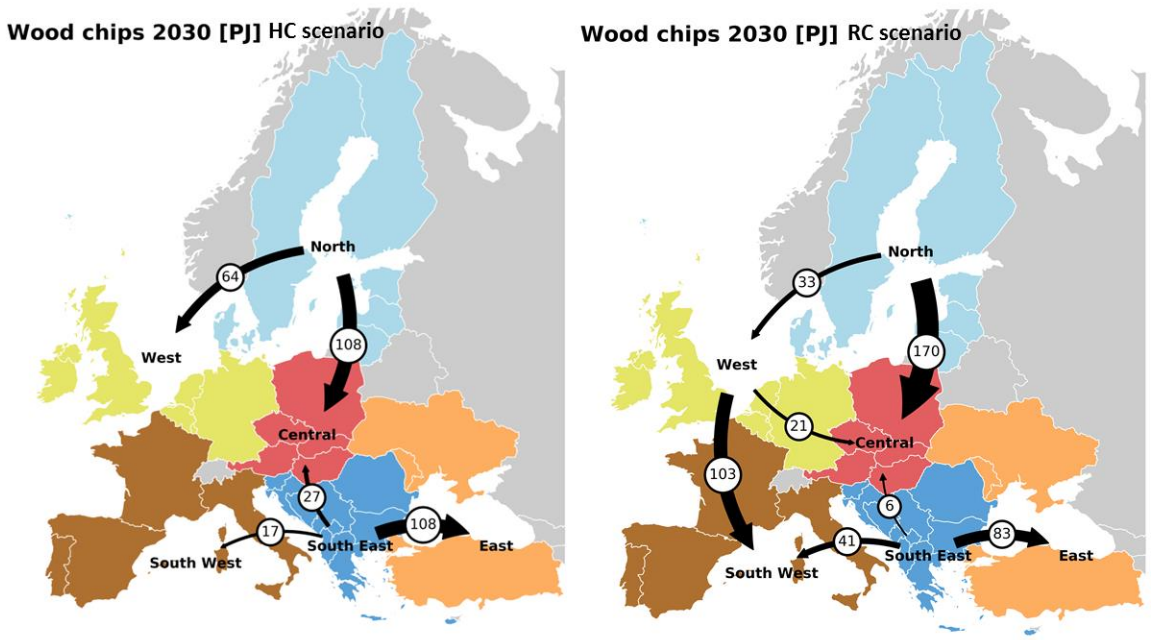


Figure 17Net trade of wood chip within the EU in 2030 for the HC ad the RC scenarios

Domestic biomass consumption

Almost 8 EJ of domestic biomass is used in 2030 in the HC scenario. This corresponds to slightly over 50% of the total domestic biomass potential. In the RC scenario the domestic feedstock consumption is 700 PJ lower than the HC scenario and almost 70% of the domestic biomass potential is consumed in 2030.

Figure 18 illustrates the modelling results of the domestic biomass consumption in comparison to the remaining/unused potential.

- The unused domestic potential is very significant in the HC scenario, almost 7 EJ in 2030. The unused potential in the RC scenario is over 3 EJ.
- Up to 2020 the type and amount of the feedstocks consumed stay the same in both scenarios. Beyond 2020, however, there is a shift towards more use of SRC, energy grasses & perennial crops and manure in the RC scenario (25% higher energy grasses and non-wood perennial crops use; more than 400% higher SRC use and around 200% higher manure use can be observed in the RC scenario when compared to the HC scenario).
- Increased amount of imports and the shift towards above mentioned feedstocks result in reduced use of stem wood, primary forestry residues, other wood processing industry residues, landscape care (both woody and grassy) in 2030.

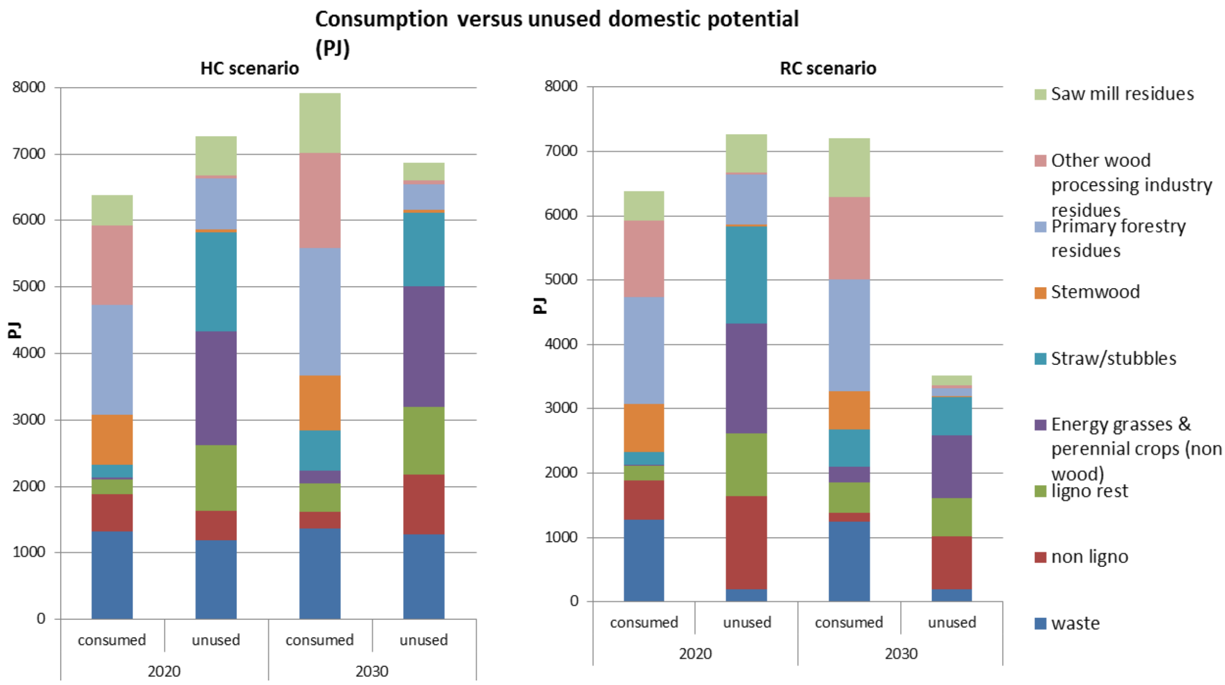


Figure 18 Domestic biomass feedstock consumption and unused potential in 2020 and 2030 according to HC and RC scenarios

4.2.2. Technology diffusion: dependence on feedstock availability

Figure 19 illustrates the dominant role of heat sector, particularly the bioheat in industry when compared with the other sectors.

CHP plays an important role both in heating and the electricity sectors. According to the modelling results more than 80% of the bio-electricity and more than 30% of the bioheat are produced through CHP in 2030[7] both in the HC and the RC scenarios.

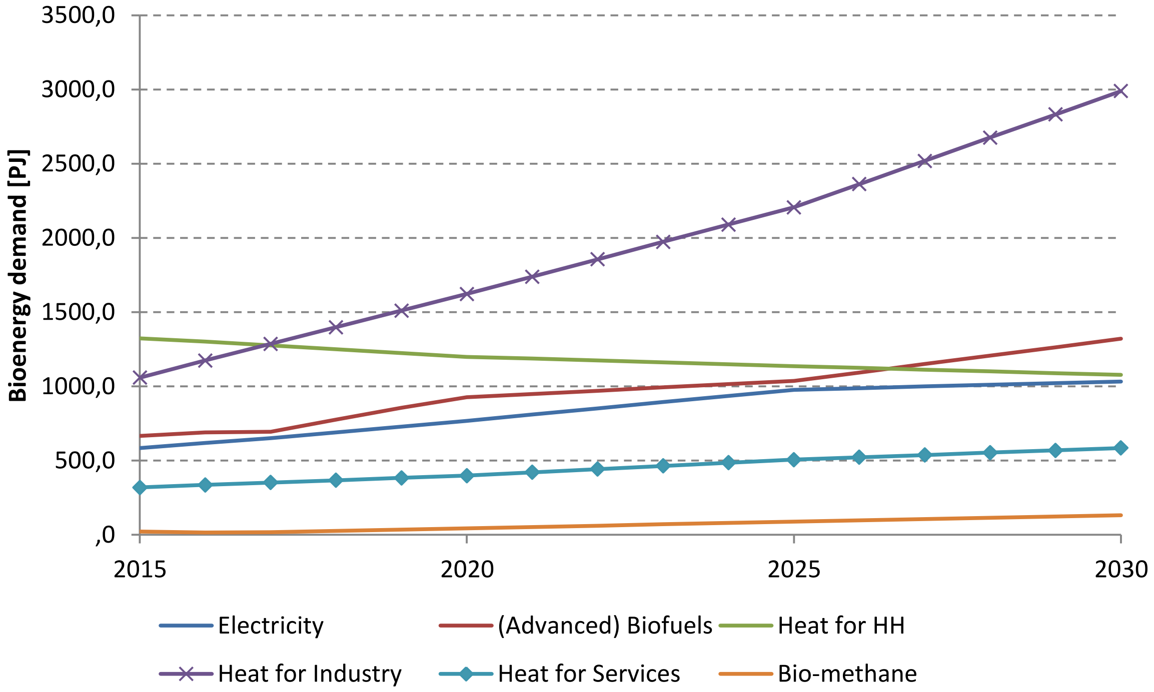
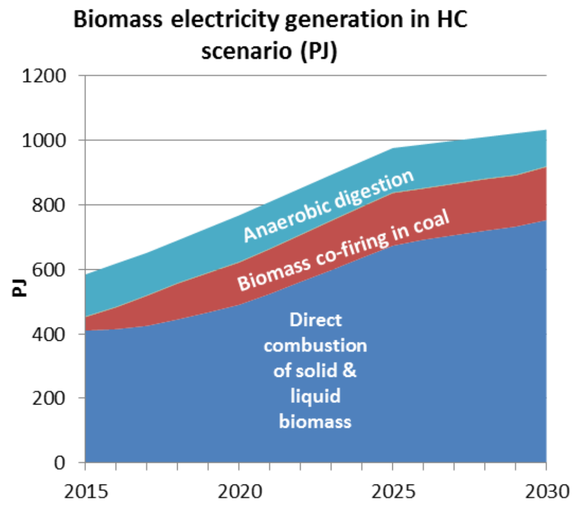


Figure 19 Bioenergy demand for the sectors electricity, heat (for industry, service sector and household (HH), (advanced) biofuels and biomethane up to 2030 for the HC and the RC scenarios.

Electricity and Heating & Cooling

In both HC and RC scenarios direct combustion of solid biomass plays the major role, comprising more than 80% of the total bio-electricity generation in 2030, see Figure 20. The main difference between the two scenarios is the role of biomass co-firing in coal fired power plants, which is slightly reduced in the RC scenario. The use of wood pellets, the main feedstock for co-firing, shifts to CHP application in the RC scenario due to higher total efficiency of CHP systems.

[7] CHP in RESolve-Biomass is modelled in a simple way: there is a yearly heat and a yearly power demand. CHP can contribute in providing heat and power. There is no hourly (or seasonal profile).



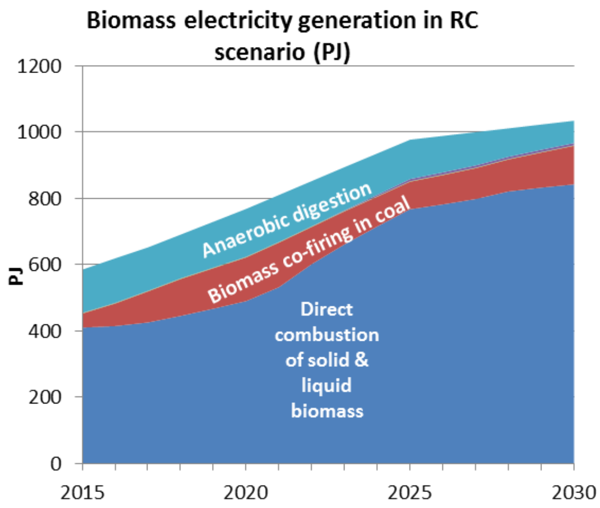


Figure 20 Electricity production from biomass resources for the High Central (left side) and the Restricted Centrale (left side) scenario according to RESolve modelling

Figure 21 illustrates the heat generation of the HC and the RC scenarios up to 2030. It also specifies the types of conversion technologies deployed in each scenario.

Results indicate that the restrictions in feedstock supply don't affect the technology portfolio in the heat sector in the time frame 2015-2030. Direct combustion of solid and liquid biomass continues to supply heat demand to households, industry and service sectors. Other technologies such as anaerobic digestion, fast pyrolysis and gasification represent less than 1% of the total heat generation from biomass resources in both scenarios.

Among the direct combustion technologies, CHP followed by the "waste combustion – heat only" option play a significant role both in the HC and the RC scenarios. In the HC scenario, in 2030, the biomass input to the "waste combustion-heat only" is as follows: 55% MSW, 40% black liquor (note that this formally is a secondary residue from woody biomass processing in paper production) and 5% verge grass. All MSW in Europe is consumed of which 95% is used by these waste combustion – heat only processes (for assumptions regarding recycling see the detailed reports in S2Biom WP1 at www.s2biom.eu). These figures indicate the importance of MSW combustion for heat among the bio-energy sectors.

