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

Functional description of the REsolve model kit and the biomass allocation

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Contents

Preface

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

In this report a set of ECN models, used within Biomass Futures Project, to quantitatively estimate how the different biomass resources can be allocated in a cost-effective way to the different energy uses is described. This biomass allocation is based on an interaction between three ECN submodels within an iterative scheme. The RESolve-biomass model is the central model for biomass allocation, covering bio-electricity, bio-heat and biofuels. However, RESolve-E and RESolve-H deal with the electricity sector(including CHP) and the heating sector respectively in a more dedicated way. Therefore an interaction between the three models is necessary for a robust quantitative assessment of the bioenergy deployment in the EU27. An overview of the interaction scheme is given and the three models are briefly described.

1

Introduction

The Renewable Energy Directive (RED) (Directive 2009/28/EC) sets mandatory renewable energy targets for each Member State to meet 20% of the EU's final energy demand from renewables by 2020. As part of the overall target, a binding minimum target for each Member State to achieve at least 10% of their transport fuel consumption from renewable sources is also included. In 2007, around 67 % of the EU gross renewable energy consumption was from biomass resources and its absolute contribution is expected to grow significantly according to the National Renewable Energy Action Plans (NREAPs) (Beurskens and Hekkenberg, 2011), see Figure 1.

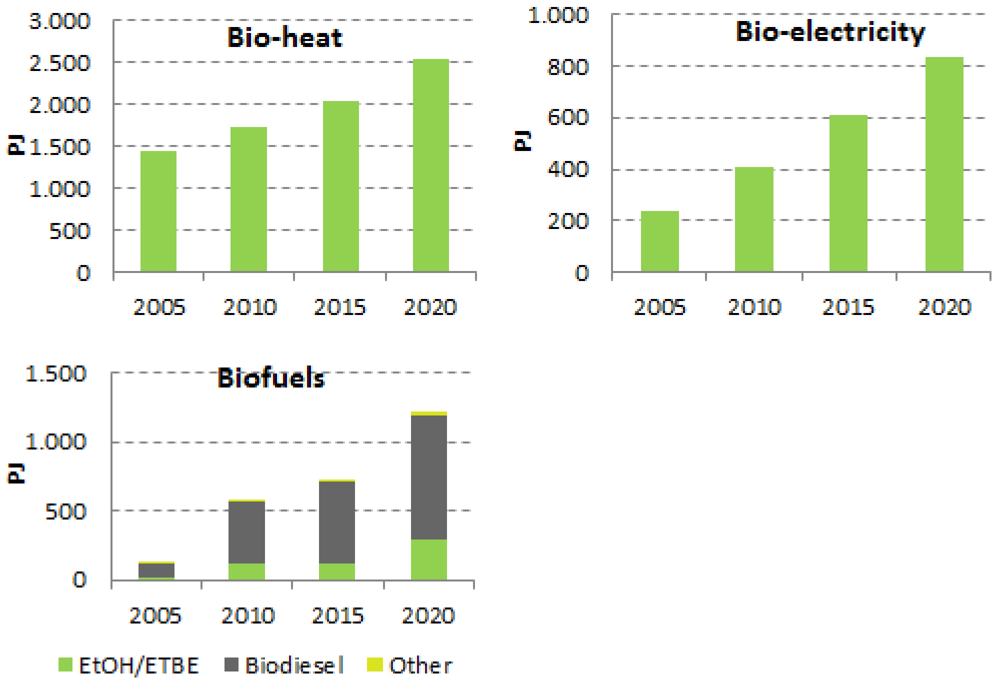
The BiomasFutures project, funded by the Intelligent Energy Europe (IEE) programme of the European Commission (EC), aims at using modelling frameworks in order to inform policy makers with quantitative information on the role biomass can play to meet the renewable energy and the Green House Gas (GHG) emission reduction targets included in the Climate Action and Renewables Policy Package of the European Commission (as adopted by the European Parliament on December 17, 2008), and the Renewable Energy Directive.

However, biomass resources, differently from many other renewable options, can serve many different sectors, among which electricity, heat and transport sectors are the centre of attention in this study.

In particular, the problem of allocation of biomass resources among the different possible uses will be investigated using the modelling tools described in this report. In principle, if biomass availability is cost competitive and unlimited, the full demand for biomass of all three sectors can be met. However, in practice demand might exceed supply, creating competition for the same biomass resources. In order to mimic such competition and estimate the role biomass can play in the EU energy system from 2010 to 2030 (with intermediate 2020) the ECN RESolve model set will be used.

The RESolve model consists of a set of three independent sub-models, known as RESolve-biomass, RESolve-E and RESolve-H. In WP5 of Biomass Futures these models interact with each other to allow for allocation of biomass use for biofuels, bioelectricity and bioheat. In this report, first the iterative allocation scheme is introduced (chapter 0), followed by a more detailed description of the sector models (chapters 3, 4 and 5).

Figure 1: Contribution of biomass in the electricity, heating and transport sectors in the EU27 according to NREAPS



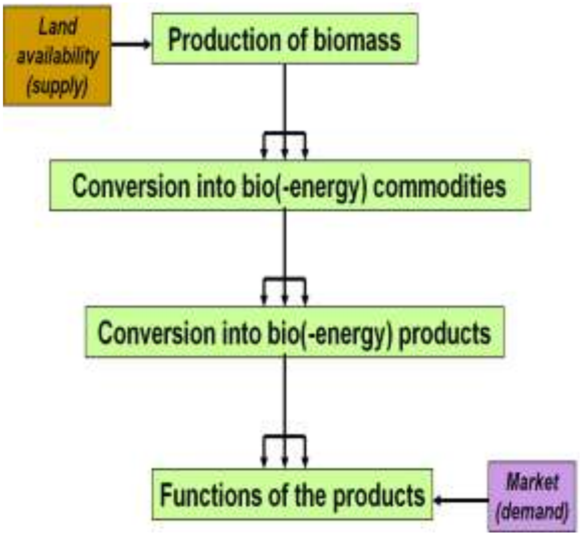
2

Biomass allocation in the RESolve model kit

2.1 Introduction

In Figure 2 a high-level scheme representing the biomass production-consumption chain is depicted. The initial supply is determined by the amount of land that is available for growing energy-related biomass; the produced biomass is then converted into energy commodities and products that can be sold in the market. Competition among different biomass resources, as well as among different energy sources takes place within the different demand sectors.

Figure 2: Biomass production-consumption chia



This study only focuses on biomass for energy generation; other important uses of biomass (such as food and biochemicals) are not addressed. Therefore the potentials considered in this study only include biomass for energy production. Thus, the following demand segments are considered:

- Biofuels demand
- Bioelectricity demand
- Bioheat demand

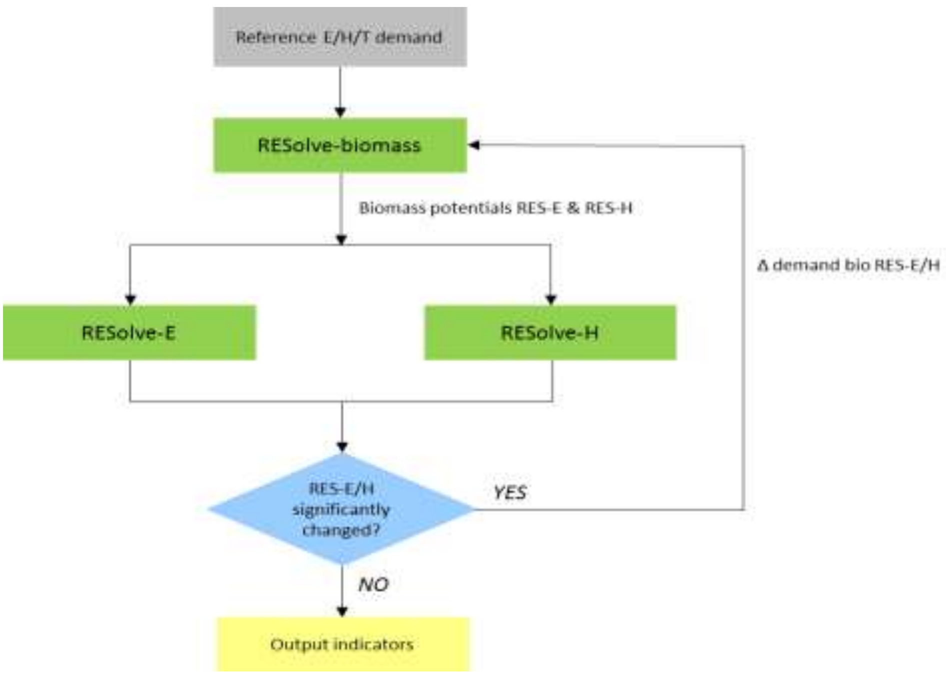
2.2 Iterative allocation scheme

The biomass allocation is based on an interaction between the three RESolve sub-models. This is accomplished as described in the following steps:

1. The starting point is an initial or reference demand for biomass for electricity, heat and biofuels. In the Biomass Futures project the National Renewable Energy (NREAP) projections are used as reference demand.
2. Based on this reference biomass demand, RESolve-biomass model allocates biomass resources according to the least additional costs with respect to a reference commodity.
3. RESolve-biomass calculates biomass use for biofuels, electricity and heat, quantified per type of feedstock. This is then used as fuel potential in RESolve-E and RESolve-H. Biomass imports are also included in this potential. The price per type of feedstock is also exported from RESolve-biomass to RESolve-E and RESolve-H.
4. Based on these biomass potentials and costs, RESolve-E and RESolve-H give a projection for biomass use for electricity and heat.
5. If this demand is significantly different from the initial demand, the change in demand is fed back into RESolve-biomass.
6. Step 2-5 are then iterated until a convergence in biomass demand is reached. At the end of this process several output indicators can be calculated.

A schematic overview of how the different RESolve sub-models interact with each other is shown in Figure 3.

Figure 3: Biomass allocation in RESolve: interaction among the sub models and iterative scheme



2.3 Biomass feedstocks used in the models

An overview of all primary biomass feedstocks used in RESolve-biomass can be found in Table 1. RESolve-biomass also generates some intermediate products, they can be found in the upper part of the last column. RESolve-E and RESolve-H use a subset of these feedstocks. The primary and intermediate feedstocks that are used in RESolve-E are indicated in blue. The feedstocks that are used in both RESolve-E and in RESolve-H are indicated in a blue-red pattern. In several occasions RESolve-E and RESolve-H don't use the primary biomass feedstock as an input, but an intermediate feedstock. For example, primary forestry residues are not directly used but wood chips or wood pellets. The only primary feedstock that is solely imported from outside the EU is palm oil. An overview of all products that are imported from outside the EU is given in the lower part of the last column.

Table 1: Primary biomass feedstocks, intermediate feedstocks and import products in the RESolve models

Biomass category	Primary biomass feedstock
Wastes	Animal waste
	Municipal solid waste
	Sewage sludge
	Grass land cuttings
	Landfill gas
	Used fats/oils
	Verge grass
Agricultural residues	Cereals
	Dry manure
	Prunings
	Straw
	Wet manure
Rotational crops	Forage Maize
	Maize
	Rapeseed
	Sugarbeet
	Sunflower
	Sweet Sorghum
Perennial crops	Grassy crops
	Woody crops
Palm oil	Palm oil
Landscape care wood	Landscape care wood
Roundwood	Current Roundwood production
	Additional Harvestable Roundwood
Primary forestry residues	Primary forestry residues
Secondary forestry residues	Saw dust
	Sawmill by-products
Tertiary forestry residues	Black liquor
	Other industrial wood residues
	Paper cardboard
	Post consumer wood

Intermediate feedstocks
Biogas
Chipped grass
Chipped prunings
Manure digestate
Pure vegetable oil
Wood chips
Wood pellets
Torrefied biomass
Torrefied wood pellets
Torrefied straw

Imported products
Palm oil
Cereals
Maize
Rapeseed
Sunflower
Wood pellets
Bioethanol
Biodiesel

Used in RESolve-E

Used in RESolve-E and RESolve-H

2.4 Common elements in the RESolve models

There are several elements that the RESolve models have in common. As mentioned in section 0 RESolve-E and RESolve-H use a subset of the primary and intermediate feedstocks as used by RESolve-biomass. Logically the models also share the same biomass prices and technology characteristics where applicable. All models run on a year by year basis and are also able to present output on a yearly basis.