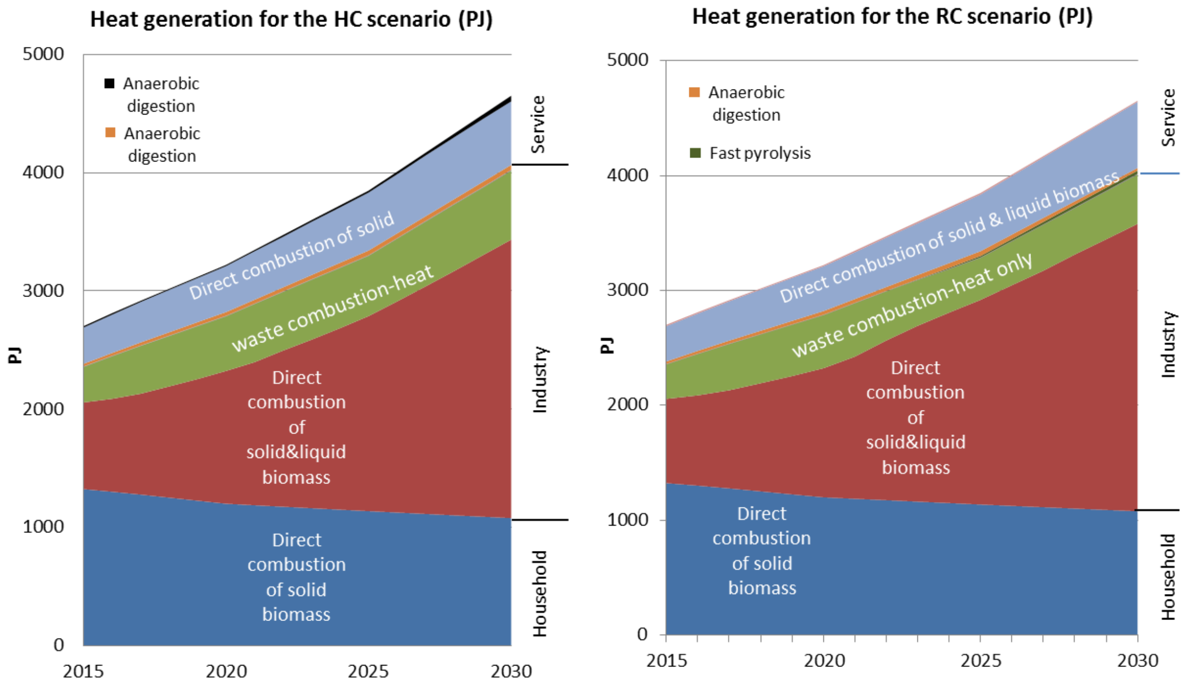


Figure 21 Heat generation modelling results for the HC and RC scenarios

The high level of sunk capital investments and the slow rate of replacement in these sectors (both electricity and heating & cooling) result in continuation of the same path, possibly compensating the domestic feedstock restriction with imports.

Biofuels

Figure 22 and Figure 23 illustrate the modelling results of the biofuel consumption, broken down into the types of biofuels. Figure 23 also differentiates the imports and the domestic production – the patterned ones being either imported biofuels or biofuels derived from imported feedstocks such as palm oil and UFO and the solid colored ones being domestically produced and consumed biofuels.

In both scenarios the role of advanced lignocellulosic biofuels is very small, also in the RC scenario, indicating the need and the urgency of additional policies to facilitate the market roll out advanced biofuels. From the results we can conclude that:

- Restrictions in food crop based feedstocks (the 7% cap) don't push the advanced technologies that can use other feedstocks.
- Import of biodiesel, palm oil and UFO stay equal in both scenarios in 2030.

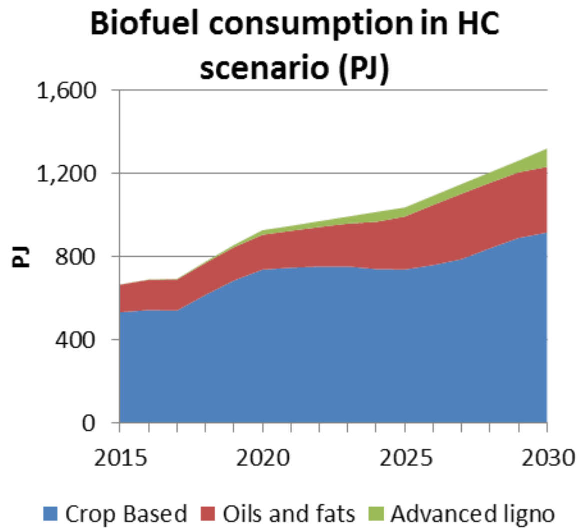


Figure 22 Biofuel consumption in HC and RC scenarios broken down to crop based, advanced and oil and fats

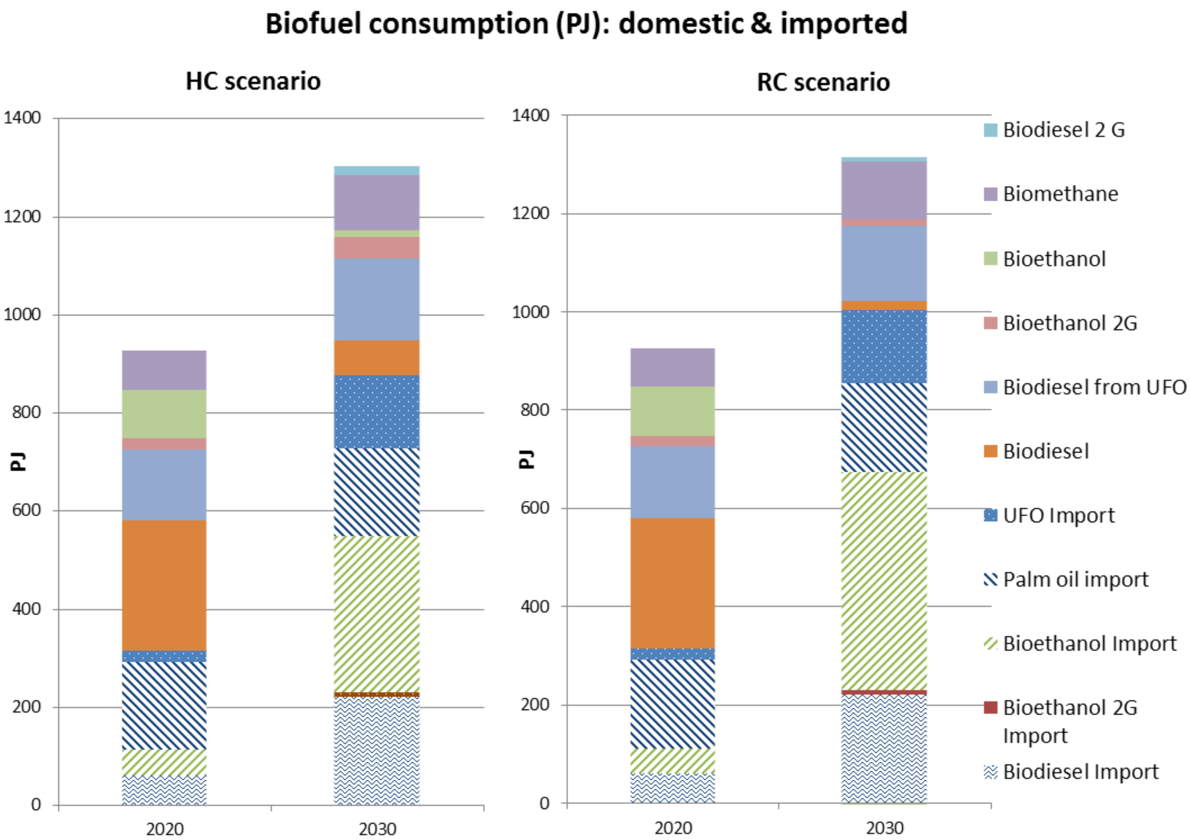


Figure 23 Biofuel consumption: domestic and imported biofuels in the HC and RC scenarios

Biobased chemicals

As already shown in the S2Biom demand assessment [11], the demand for biobased chemicals is relatively small when compared with the bioenergy demand. As such, biomass supply restrictions applied to the RC scenario don't affect the production of bio-PLA, bio-BTX, biomethanol, biomethane and biohydrogen as presented in Figure 24.

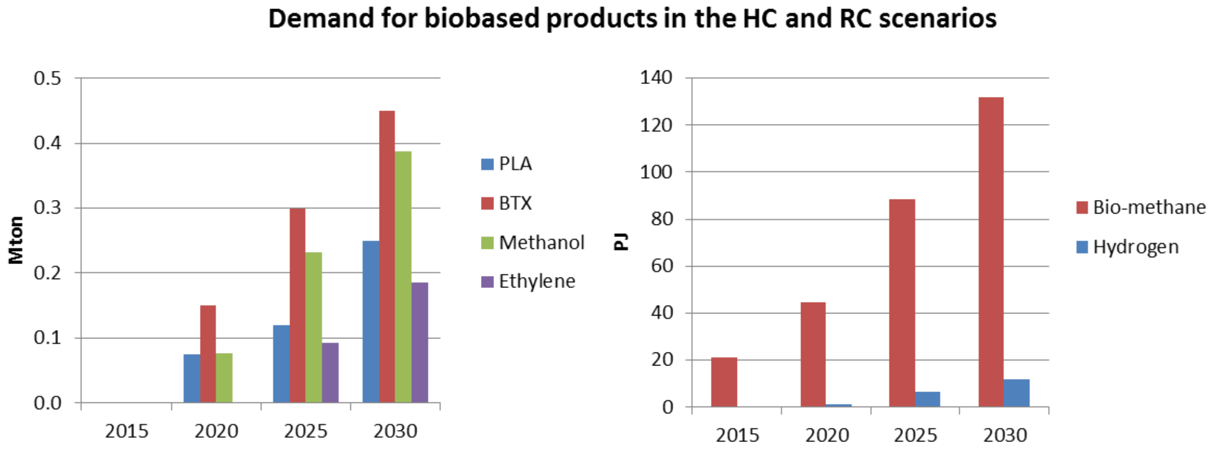


Figure 24 Generation of biobased chemicals according to the HC & RC scenarios

4.2.3. System costs aspects

For the costs analysis we reviewed to cost elements: Marginal generation costs and total costs.

Marginal generation costs

Figure 25 and Figure 26 present the marginal costs of several commodities for the HC and the RC scenarios. The general trend is that marginal costs of the RC scenario are higher than the HC scenario costs. Restrictions in biomass potentials cause this cost increases in the RC scenario.

Among the different categories wood chips followed by Bio-BTX, biohydrogen, biomethane experience more than 25% increase in marginal costs. This relates to the feedstock potential restrictions introduced in the RC scenario. The marginal costs of wood pellets are affected less due to relatively cheap wood pellet imports from outside the EU. Wood chips costs, however, increases around 35% due to feedstock potential restriction.

The large difference between the marginal costs of biodiesel and bioethanol indicate a possible shift to more ethanol consumption from 2030 onwards. This may result in blending wall issues in Europe. The figures also indicate that 2G ethanol could actually enter the market, while 2G biodiesel will still be too expensive.

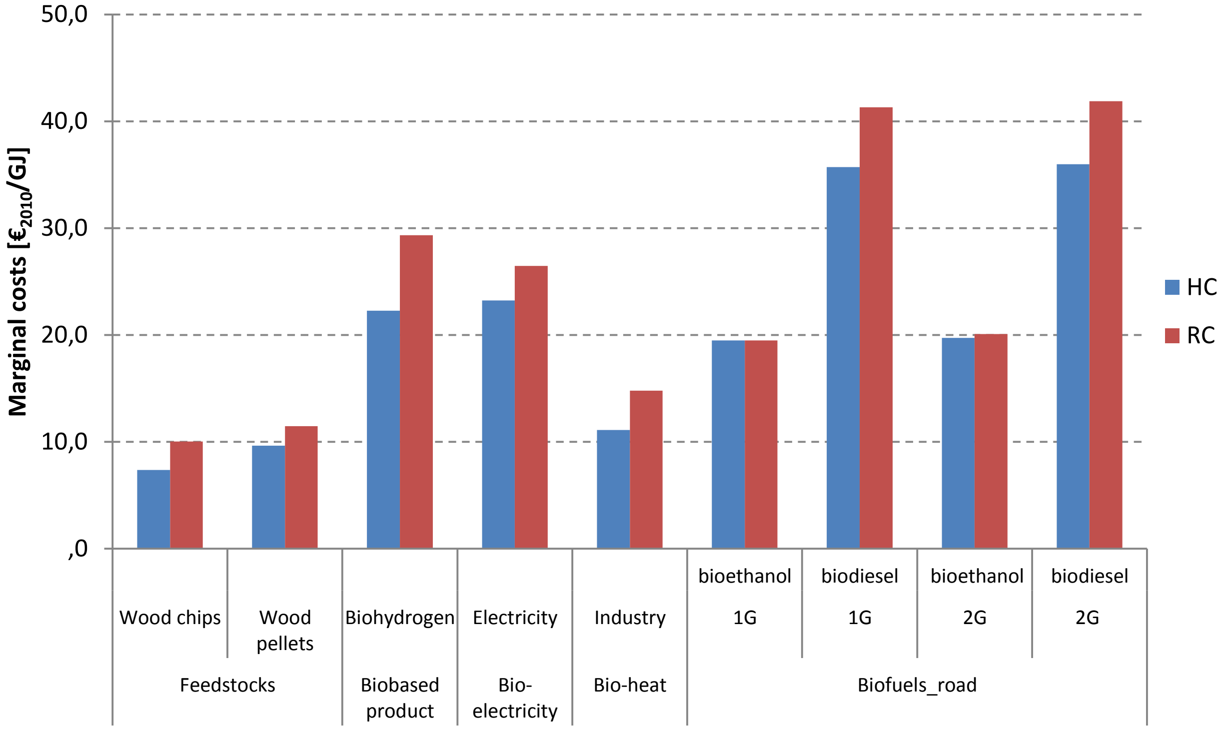


Figure 25 Marginal cost comparison of the HC and the RC scenarios in 2030

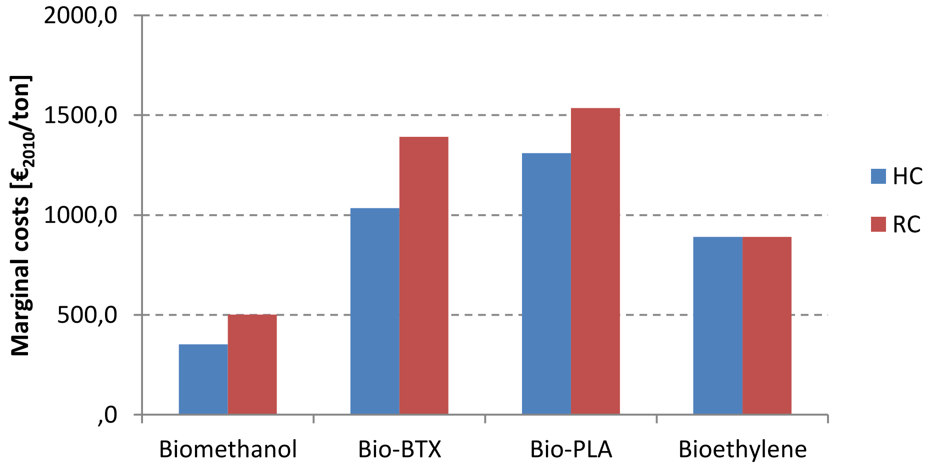


Figure 26 Marginal costs of bio-based products in 2030 for the HC and RC scenarios

Total costs

Figure 27 illustrates the total system costs of the two scenarios.

- In both scenarios, processing costs comprise the largest cost category of the whole system, followed by the feedstock costs (domestic and imported).
- Beyond 2020, total cost of the RC scenario is slightly higher than the HC scenario (around 7%). This has to do with the restrictions on the domestic biomass supply and higher volumes of imported commodities. However, this impact remains relatively limited.
    - The feedstock costs in the RC scenario are around 10% higher than the feedstock costs in HC.
    - Next to the feedstock costs, the international transport costs are higher in the RC scenario (around 40% higher, which is in line with the higher volumes of import).

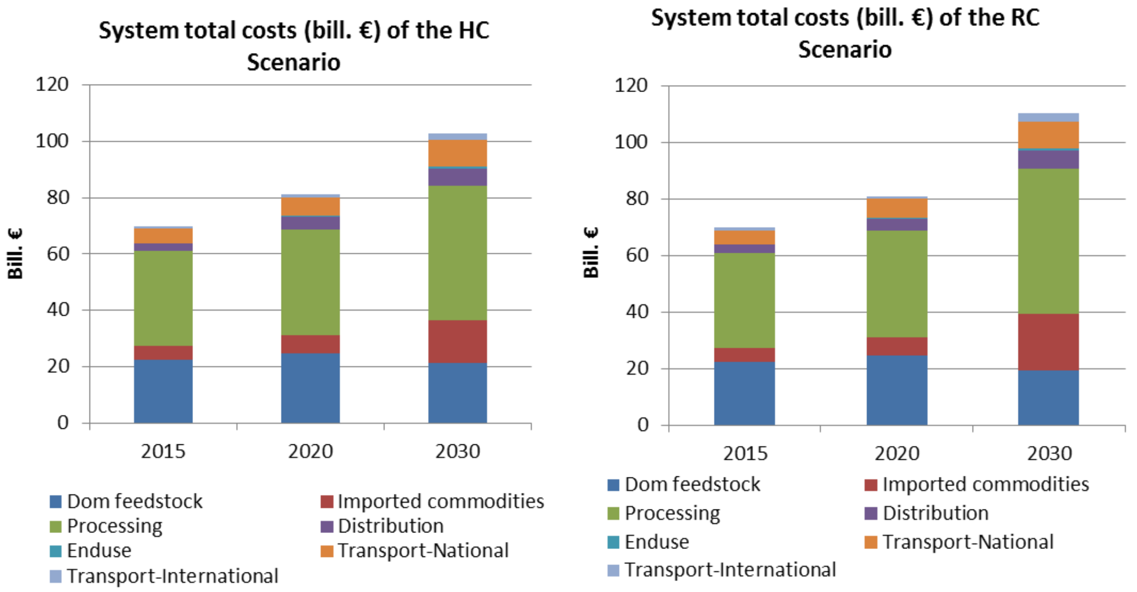


Figure 27 Total system costs of the HC (left side) and the RC (right side) scenarios[8] in €$_{2010}$.

4.3. Comparing the centralized and decentralized scenarios

4.3.1. Consumption and imports

Between the centralized and decentralized scenarios, the amount of consumed biomass is not significantly different, with only 1% lower consumption in the decentralised scenario, see Figure 28. Comparing the HC and HD scenarios we can

[8] Note that pre-treatment costs, for example palletization, are included in the processing costs.

see that in the decentralized scenario there is significantly less import of biomass feedstock from outside of the EU – a reduction of 10% compared to the HC scenario. In absolute numbers there is 120 PJ less import, all of which a reduction in the imports of wood pellets, which is almost fully offset by a slightly higher consumption of domestic biomass. This illustrates that fuel costs are not a major factor in ex-EU imports, as they come in very energy-efficient bulk carriers.

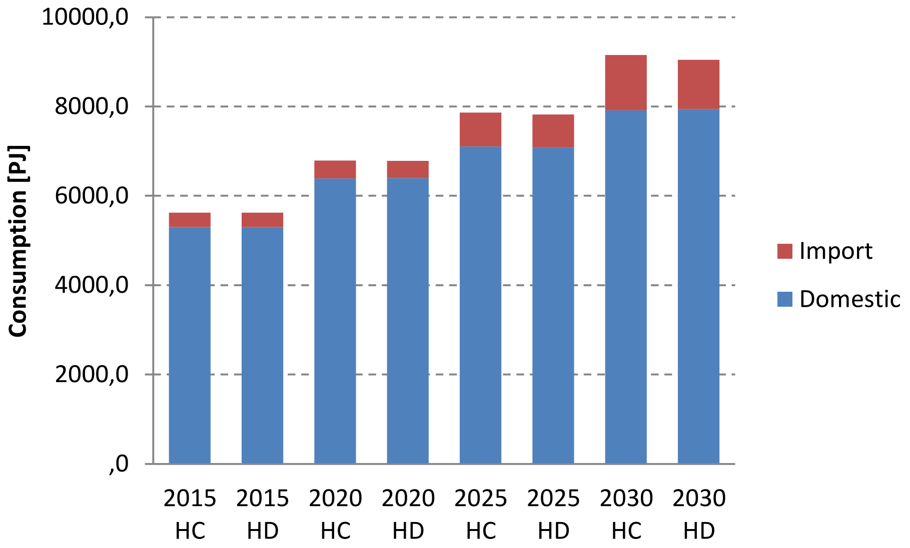


Figure 28 Consumption of biomass feedstock in the assessed region by source (in PJ).

When looking at consumption in the different sub regions within the EU28-plus region, Figure 28 shows that this increase in domestic consumption is not spread equally over all regions. In the West of Europe a 45 PJ (5% of regional consumption) reduction of biomass consumption will be seen if the decentral scenario plays out. On the other hand, the same scenario has a 40 PJ (3% of regional consumption) increase in consumption as effect in the Northern region of Europe. In general there is a lower consumption of lignocellulosic biomass in Central (-30 PJ), South East (-30 PJ) and West (-45 PJ), but a higher consumption of it in the North (+40 PJ) and South West (+15 PJ). The consumption of non-lignocellulosic biomass has slightly increased in all regions, with a total of 30 PJ more. Only in West Europe is waste consumption higher in HD compared to HC (+40 PJ).

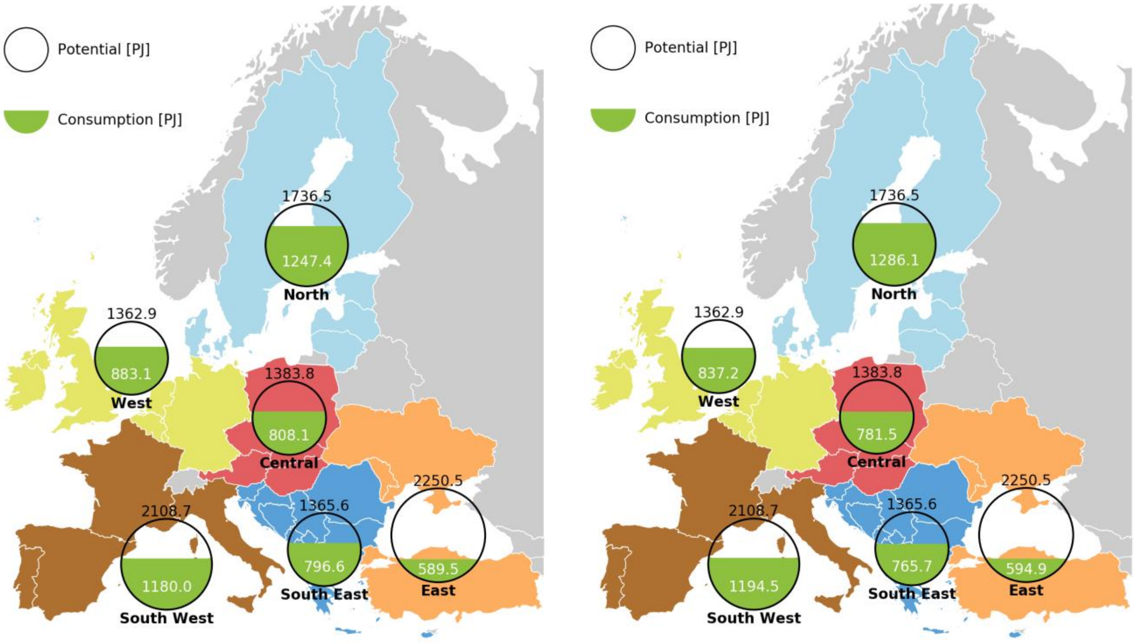


Figure 29 Lignocellulosic biomass consumption in the different regions in 2030 in the HC (left) and HD (right) scenarios.

4.3.2. Types of biomass and conversion technologies

Central vs decentral

Wood pellets are an excellent example of biomass feedstock that is often used in more large scale, centralized technologies: circa half of its use is in large-scale installations, the other half is in decentralized systems, including household appliances. The increased fossil fuel prices, and thus transport costs, are making other domestic feedstock more attractive to use. But interestingly enough, when looking at the overall use of centralised or decentralised technologies, the HD scenario gains more of its bioenergy and biochemicals from technologies that are larger in scale and are generally supplied by feedstock from a more distant geographical source. The ratio of centralized technologies used is 43% in HC and 45% in HD.

This can be explained by the increase in the use of the conversion technology CHP using solid biomass > 10 MW, the single largest source of the increase of central conversion technology use (this technology is used for the product-market combination (PMC) heat in industry). This technology consumes 120 PJ more wood chips in the HD scenario than in the HC scenario and 180 PJ more wood pellets, which are – due to their high density – relatively cheap to transport. Pelletisation of domestic woody biomass is employed 7% more (50 PJ) in the HD scenario, because the increased density of wood pellets over wood chips will result in a larger transport cost reduction than the cost of the extra conversion step. In contrast to the increase of large scale CHP, there is a decrease in the utilization of biomass co-firing in coal fired power plants. The electricity output from co-firing decreases from 165 PJ in the HC scenario to 19 PJ in the HD scenario in 2030. A reason might be that biomass co-firing has a relatively low conversion efficiency. When biomass is converted more efficiently in a CHP, less biomass is needed and therefore lower expenditures for transport.

When looking at the conversion technologies that have technological learning implemented we can see that various decentral technologies have increased their production, by up to 250% in HD compared to HC. We can also see that the average capacities of these plants are more than double that in HC (214 against 108 MW_{input}). For cellulose ETOH (a central technology) the capacity is larger in HC than HD (3949 against 2209 MW_{input}). This seems to support our hypothesis that in HD the decentralized technologies are favored and in HC the opposite.

Biomass feedstock consumption

Next to a reduction in wood pellets, there is also significantly less consumption of saw dust and saw mill byproducts in the HD scenario (100 PJ, -12% compared to HC). These are generally feedstocks for direct co-firing of biomass in coal-fired power plants and are usually transported over large distances to the power plants (after being converted to wood pellets). Increased transport costs reduce the attractiveness of co-firing of these feedstocks.

There is also a reduction in consumption of stover from grain maize (-40 PJ, -20% compared to HC) in the HD scenario, although the conversion technologies using this material as a feedstock are more frequently deployed. These technologies can also take a number of other feedstocks as input, e.g. wood chips. It is likely that stover has become less attractive as a feedstock due to its low density, resulting in higher transportation costs.