All models are able to produce results up to 2030. The geographical scope and resolution of the models are also the same. All models cover the EU27 on a country by country basis. Where applicable the models share the same prices of other commodities (fossil fuels, reference electricity price). Support measures are harmonized among the models, although the support measure in RESolve-biomass are somewhat more aggregated than in the other two models. Furthermore the RESolve model cover the renewable developments in a dynamic fashion, while the developments in the fossil sector are treated as exogenous and static.

The three RESolve models are described in some more detail in the next three chapter.

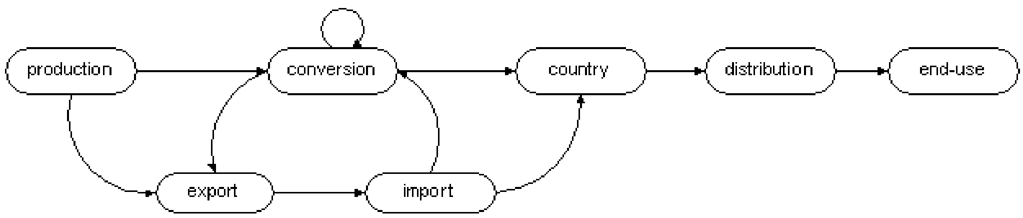
3

RESolve-biomass

3.1 Introduction

RESolve-biomass determines the least-cost configuration of the entire bioenergy production chain through minimal additional generation cost[1] allocation, given demand projections for biofuels, bioelectricity and bioheat, biomass potentials and technological progress, see Figure 4 (Lensink et al, 2007; Lensink & Londo, 2010; Faaij & Londo, 2010). By doing so it mimics the competition among the three sectors for the same resources. The RESolve-biomass model includes raw feedstock production, processing, transport and distribution. Constraints on avoided emissions, over the entire chain, can be included in the model as well. One of the most important features of the RESolve-biomass model is the ability to link the national production chains allowing for international trade. By allowing trade, the future cost of bioenergy can be approached in a much more realistic way than when each country is evaluated separately.

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



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

The RESolve-biomass model includes:

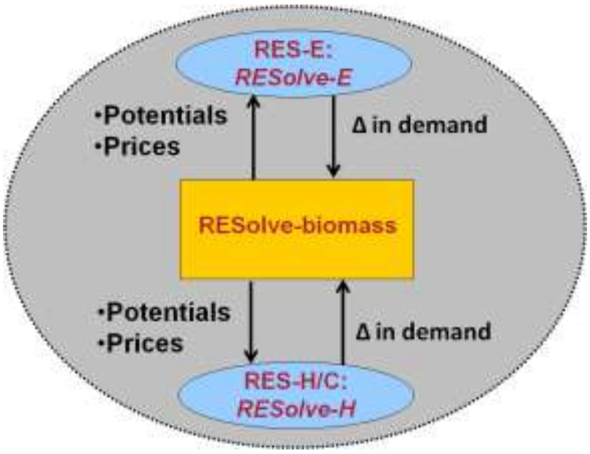
- 31 crop/non-crop raw materials (primary feedstocks),
- 45 conversion steps with 10 intermediate products ,
- 1 auxiliary and 7 by-products

[1] the total costs of bioenergy generation minus the cost of reference conventional fossil fuel energy production.

- 7 biofuels and associated distribution technologies, bioelectricity and bioheat as final products
- 30 countries: EU27 and Switzerland, Norway and Ukraine + import from the rest of the world.

Once the primary biomass resources are allocated to each sector (on a country level) they are analysed in the sector models RESolve-E and RESolve-H, in which the complexities of electricity and heat sectors are also reflected. Moreover, competition with other RES technologies for electricity and heat, and their implications to bioenergy deployment are studied. The resulting (change in) demand for bioelectricity and bioheat feeds back into RESolve-biomass. The whole procedure is iterated until a consistent solution in terms of cost allocations, demands and potentials is achieved. The interaction between the models is summarized in Figure 5.