On the other hand, there are also feedstocks that are used more in the HD scenario than in the HC scenario. The reduction of wood pellets in the European bioenergy system is partly made up by the increase of wood pellets from domestic primary forestry residues (+55 PJ, 4% more compared to HC). The high transportation costs make the local consumption of dry manure more attractive, resulting in a higher use of this waste product (+40 PJ, 90% increase compared to HC). Sunflower seeds are used more in the decentralised scenario (+20 PJ, 40% more compared to HC), where their oil is used for biodiesel production. Miscanthus is also a feedstock that is used more in the HD scenario (+20 PJ, 20% increase compared to HC), mostly as a feedstock for local heating plants in industry. The increased demand for additional harvestable roundwood (+8 PJ, consumption is 90 times higher than in HC) is consumed in the residential heating sector, where an increase in the use of logwood stoves replaces a decrease in the use of wood chips boilers. For an overview, see Figure 30.

For the biomass types named in the paragraph above, but also for others, there is a significant relative change in consumption compared to the HC scenario. However, when looking at the biomass consumption as a whole the key message is that the resource base does not change significantly between the HC and HD scenarios.

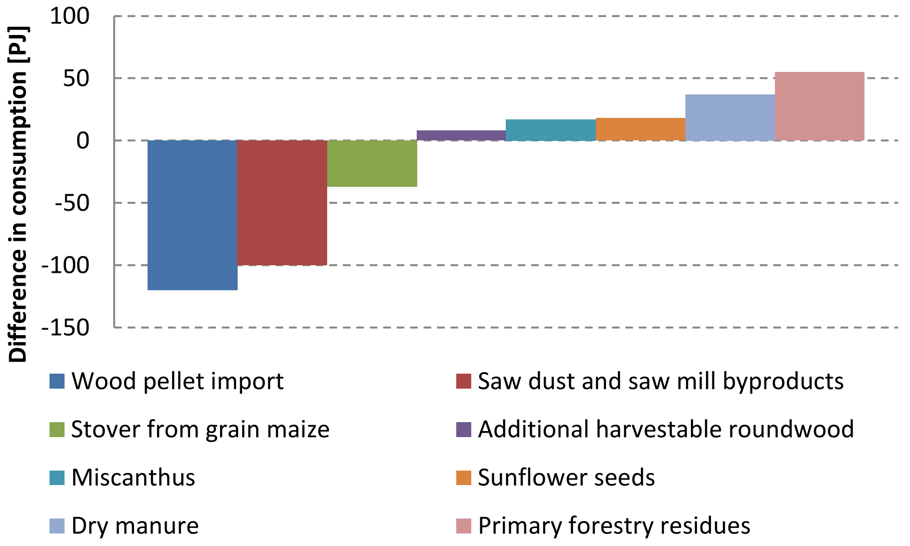


Figure 30 Difference in feedstock consumption between HC and HD (in PJ). A negative number signifies lower consumption in the HD scenario.

Biofuel consumption

The consumption of biofuels is the same in both HC and HD, as demand for all bioenergy and biobased product categories is kept the same among all scenarios. Also the total liquid biofuel consumption is equal among the two scenarios, but there is significantly lower consumption of advanced biofuels in HD compared to HC (-16 PJ, 18%). There is a doubling in the consumption of pyrolysis diesel as advanced biofuel between HC and HD (+16 PJ), but there are significant reductions in consumption of other types of lignocellulosic biofuels, most notably a 24 PJ reduction in second generation bioethanol. On the other hand the consumption of crop-based biofuels is higher in HD, which offsets the reduction in lignocellulosic-based biofuels. The highest increase can be found in the 22 PJ increase of first generation biodiesel, produced through the transesterification of oil seeds. [9]

[9] Note that a cap of 7% of crop based biofuels was used until 2030.

Consumption of heat in industry

As mentioned above, in industry there is a significant increase of large scale CHP using solid biomass (>10 MW), resulting in 180 PJ more heat from this technology in HD compared to HC (an increase of 15%). Smaller increases of consumption are seen by the conversion technologies local heating plants for processed grassy crops (+15 PJ) and medium scale CHP using straw (+18 PJ). This displaced the need for heat from the technologies waste combustion (-95 PJ), large scale pellet boiler (-80.4 PJ), local heating plant wood chips (-42.6 PJ), and commercial logwood boilers (-11.3 PJ).

4.3.3. Intra-European trade flows

In energy units the amount of feedstocks traded between the different sub regions is slightly higher in HD compared to HC (2%). Although the difference is small, this is an interesting conclusion, the more because both liquid and solid feedstocks and products have increased, with a 50% higher increase in solid feedstock trade compared to the increase in liquid biomass and bioproducts. The largest increases in net trade flows are for biodiesel (40 PJ), wood chips (70 PJ), first generation ethanol (10 PJ), and UFO (used fats and oils; 10 PJ). The largest reductions can be found in the trade flows of wood pellets (-50 PJ), palm oil (-40 PJ), and UFO-based biodiesel.

The net flow of wood pellets is mainly influenced by the reduction in wood pellet import, see Figure 31. A lower import in HD results in a significantly lower trade from West Europe (the import hub from imports outside of Europe) to South West Europe (60 PJ reduction). This is only partly offset by a higher import from North to the South West, which increased by 30 PJ. This increased trade from North to South West in turn is compensated by a reduction in exports to West and East Europe. All in all, both West and South West have a significant reduction of imports of wood pellets in 2030.

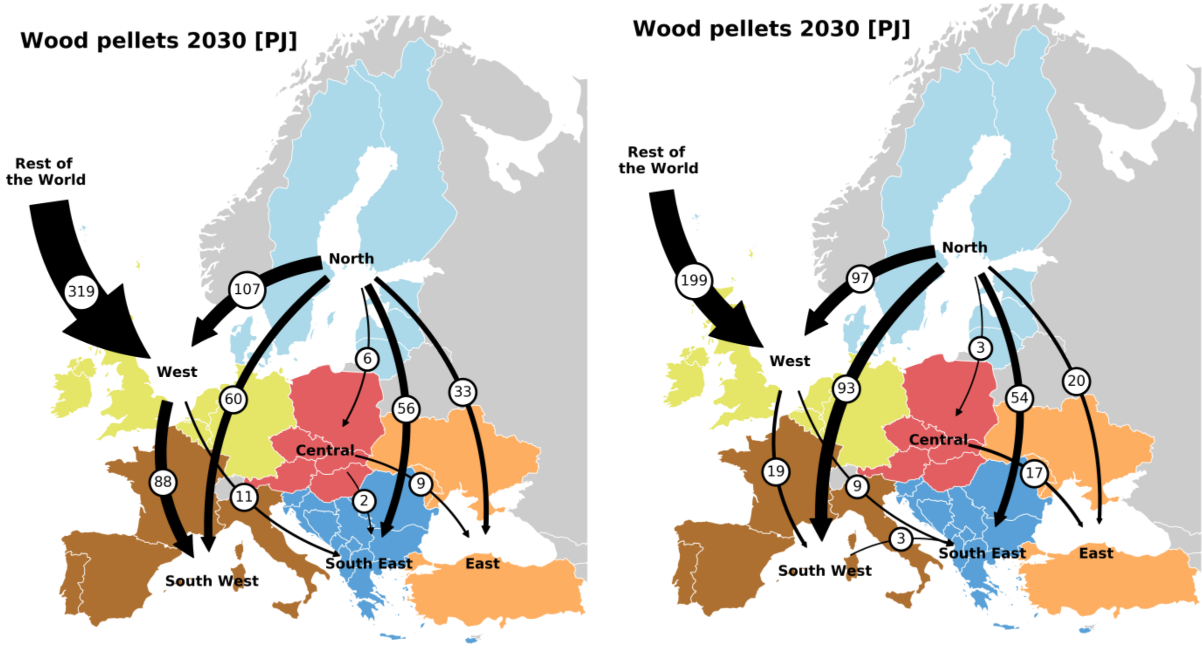


Figure 31 Net trade flows of wood pellets in 2030 in HC (left) and HD (right).

Regarding wood chips, the main sources of trade are the regions North and South East Europe, see Figure 32. There is a significant increase of wood chips exported from North Europe (+60 PJ, +35%), most of which is exported to West Europe. Also South West Europe imports more wood chips in the HD than in the HC scenario (+12 PJ, +70%), sourcing it from South East Europe, which almost directly results in a reduction of exports from this region to East Europe.

Looking at the net intra-European trade flows of biofuels, the only significant change between the two scenarios lies with the 21% (37 PJ) increase of biodiesel trade from West Europe to the other regions, see Figure 33. This is due to higher exports to all other regions, with the highest increase in exports to South East Europe (14 PJ).

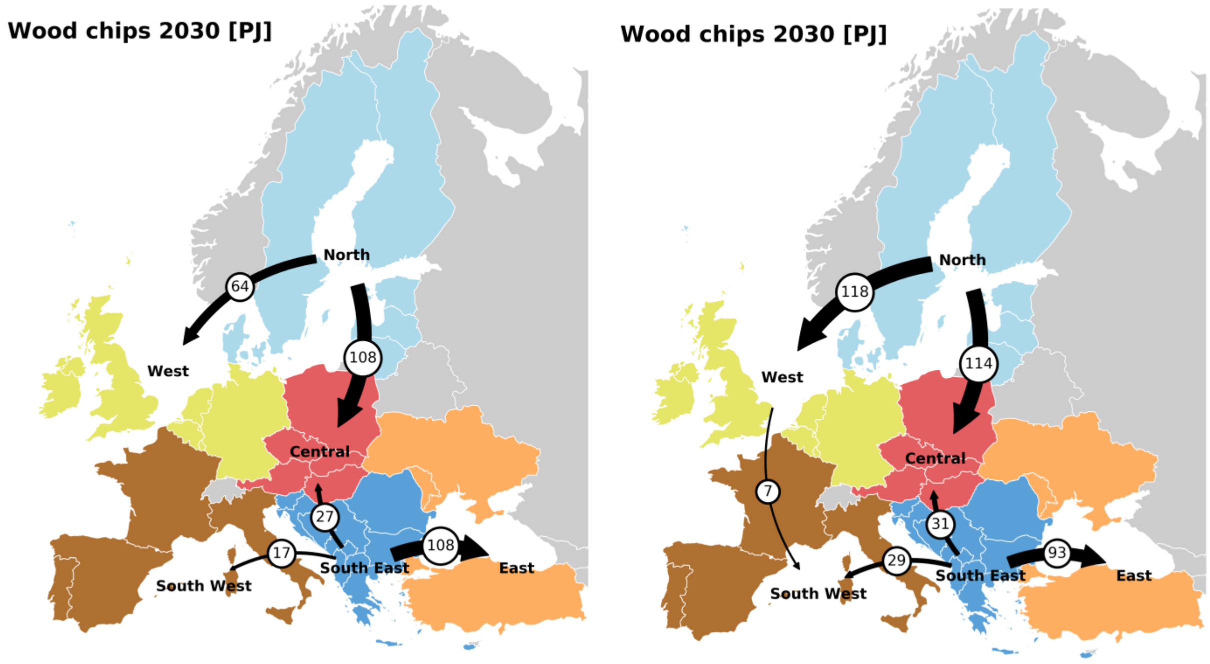


Figure 32 Net trade flow of wood chips in 2030 in HC(left) and HD (right).

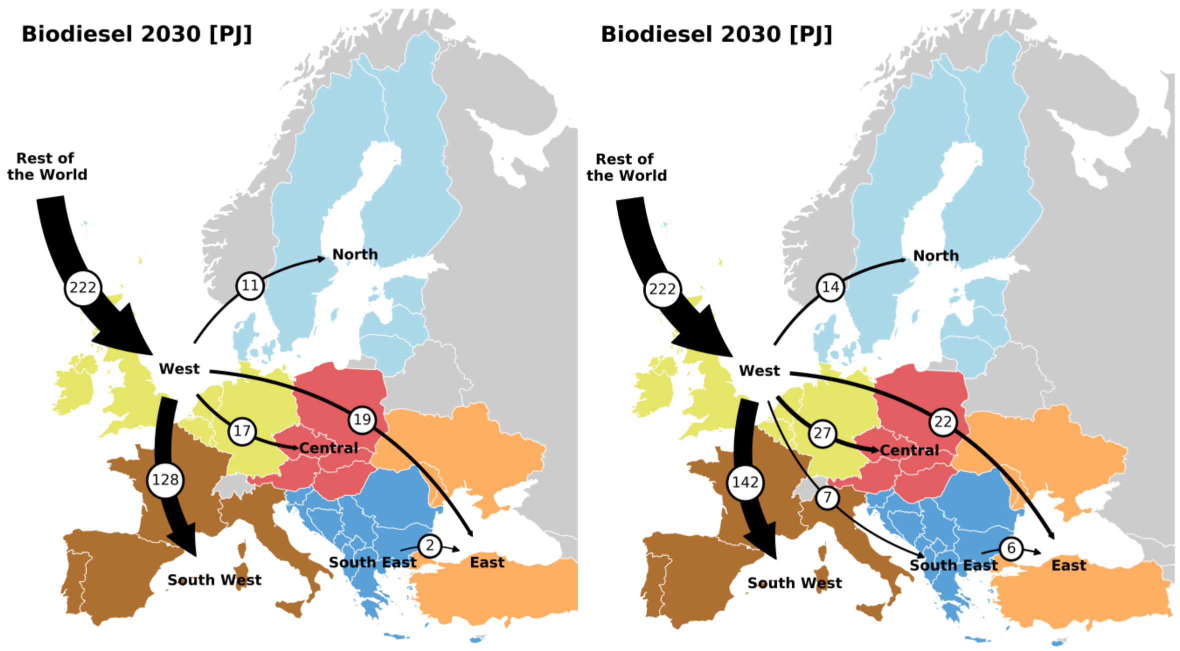


Figure 33 Net trade flows of biodiesel in 2030 in HC (left) and HD (right).

4.3.4. Costs

The marginal costs for the various biobased energy carriers and chemicals in HD are higher than in HC. This is at least partly due to the sheer fact that the HD scenario uses higher fossil energy costs. For biomethane, electricity, and biomethanol the marginal costs are 14-16% higher in the HD scenario, for biohydrogen this is 10% and for most other biobased products the marginal cost increase is between 4-7%. Only the marginal costs for BTX are lower (-10%).

The overall biomass consumption system costs are higher in the HD than in the HC scenario by about 3% (3.1 billion euros). Almost all of this increase is caused by higher costs for processing biomass by the conversion technologies (2.6 billion euros). Part of this increase in capital costs can be explained by the strong increased utilization of capital intensive but efficient CHP installations at the cost of low capital intensive but rather inefficient biomass co-firing. Furthermore, in case of high prices for fossil energy, as in the HD scenario, also the expenditure for auxiliary products like natural gas and electricity are higher. Higher fossil fuel prices have also increased transportation costs, both for national and international transport (600 million euros). The total cost of domestic feedstock has increased, but this increase has mostly been offset by a decrease in costs of imported commodities (+800 and -900 million euros).

However, although the costs of the biomass consumption system are higher in HD than in HC, at the same time the fossil-based reference scenario has much higher cost increases between HD and HC. Thus, the savings realized by switching from fossil to biobased products are much higher in the HD scenario (5 billion for HC and 61 billion for HD). This implies that although a high-fossil priced scenario leads also to higher prices for bioproducts, at the same time the high prices for fossil fuels make bioproducts a much more attractive alternative.[10]

4.4. Additional analyses

4.4.1. What is the effect of accelerated phase out?

This question has been addressed by doing the additional analysis *Lock-in* as described in section 3.4. An important effect that we see is that the amount of lignocellulosic based biofuels more than double, see Figure 34. As a consequence we see a significant increase in consumption of straw and energy grasses and non-wood based perennial crops (see Figure 35) and a lower import volume.

[10] Note that system cost of the biobased system are a sum of all the *costs*, not as sum of all market prices of the commodities. Since the reference commodities are valued at their market price, negative system costs wirth respect to the fossil reference does not mean that the biobased system is cheaper for society. It is, however, well possible to compare the total system cost of the biobased system of different scenarios.

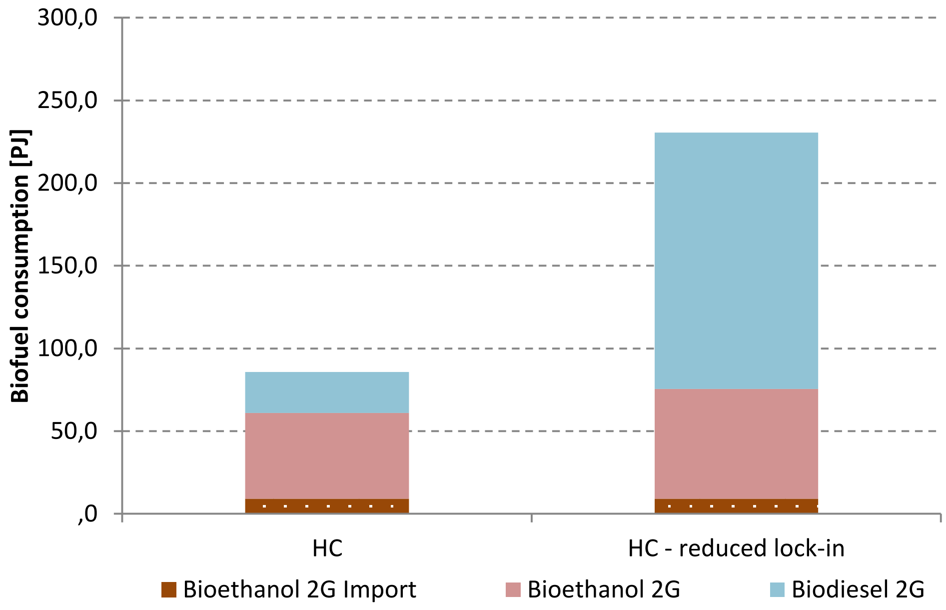


Figure 34 Consumption of lignocellulosic based biofuels in 2030 in the HC scenario and it's variant with reduced lock-in effects (HC – reduced lock-in).

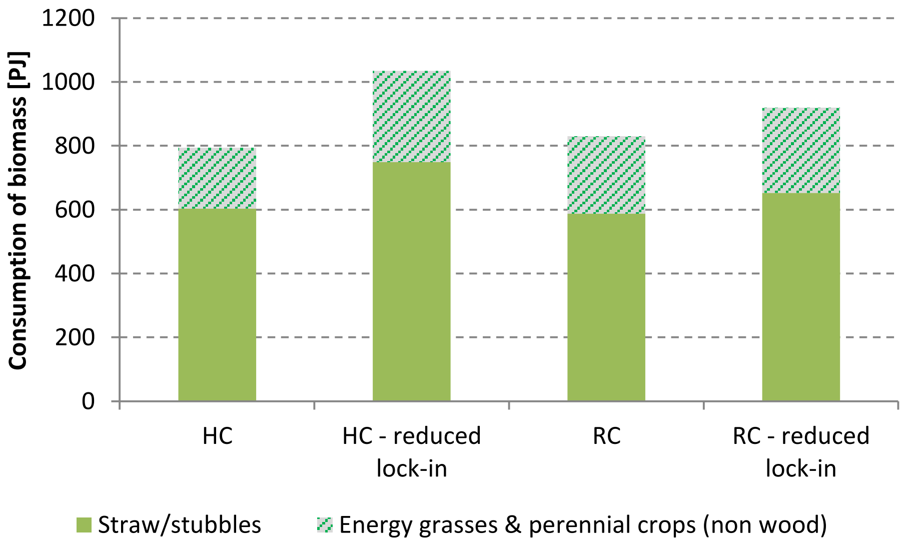


Figure 35 Consumption of Straw/stubbles and Energy grasses & non wood perennial crops for the HC and RC scenario's and their variant with reduced lock-in effects.

The increase of lignocellulosic based biofuels mainly concerns biodiesel. Where in the HC scenario the volume of advanced biodiesel is very small, in the variant where we reduce the effects of lock-in effects it's share becomes non-negligible. Because advanced biodiesel can develop in this variant, cost will drop, due to learning effects.

The result is that the marginal cost for biodiesel in 2030 are 10-20% lower in the variants with reduced lock-in effects.

Another consequence of reduced lock-in effects is that they result in lower system costs. A reduction in system costs in 2030 of 6-7 Billion euros per year is observed. However, this is only in case early retired installations can be reused or retrofitted.

4.4.2. Do biochemicals have a large impact on the market for bioenergy?

This question has been addressed by doing the additional analysis *The effect of biobased chemicals* as described in section 3.4. The effect of the demand for chemicals from lignocellulosic biomass is small. The total additional amount of biomass needed to fulfill the demand for biobased chemicals is only 1-1.5% of the amount needed for the bioenergy demand. Furthermore the effect on marginal costs of bioenergy and wood chips and pellets is in general less than 1%.

4.4.3. Does the large demand for bioenergy disturb the opportunities for chemicals from lignocellulosic biomass?

This answer has been addressed by doing the additional analysis *The effect of a low bioenergy demand on biobased chemicals* as described in section 3.4. The effect of a low demand on the financial gap of biobased chemicals in 2030 is illustrated in Figure 36. The financial gap can be interpreted as the difference between the marginal costs of the biobased chemical and the fossil derived chemical. Figure 36 shows that the effect on several biobased chemicals of a low demand for bioenergy is significant, namely for PLA, methane, hydrogen and ethylene (effect 11-31%). For BTX and methanol there is an effect, but much smaller (0-7%).

In general the cost competitiveness of biobased chemicals is more determined by the price of fossil energy carriers than by the competing demand for biomass from the bioenergy sector, but both effects add up. In case of high prices for fossil energy carriers, PLA could be cost competitive also with a high demand for bioenergy. With a low demand for bioenergy its prospects are better. However, when the fossil energy prices are low, it can't compete in prices with its fossil alternative[11]. It seems that in 2030 in all cases biogenic methane will never be cost competitive, although in case of a high price for natural gas and a low demand for bioenergy it might be close to cost competitiveness.

[11] Polystyrene

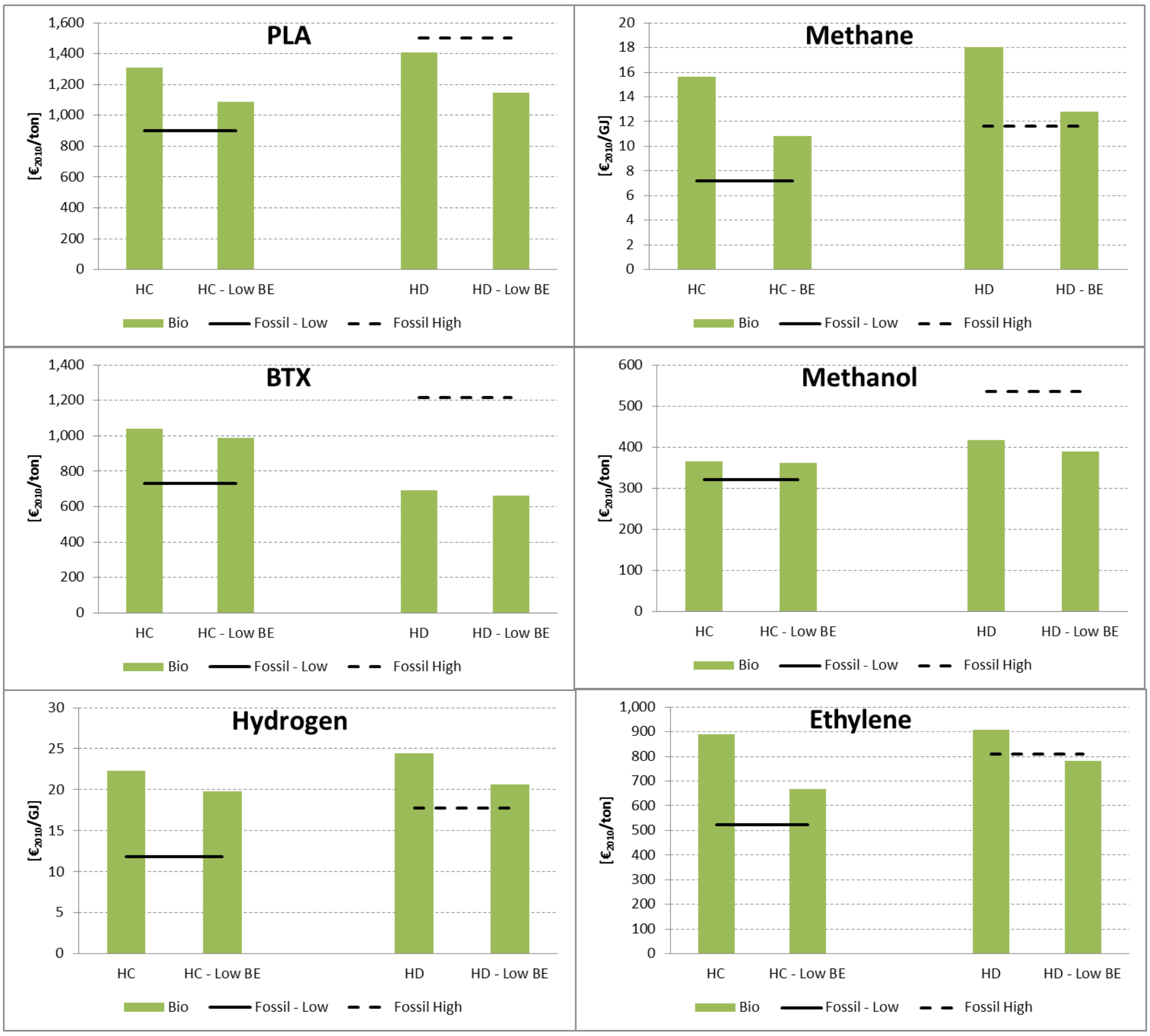


Figure 36 Effect of a low demand for bioenergy on the financial gap of biochemicals in 2030. HC and HD correspond to the default bioenergy demand. HC-Low BE and HD-Low BE correspond to a low demand for bioenergy. The straight and dashed black lines correspond to the price of the fossil derived chemicals for respectively low and high fossil prices.

Biobased BTX, with the gasification process as used in our model[12], is the only biochemical where the marginal costs of the default HD scenario are lower than the values of the default HC scenario. This can be explained by the fact that the gasification process has a much higher output of methane than BTX[13]. In Figure 36 we see that the marginal costs for biomethane for the HD scenario are higher than for the HC scenario. This means that the revenues for the methane part of the gasification process are higher in case of the HD scenario and therefore the revenues for the BTX part can be lower. This effect also explains the low impact of the demand for bioenergy on the marginal costs: low prices for biomass result in low expenditures on biomass, however, the effect is partially counteracted by the low

[12] See [14]

[13] The ratio methane to BTX is 79:21 with respect to energy output

revenues for methane in case of a low demand for bioenergy. In case of biomethanol we also see a small effect of the bioenergy demand on the marginal costs. This can again be explained by the process having an energy output next to the biochemical: heat. The low price for heat from biomass compensates to a large extent the effect of low biomass prices. Hydrogen derived from gasification of biomass maintains a positive financial gap both in case of high fossil prices and in case of a low demand for bioenergy. Biobased ethylene could be cost competitive with fossil alternatives in case of high fossil energy prices combined with a low demand for bioenergy. When the fossil energy price is very low it, however, seems to remain too expensive.