Figure 5: Interaction among RESolve model



3.2 Production & conversion

It is assumed that every country in the model has one production plant for each raw material and one processing plant for each conversion (sub) process. Feedstock production costs and potentials are provided as input for the model from Elbersen et al., (2012). The feedstocks included in the RESolve-biomass model can be found in Table 1.

In order to produce heat, electricity or biofuels from the biomass resources, one or more conversion steps are needed. Each country has a complete chain of conversion facilities, with country and process specific costs for each conversion step. For each step, different indicators are used to calculate costs and output:

- Raw material costs [€/GJ]
- Full load hours [hours/year]
- Lifetime [year]
- Operations and Maintenance costs (O&M costs) [€/(GJinput/year)]/ [€/(ton input/year)]/)]/ [€/kW_output/year]
- Specific investment costs [€/(GJinput/year)]/ [€/(ton input/year)]/)]/ [€/kW_output]
- Introduction year of a technology
- Yield of product (Efficiency)
- Interest rates (WACC) of a technology

For biofuels, the investment costs reduce in time depending on the past cumulative output volumes of the technology. As such, the model includes endogenous learning (de Wit et al, 2010). For bioelectricity and bioheat 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 biofuels included in the RESolve-biomass model are:

- Bioethanol (1st and 2nd generation)
- Biodiesel
- Bio-FT-diesel
- Bio-DME
- Bio-SNG
- Bio-ETBE

The demand for bioelectricity and bioheat are subdivided, in line with the Member States' Renewable Energy Action Plans, into

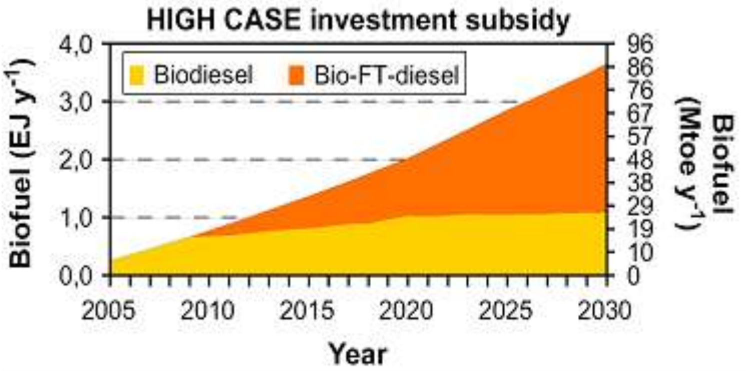
- Solid biomass
- Liquid biomass
- Digestable biomass (biogas)

3.3 Output

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

- yearly composition of different biofuels in the market under different subsidies schemes. An example is presented in Figure 6 (Lensink & Londo, 2010), where the penetration of biodiesel and bio-FT diesel under an investment subside scheme are assessed, in the case of a *high* demand target of 25% of biofuels in 2030.
- composition of bio-energy and bio-heat technology mix,
- total generation costs,
- LCA GHG emission data

Figure 6: Penetration of biofuels products under an investment subside scheme, in the case of *high* demand target of 25% by 2030 (From Lensink et al., 2010)



4

REsolve-E

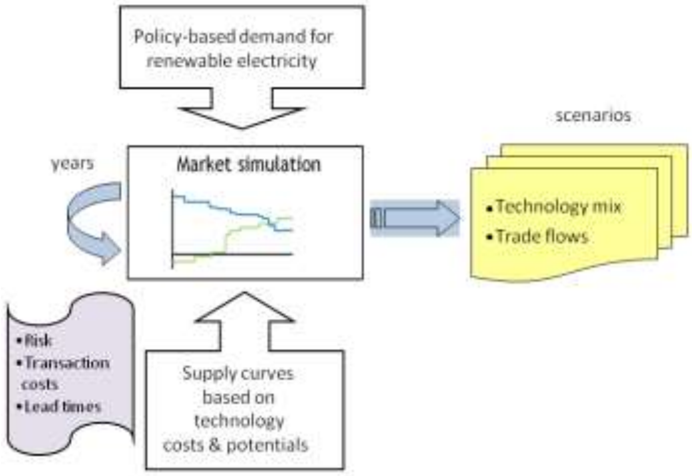
4.1 Introduction

For the simulation of the renewable electricity (RES-E) and bio-CHP developments in the EU RESolve-E model, formerly known as ADMIRE-REBUS, is used (Daniëls & Uyterlinde, 2005). The RESolve-E model is based on a dynamic market simulation in which national RES-E supply curves are matched with policy-based demand curves. The supply and demand curves are constructed as follows:

- Future potentials are estimated for all technology bands within a country, based on a consistent approach, which allows for technology development and learning effects through time. In the model, realisable potentials are used, meaning that all restrictions except economic ones are accounted for.
- An endogenous cost calculation module determines the costs of renewable technologies, using a net present value calculation. This calculation includes all costs and revenues expected over the lifetime of a technology, and thus incorporates the effect of different support policies in a straightforward way. Costs are expressed in terms of the 'Required Green Price', the average minimal green price that the investor has to obtain from the market over the lifetime of the production capacity in order to make the construction of additional green capacity (or the production with existing capacity) attractive.
- Thus, supply curves, based on costs and potentials, are constructed, and their development is simulated through time.
- In parallel, policies acting on the demand side, such as price support of the demand or quota's on consumers or suppliers, are translated into national demand curves.
- Based on technology, market and political risks, a technology and country-specific adder to this Required Green Price is calculated.

The results are calculated in a way that takes into account the discriminative characteristics of some policies, and the ability of producers to choose whether they produce for the domestic market or wish to trade their production. Because of the different levels and conditions of national support schemes, there will not be a single market equilibrium for the EU, but rather different submarkets emerge with local equilibria. Another important model result is the technology mix per country and for the complete EU, e.g. the expected deployment of renewable technologies.
The simulations can be done for several target years up to 2030, taking account of various other factors complicating investment in renewables, such as (political) risks, transaction costs and delays due to planning and permitting processes. These factors contribute to a realistic simulation of the effectiveness of different policy instruments.
A schematic overview of the RESolve-E model is presented in Figure 7.

Figure 7: Schematic overview of the RESolve E model



Policies included in *RESolve-E* are:

- Obligations on renewable electricity consumption
- Feed-in tariffs and Feed-in premiums
- Consumer and supplier premiums
- Tenders
- Investment subsidies
- Fiscal investment measures
- Low interest loans

Input needed for the calculation of the Required Green Price (RGP) is listed below.

Technical parameters:

- Biomass feedstock prices [€/GJ]
- Efficiencies [%]
- Full load hours [hours/year]
- Technical lifetime [year]
- Fixed Operations and Maintenance costs (O&M costs) [€/kW/yr]
- Variable O&M costs [€ct/kWh]
- Investment costs [€/kW]
- Maturity of the technology

Financing parameters:

- Debt/Equity ratio [%]
- Return on equity [%]
- Return on debt [%]
- Debt period [year]
- Depreciation period [year]
- Tax rate [%]
- Inflation rate [%]

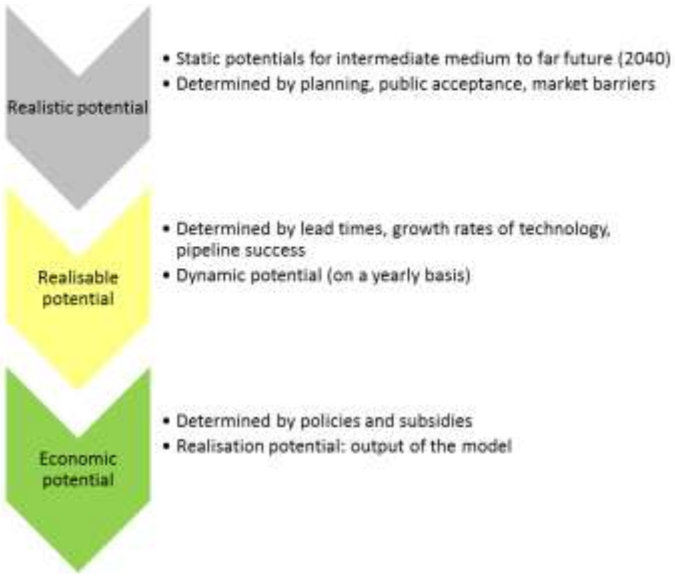
The *RESolve-E* model includes:

- 19 biomass feedstocks (see Table 1),
- 13 technologies, of which 5 different biomass technologies,
- 29 EU countries: EU27, Switzerland and Norway.