4.4.4. What is the effect of an early introduction of advanced technologies?

The effect on all indicators is very small: on the biomass mix, the technology mix as well as on the total costs and marginal costs. Advanced technologies need more than being available in an early stage to have an impact. Also when we combine the effect of an early introduction with the effect of accelerated phase out as described in section 4.4.1, we don’t see any significant effect of an early introduction of advanced technologies.

4.4.5. What is the effect of an improved mobilization of biomass?

This answer has been addressed by doing the additional analysis *The effect improved mobilization of biomass* as described section 3.4. The results is an increased utilization of domestic feedstock, in particular for straw and landscape care wood, so feedstocks that are currently underutilized. Furthermore, we see a reduction of import of wood pellets and ethanol from outside Europe and lower intra-European trade. The reduction of the trade flows of wood pellets is visualized in Figure 37.

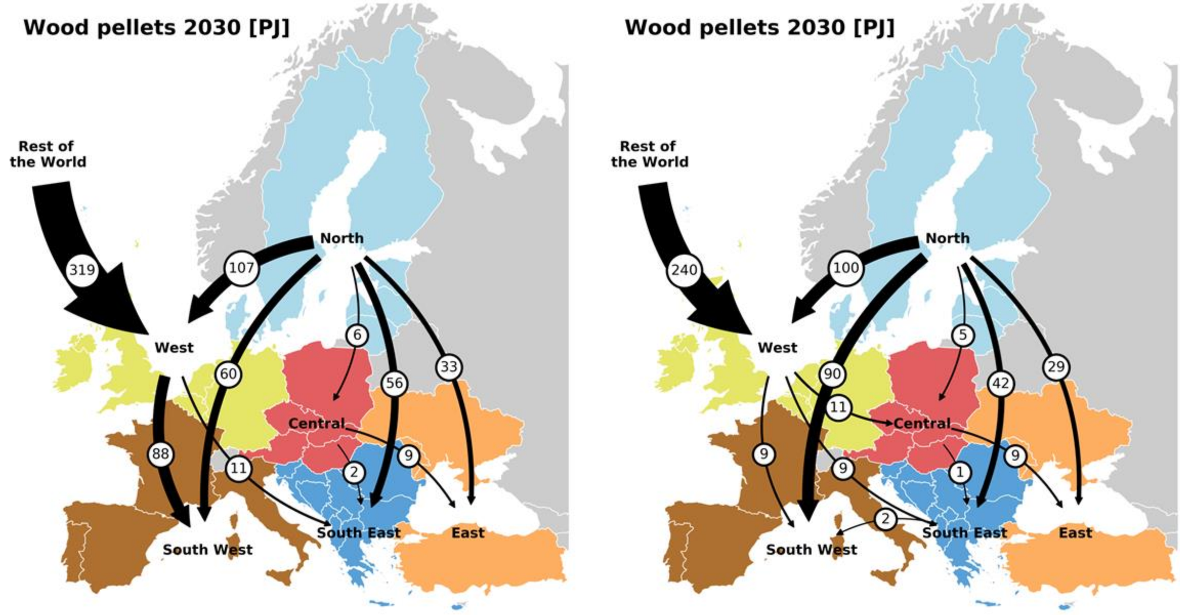


Figure 37 Net wood pellet flows between regions in 2030 in case of the default HC scenario (left) and in case of the HC scenario with an improved feedstock mobilization (right).

Underlying results reveal that improved mobilization of feedstocks results in a higher share of lignocellulosic based biofuels, in particular for second generation ethanol and pyrolysis diesel.

One might expect that if biomass is mobilized more rapidly, it will also reduce the overall cost for the bioenergy and biochemical system. This is indeed the case. Marginal costs of commodities reduce by 1-7%. The total costs of the system reduce by 1.7 Billion euros per year (HC) and 4.6 Billion euros per year (RC).

4.4.6. The effect of another perspective – what is the effect of a lower discount rate?

This answer has been addressed by doing the additional analysis *Capital cost analysis* as described in section 3.4. One might expect that technologies with relative high investment costs per unit of output benefit more from low interest rates. This effect is reflected in the results via an increased share of advanced biofuels and a slight shift towards more decentral/small scale production. A shift towards other technologies and to another scale also has an effect on the type of biomass consumption and the origin of the biomass. We see an increase in consumption of domestic biomass. For example the domestic consumption of straw increases by more than 15%, as illustrated in Figure 38. Furthermore, we see a decrease of the imports from outside Europe and a decrease of intra-European trade.

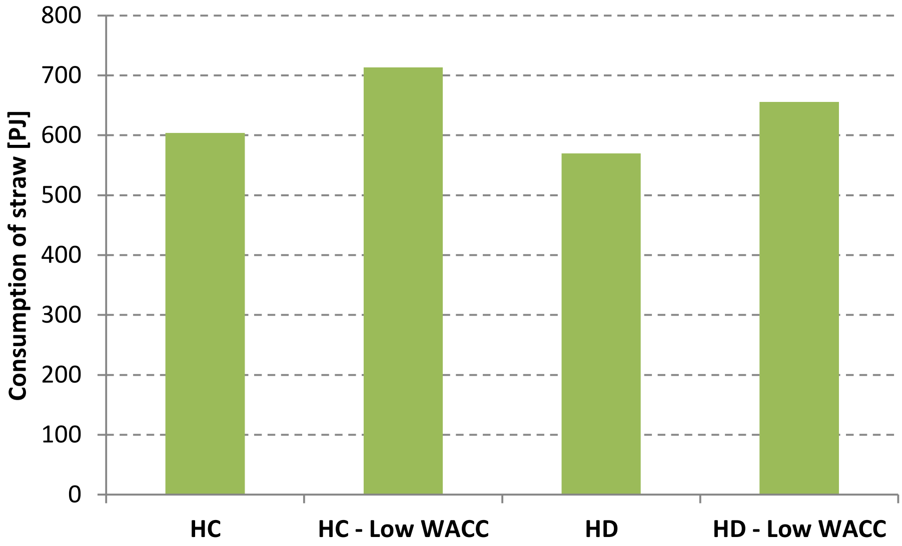


Figure 38: Domestic consumption of straw [PJ] for the HC and HD scenario's and their variants with a low interest rate, as indicated by Low WACC.

4.4.7. Is it possible to keep the same biofuel ambitions in 2030 without using food based biofuels?

One might wonder if it is possible to abandon food based biofuels without scarifying biofuel ambitions. On the basis of our assumptions regarding e.g. maximum deployment of new technologies and feedstocks, this is very unlikely. It is, however, possible to limit the amount of food-crop based biofuels; in our analysis, still 1.5% of crop-based biofuels would be needed by 2030 (as a share of the total demand for fuels for road transport). Such a low percentage is, however, still very ambitious. To be able to achieve such ambitions the following criteria need to be fulfilled:

1. The voluntary minimal percentage of 1% advanced biofuels in 2020 should be made mandatory
2. A rapid introduction of advanced technologies is needed, to the maximum rates we consider possible.
3. An ambitious and mandatory minimal % path of advanced biofuels between 2020 and 2030
4. Putting the pathway towards 1.5% crop based biofuels in 2030 as a mandatory cap.

Although biofuels based on used fats and oils are expected to play an important role in 2020 and 2030, the availability of this kind of feedstocks is a bottleneck. Therefore, in case of a low share of crop based biofuels, advanced lignocellulosic based biofuels need to increase at a high rate. A mandatory percentage of 1% advanced biofuels in 2020 is needed to start volume production of these technologies at a sufficiently early stage. At this moment only second generation ethanol is available as a technology on a commercial scale. To make sure that this technology can make a maximum contribution in 2030 it needs to be rolled at a maximum pace. However, second generation ethanol is not the only advanced type of biofuel needed. A high replacement of first generation biofuels by second generation biofuels in 2030 can only be realized if biogenic diesel replacements are available three years earlier than assumed in the rest of this study[14]. To make sure that the roll out of lignocellulosic based biofuels happens at a maximum rate an ambitious and mandatory target pathway between 2020 and 2030 needs to be put in place. Likewise, crop based biofuels would need to be forced to phase out. So next to the maximum 7% cap on crop based biofuels that are currently in place, a cap of 1.5% needs to be put in place for 2030, and a related mandatory pathway towards it. The current maximum and minimum percentages corresponding towards a low crop based biofuel share are summarized in Figure 39.

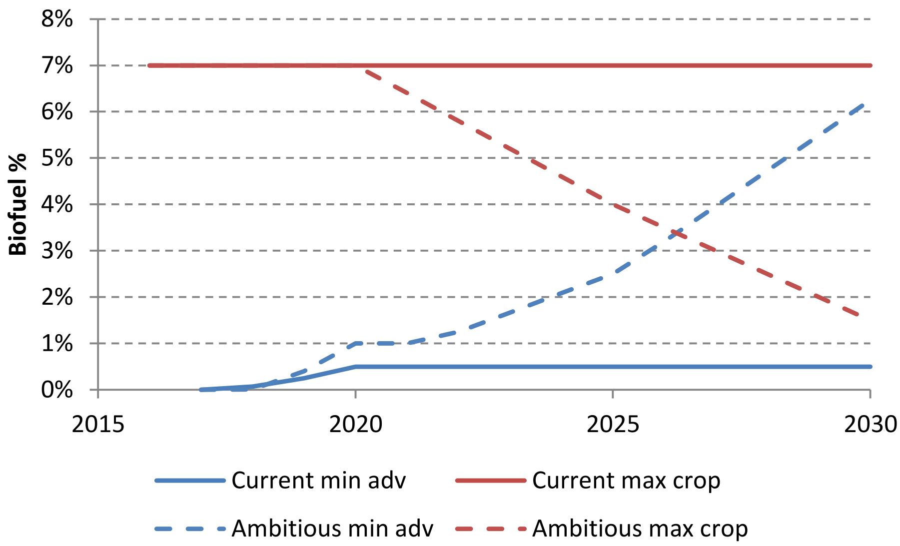


Figure 39 The current minimal advanced biofuel percentage (straight blue), current maximum crop based biofuel percentage (straight red), minimal advanced biofuel percentage (dashed blue) and maximum crop based biofuel (dashed red) for achieving a low share of crop based biofuels.

In Figure 40 the different amounts of biofuels are given in 2030 for the HC scenario and the HC scenario with a 1.5% cap on crop based biofuels (HC 1.5% 1G). One can see in Figure 40 that, although second generation biodiesel show the largest increase in relative terms, second generation ethanol shows the largest increase in absolute terms and will also have a larger total volume in 2030.

[14] In the major part of this study we assumed introduction years of DME, Fischer-Tropsch diesel and pyrolysis diesel to be in 2023. For HTL diesel we assumed this to be in 2025. In the analysis in this section all these introduction years are put three years earlier.

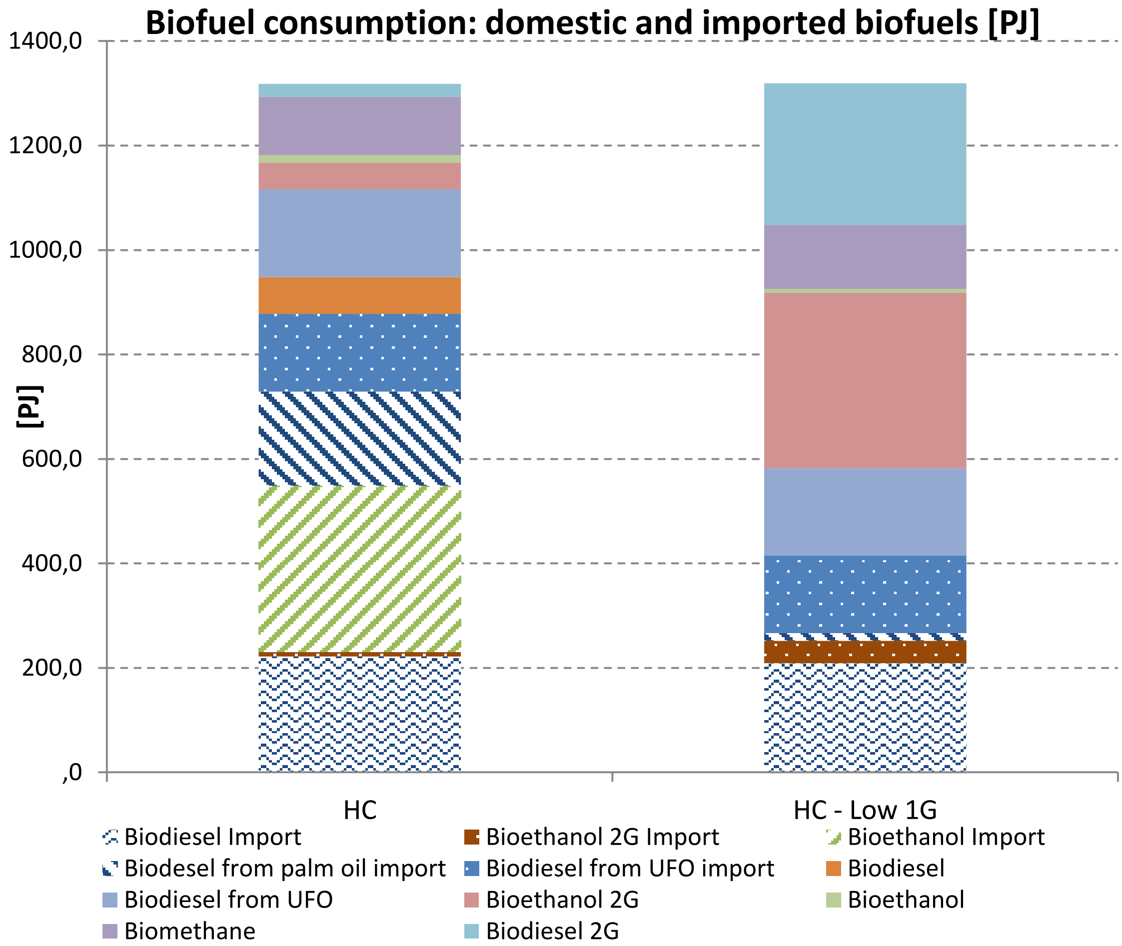


Figure 40 Biofuel volumes per category in 2030 in PJ for the default HC scenario (HC) and in case of a 1.5% cap on crop based biofuels (HC – Low 1G).

The transition to such a large share of lignocellulosic based biofuels also has a significant impact on the biomass consumption mix and on trade flows. There is a strong increase in lignocellulosic biomass consumption, both domestic biomass and imported wood pellets, as shown in Figure 41. A strong increase in the amount of wood pellets imported can be observed, however, the total amount of imports decreases, due to a strong decline in liquid biomass imports.

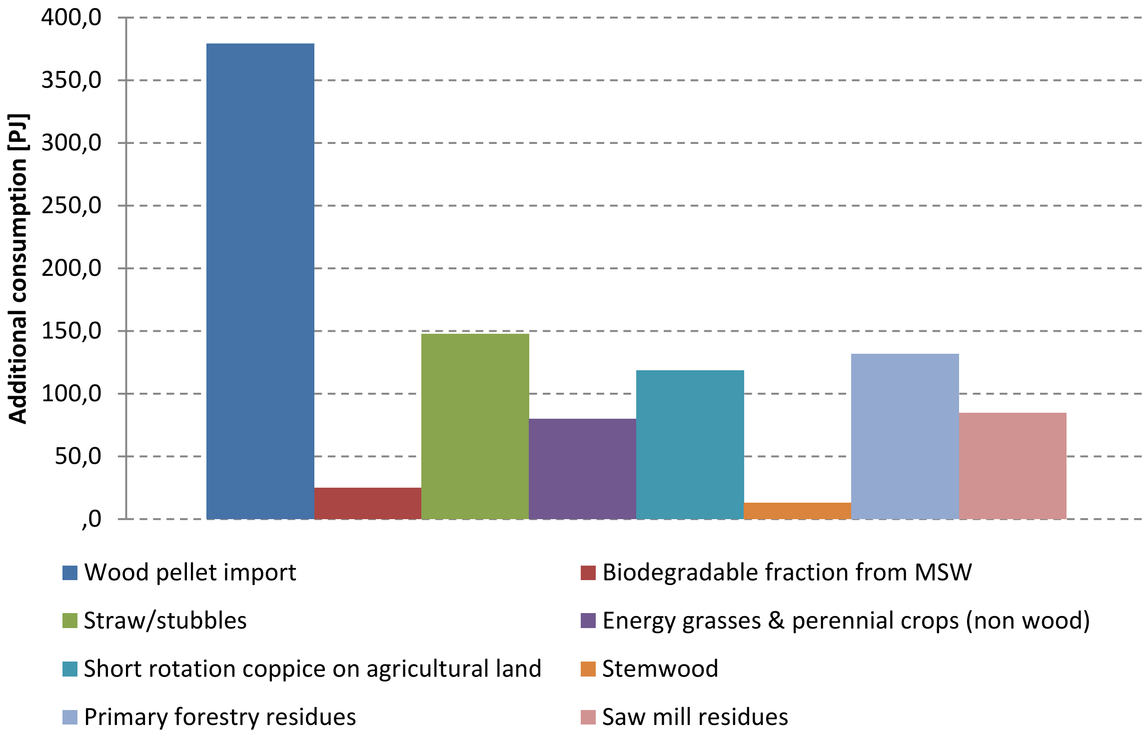


Figure 41 Additional consumption of lignocellulosic biomass in 2030 for the HC scenario with a low share of 1G biofuels as compared to the standard HC scenario. Only biomass categories that show a significant increase are shown.

A shift towards such an enormous amount of lignocellulosic based biofuels also comes at a cost: the total system costs increase by 5 Billion euros per year in 2030. Furthermore, due to the pull at lignocellulosic feedstocks the marginal costs rise strongly: wood pellets by almost 50%, biodiesel by 50% and ethanol by 75%.

5. Conclusions and recommendations

In this chapter we provide general conclusions, policy recommendations and recommendations for further research.

5.1. Conclusions and key messages

The key conclusions from the analyses done in this report are as follows:

- Europe has sufficient biomass at its disposal to meet its 2030 ambitions in terms of biobased energy and chemicals. There are, however, clear differences between regions within Europe, and intra-European trade as well as ex-EU imports will be important.
- If new developments, such as additional sustainability criteria, would reduce domestic potentials, there is sufficient remaining (domestic and to be imported) biomass available to still meet these ambitions, with relatively modest additional costs.
- The technology mix used for conversion of biomass into the various energy carriers (heat, electricity and fuels) remains remarkably stable in our scenarios. This implies that this mix is relatively robust, or more specifically: the resource scarcity stimuli towards centralization or decentralization that we applied are not sufficiently strong to affect the development of conversion technologies.
- Heat remains the dominant use of biomass, not only in terms of energy but also in terms of financial turnover. More high-value applications such as chemicals and biofuels can play a role in improving business cases for integrated refinery systems, but profitable sales of heat should not be neglected, nor the relevance of heat-only and CHP options.
- Biomass applications for chemicals create only very modest biomass demand volumes compared to the energy applications, at least towards 2030. As a consequence, this demand does not fundamentally compete against energy applications. Vice versa, the competitiveness of chemical applications can be affected by changes in demand for energy. However, chemicals that can be co-produced with energy carriers such as BTX (a co-product with methane) or methanol (with heat as a co-product), are less susceptible to such competition effects.
- The competitiveness of biobased chemicals varies strongly between the different reference chemicals studied. Some show consistently lower costs than the fossil reference, while others remain more expensive in all scenarios. Obviously, the price of fossil fuels is an important determinant in this.

- A development pathway towards more advanced, ligno-based biofuels instead of crop-based biofuels will not come through autonomous developments alone. Important preconditions for such development are[15]:
  - Active mobilization of lignocellulosic feedstock for large-scale conversion systems;
  - Clear objectives for the development of advanced biofuels, e.g. through a specific sub-target for them
  - Additionally, a gradual reduction of the (currently 7%) cap on crop-based biofuels could be considered.

5.2. Policy recommendations

We realize that policy making is always the craft of reconciling (partly) conflicting interest. Therefore we have no intention of claiming what 'must' be done. However, from a position of 'honest broker of policy alternatives', we can make the following recommendations:

- If further scientific insights and societal pressure demand so, additional sustainability restrictions to biomass use for energy do not by definition ruin the perspectives for bioenergy and biochemicals. Although much will depend on the level of strictness, and administrative burden to such regulations, biomass availability as such is sufficient to accommodate a reduction of feedstock potential. Such restrictions can, however, induce a change towards more ex-EU imports of biomass and less use of domestic feedstock.
- Active policies to mobilize sustainable feedstocks will be relevant. Particularly for the realization of advanced biofuels, such policies will be necessary, next to policies aimed at technology development and final demand pull. In a policy context with more restrictions on biomass potential, relatively low-impact feedstocks such as manure and perennial lignocellulosic crops will become more important.
- Next to competition issues between biomass applications for energy and chemicals, there can also be significant synergies. This particularly applies to integrated conversion systems that produce both chemicals and energy carriers: in such systems, chemical production routes are less prone to being outcompeted by energy applications. However, given the difference in size between energy and chemical routes, also in terms of financial turnover, there will certainly be room for energy-only applications of biomass.

[15] Note that our analysis was done before the European Commission's Clean Energy Package came out. This package a cap of 3.8% on food based biofuels and a minimum of 3.6% of advanced biofuels, see https://ec.europa.eu/energy/en/news/commission-proposes-new-rules-consumer-centred-clean-energy-transition

5.3. Limitations and related recommendations for further research

As with any model exercise, the limitations to the model directly bring limitations to our analysis and conclusions. Here, we translated these limitations in recommendations for further research as well.

- It should be clear that the demands for biobased energy carriers and biochemicals has been defined exogenously in task 7.2 of the project, and are not model outcomes as such. It might for example well be that in a more integrated approach the share of bioelectricity would be lower, given the recent rapid cost reduction for wind and solar energy.
- The optimization routines of the model have entirely focused on least costs per GJ or tonne. While GHG intensities were available for most (but not all routes), the optimal outcomes from the analyses need not be optimal in GHG terms.
- The scenarios were translated to model inputs in a rather stylized manner. For consistent analyses this is useful, but in practice, the sustainability discussion may for example also influence biobased options in other ways than on the resource base only (think of differences in focus between electricity, heat, biofuels and biobased chemicals).
- Synergies between biobased chemical and biofuel routes were included in a simplified way, merely by joint learning curves. This is worth more detailed analysis.

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Annex I: Description / update of RESolve-Biomass model

RESolve-Biomass determines the least-cost configuration of the entire bioenergy production chain, given demand projections for biofuels, bio-electricity, bioheat and biobased chemicals[16], biomass potentials and technological progress, see Figure 42 [1,2]. By doing so it mimics the competition among these four sectors for the same resources. The RESolve-Biomass model includes raw feedstock production, processing, transport and distribution. 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 bioenergy and biochemicals can be approached in a much more realistic way than when each country is evaluated separately.

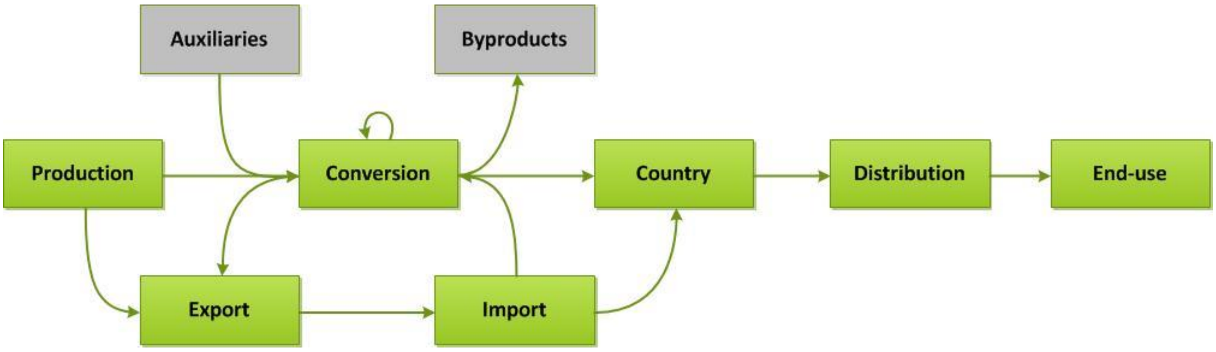

Figure 42 RESolve-Biomass model [1]

RESolve-biomass allows for trade of feedstocks and final products by means of trucks, trains and short sea shipments within Europe. Import from outside of goes via ocean tankers. The only costs associated with international trade are transport costs (including handling), for which generalized 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. The RESolve-Biomass model includes:

- 39 crop/non-crop raw materials (primary feedstocks), see Annex III
- 55 conversion processes delivering final products, 25 processes delivering intermediate products
- 3 auxiliary and 7 by-products
- Several types of biofuels and associated distribution technologies, bio-electricity and bioheat as final energy products and chemicals from lignocellulosic biomass. For an overview of all final products see Table 3.
- All EU-28 MS and 9 non-EU-28 countries are considered individually. The optimal solution is found for the aggregate of all 37 countries (the target area).
- Import from outside the target area is possible. In the model currently 10 source regions are used.

[16] More specifically: chemicals made from lignocellulosic biomass

Table 3: Overview of all final products in RESolve-Biomass

PMC[17]	Final product
Heat	Heat in the household sector
	Heat in the industrial sector
	Heat in the services and agricultural sector
Electricity	Electricity
(Advanced) biofuels	ATJ[a] gasoline
	Bio-DME[b]
	Bio-FT-diesel
	Biodiesel
	Biodiesel from UFO
	Bioethanol 1st
	Bioethanol 2nd
	Biomethane for Transport
	HVO[d] from crop based biomass
	HVO from UFO
	HTL[e] diesel
	HTL gasoline
	Pyrolysis diesel
C6 sugars	Bio-PLA[f]
Bio-methane	Bio-methane for the gas grid
BTX	Bio-BTX[g]
Methanol	Biomethanol
Hydrogen	Biohydrogen
Ethylene	Bioethylene

[a]ATJ = Alcohol to jet
[b]DME = Dimethyl ether
[c]UFO = Used fats and oils
[d]HVO = Hydrotreated vegetable oil
[e]HTL = Hydrothermal liquefaction
[f]PLA = Polylactic acid
[g]BTX = Benzene, Toluene and Xylene

It is assumed that every country in the model has one possible production location for each raw material and one location for a possible processing plant for each conversion (sub) process. This means that each country has the possibility to have a full chain of conversion facilities. The model decides if a certain feedstock and technology will actually be utilized. As an example, all conversion pathways related to pyrolysis oil are given in Figure 43.

[17] PMC = Product Market Combination

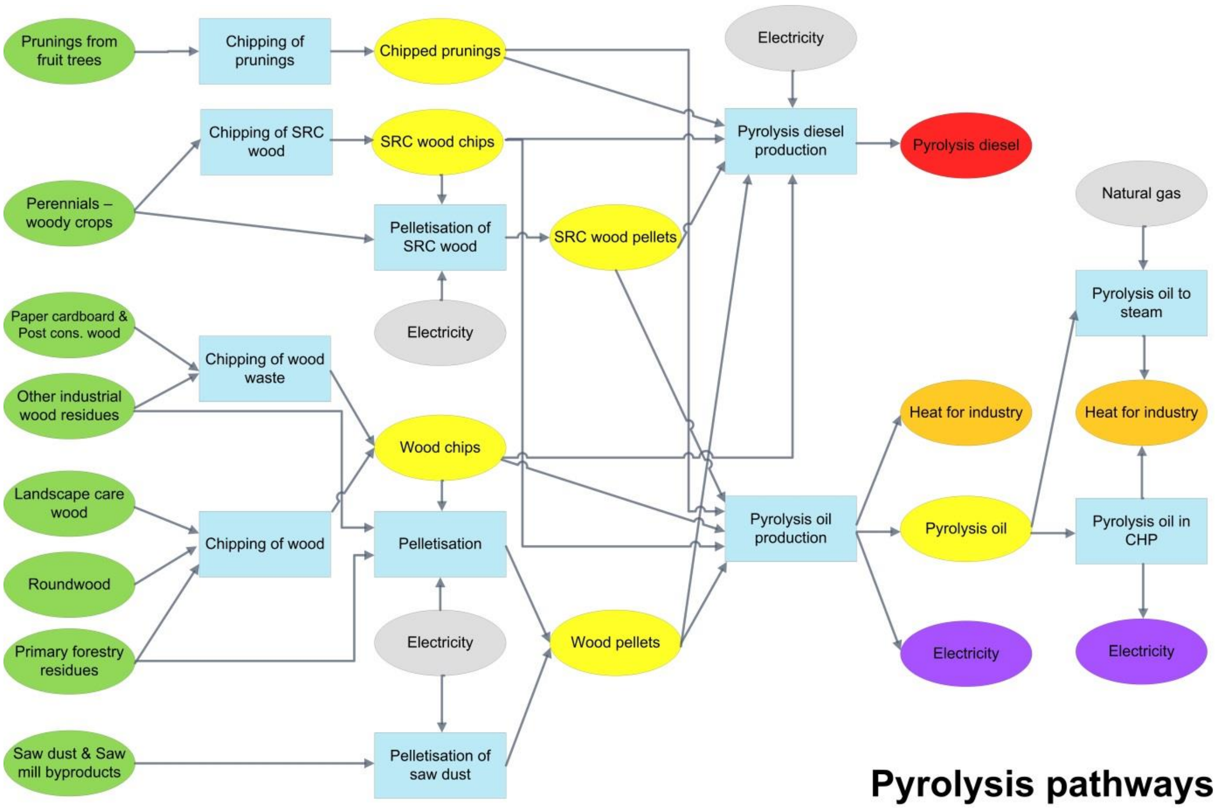

Figure 43: All conversion chains related to pyrolysis oil. Products are represented by ovals. Processes are represented by rectangles. Intermediate products have a yellow colour, raw primary products have a green colour and auxiliary products have a light-grey colour.

In order to produce heat, electricity, biofuels or biobased chemicals from biomass resources, one or more conversion steps are needed. For each conversion step, different indicators are used to calculate costs and output:

- Auxiliary and by-products
- Full load hours
- Lifetime
- Operations and Maintenance costs (O&M costs)
- Specific investment costs
- Introduction year of a technology
- Conversion efficiencies
- Weigthed Average Cost of Capital (WACC) of a technology.

For biofuels and large scale advanced technologies, the investment costs reduce in time depending on the past cumulative output volumes of the technology or via the development of the scale of installations. As such, the model includes endogenous learning [17]. See Table 2 for a complete overview of technologies that use endogenous learning. For all other conversion routes the change in investment and

O&M costs over time is given as an exogenous input, so endogenous learning is not applied.

The final demand for electricity, heat and biofuels is specified per country, see section 2.3. For biofuels, the biofuel mix is determined according to the least cost taking into account country specific distributions over diesel, gasoline and natural gas for passenger vehicles and maximum blending ratios for different types of biofuels. The demand for biochemicals from lignocellulosic biomass is not specified per country, since those demands are not analyzed per country in this project. Therefore this total demand applies to the area as a whole. The model determines where it can be produced most cost effectively.

RESolve-Biomass covers both the upgrade of biogas to biomethane for use in transport and the upgrade of biogas to biomethane for injection into the gas grid. Upgrading for transport and for the grid are treated as separate processes. Biomethane for the gas grid is not final consumption of energy. Gas in the grid is distributed to final end use applications. For example to gas boilers at households. In RESolve-Biomass a fixed distribution over end use applications is used. This ratio is derived from Eurostat and kept the same for all countries for simplicity. Furthermore it is kept constant in time. Note that not all biomethane in the grid ends up as final energy consumption. Part of biomethane ends up as non-energetic consumption.

RESolve-Biomass is a myopic optimization model. Every year is optimized individually and the first optimization year is 2005 To avoid an unrealistic rapid uptake of feedstock and conversion technologies, growth restrictions are applied separately for feedstock and conversion technologies. Furthermore, the model includes a vintage approach: construction years and lifetimes are used. This helps in estimating the room there is for new installations to enter the market. Because of its myopic character, the use of a vintage approach and the growth restriction, past developments influence the outcome for future years.

The model puts a restriction on the amount of biomass that can additionally be made available[18] in year y+1 compared to year y. This means that not the full unutilized potential is available. The effect of mobilization rate restrictions for biomass feedstocks as applied in the model are illustrated in Figure 44. The blue Default-Zero line corresponds to the default rate parameters in case there was zero utilization in 2005. In that case it seems realistic that what can be converted in the year 2006 is much lower than the potential. However, after initial utilization the chain starts to develop and the total amount of biomass that can be utilized can grow at a fast rate as illustrated by the blue line for the period until around 2015. In 2015 about half of the potential is utilized and it starts to become more difficult to mobilize additional biomass. Therefore the growth rate declines. In particular once most, say 90%, of the

[18] If there is potential, it does not mean that it is all directly available for conversion. For example, in the case of forestry residues, first a logistical chain needs to be put in place, etc.

potential is mobilized it is difficult to gather the remaining part. This effect is reflected in the low slope of the blue curve after it reached 90%.

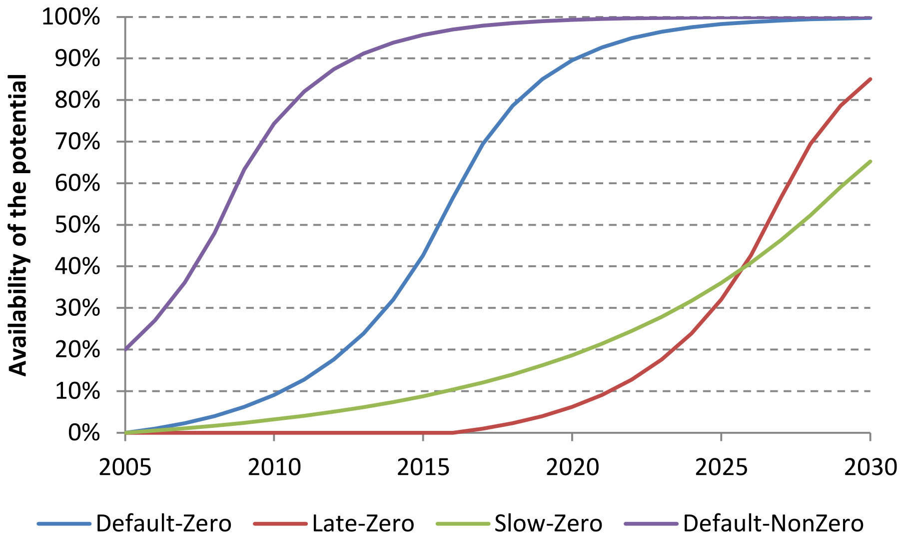

Figure 44: Mobilization restrictions for feedstocks influence the amount of biomass that can be available for conversion.

It should be mentioned that the Default-Zero curve corresponds to a utilization path that requires a full utilization of the additional biomass that can be mobilized each year. In case the mobilization would be lower for certain years, it would mean that 100% utilization will also be reached later. A similar situation applies for the Late-Zero graph. This graph has the same rate parameters as the Default-Zero graph, only the first uptake will start much later. Such a utilization path could apply for straw. Which is currently not utilized in many countries, but might start being utilized in the near future. The green Slow-Zero corresponds to a utilization path that has zero utilization in 2005 and has a slow growth rate, therefore it takes a long time before a large fraction of the potential is utilized. The purple line, Default-NonZero, shows an example where in 2005 already 20% of the potential is utilized. Comparing this utilization path with the Default-Zero, we see that an initial consumption logically results in an earlier convergence towards full utilization. In the model it is possible to modify the growth rate paramters per individual feedstock and per individual country.

Output

The RESolve-biomass model calculates the minimum additional cost allocations for bioenergy and biochemical that satisfy the demand, allowing for trade between the countries, and import. Typical output of the model is

- Consumption of domestic and imported biomass, including several categorization levels
- Yearly composition of different biofuels in the market
- Composition of bio-electricity and bio-heat technology mix

- Total generation costs
- Marginal costs of intermediate and final commodities
- Insight into regional differences: demand, production and import/export flows

Model updates within S2Biom

Compared to the application of RESolve-Biomass as applied in the IEE project Biomass Policies [3] the following modifications have been applied:

- Demand and production routes for chemicals from lignocellulosic biomass have been added to the model
- Nine non-EU countries have been added to the model: Albania, Bosnia and Herzegovina, Moldova, Montenegro, The former Yugoslav Republic of Macedonia, Serbia, Turkey, Ukraine and Kosovo
- Pyrolysis pathways have been added, see Figure 43
- Several other technologies have been added, using the database from S2Biom WP2, see section 2.2.1
- Update of techno-economic data using the database from WP2 of S2Biom, see also section 2.2.1

Annex II: Regions considered in this study.

The S2Biom project includes Western Balkans, Moldova, Turkey and Ukraine in addition to the EU-28 Member States. The countries are grouped under 6 regions, namely Central, East, North, SouthEast, SouthWest and West. The country groupings per region are introduced in Table 4.

Table 4 Country groupings per Region

Central	East	North	SouthEast	SouthWest	West
Austria	Moldova	Denmark	Albania	Spain	Belgium
Czech Rep	Turkey	Estonia	Bosnia and Herzegovina	France	Germany
Hungary	Ukraine	Finland	Bulgaria	Italy	Ireland
Poland		Lithuania	Cyprus	Malta	Luxembourg
Slovakia		Latvia	Greece	Portugal	The Netherlands
		Sweden	Croatia		United Kingdom
			Montenegro		
			Macedonia		
			Romania		
			Serbia		
			Slovenia		
			Republic of Kosovo		

Annex III: Biomass types considered in RESolve-Biomass

Table 5: Biomass types in RESolve Biomass as used in S2Biom, grouped in the proposed classification.

Product Name	Biomass Category	Product Name	Biomass Category
Domestic primary products		***Domestic secondary residues***	
Agricultural		*Agricultural*	
Forage maize	Rotational crops	Food and Beverage Industry[19]	Wastes
Rapeseed	Rotational crops	*Forestry-based*	
Soya	Rotational crops	Saw dust	Secondary forestry residues
Maize	Rotational crops	Sawmill by-products	Secondary forestry residues
Sugarbeet	Rotational crops	Other industrial wood residues	Secondary forestry residues
Sunflower seed	Rotational crops	Black liquor	Secondary forestry residues
Cereals	Rotational crops		
Miscanthus	Perennial crops	***Domestic tertiary residues***	
Reed Canary Gras	Perennial crops	*Agricultural*	
Switchgrass	Perennial crops	Used fats/oils	Wastes
Forestry-based		Dry manure	Agricultural residues
Current Roundwood production	Roundwood	Wet manure	Agricultural residues
Additional Harvestable Roundw.	Roundwood	Common sludges	Wastes
Perennials - woody crops	Perennial crops	Collected VFG	Wastes
		MSW	Wastes
Domestic primary residues		Landfill	Wastes
Agricultural		*Forestry-based*	
Leave and beet top from sugarbeet	Agricultural residues	Post-consumer wood	Tertiary forestry residues
Straw from cereals	Agricultural residues	Paper cardboard	Tertiary forestry residues
Straw from rice	Agricultural residues		
Stubbles from OSR and Rapeseed	Agricultural residues	***Imports of primary products***	
Prunings and pits from olives	Agricultural residues	Biodiesel import	
Prunings from fruit trees	Agricultural residues	Bioethanol 2G Import	
Stover from grain maize	Agricultural residues	Bioethanol Import	
Verge grass	Wastes	Palm oil import	
Forestry-based		UFO Import	
Landscape care wood	Landscape care wood		
Primary forestry residues	Primary forestry residues	***Imports of a blend of primary product and residues***	
Primary forestry residues new	Primary forestry residues	Wood pellets import	

[19] Digestable waste streams from the food and beverage industry