4.2 Potentials

In RESolve-E three type of potentials are relevant as indicated in **Figure 8Figure 7**. The highest level of potentials used are the realistic potentials. This realistic potential, for each technology and country, is determined exogenously.The realistic potentials are defined as ”*what is maximally achievable in 2040 if* there are no economical constraints, i.e. that the technology is economically feasible*". Realistic potentials differ from technical potentials in the sense that social acceptance and environmental constraint are implicitly taken into account. There is, for example, a limit to the amount of wind mills that people find acceptable to have in their country, even though physically there is still enough space left. The production capacity of renewable energy per technology can never exceed this potential. In the model the realistic potential is defined for 2040, i.e. what is maximally achievable in the medium to far future. Since the biomass potentials come out of RESolve-biomass , which runs untill 2030, we assumed that 2040 potentials are the same as 2030 potentials.

Figure 8: Potentials in RESolve-E



The realisable potential takes into account various limitations on the deployment growth and is linked to a certain year. In any given year, the realisable potential takes into account constraints due to the limited production capacity of the capital goods industry, the limited speed of opening up the available resources (e.g. biomass), the limited amount of potential entering exploratory courses ('pipeline potential') and the limited amount of investment plans passing these courses and the accompanying legal procedures successfully. For the actual size of the realisable potential, past developments in the renewable electricity market are very important. In the model, the realisable potential incorporates the model results of past years using a vintage approach.

The economic potential, on the other hand, is the potential that will actually be realised depending on the policies in place. The economic potential is, thus, the outcome of the model.

On the basis of the realistic potentials, RESolve-E calculates the realisable potentials and costs in GWh and €ct/kWh.

RESolve-E alone does not allow trade of biomass feedstocks between the countries, however, since the primary biomass feedstocks are derived from RESolve-biomass, which does cover trade of feedstocks, it is covered indirectly. This means, for example, that primary forestry residues from country A, which are converted into wood pellets in the same country, later transported to country B and then utilized for CHP in country B, count as biomass potential for country B for the RESolve-E model. The same is valid for the RESolve-H model.

4.3 Technologies

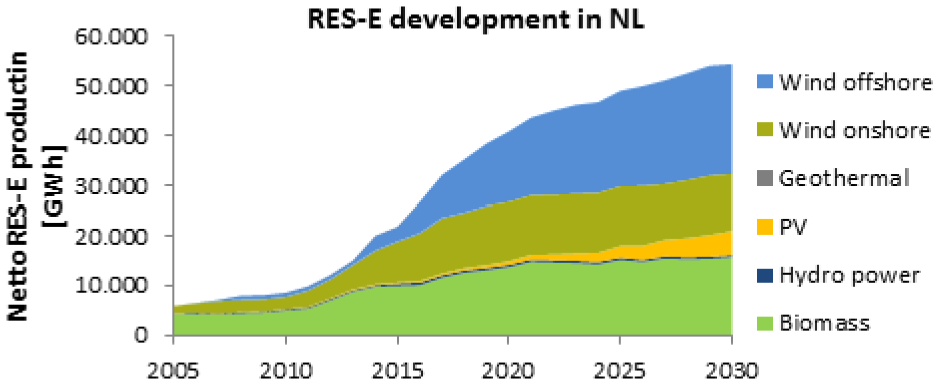
The technologies and the conversion processes, included in the RESolve-E model are:

- Wind onshore
- Wind offshore
- Small and medium hydro power
- Large hydro power
- Solar PV
- Geothermal electricity
- Tidal
- Wave
- Biomass
  - Direct co-firing in coal fired power plants
  - Gasification: Biomass Integrated Gasification Combined Cycle (BIGCC)
  - Combustion (Electricity only)
  - CHP
  - Digestion-CHP

4.4 Output

RESolve-E constructs the supply and demand curves for each RES-E technology based on the policy data, costs and realistic potentials. By matching supply and demand, the RES-E mix and the market prices are calculated. As an example, a sample RESolve-E projection for the Netherlands is presented in Figure 9

Figure 9: RES-E development in the NL



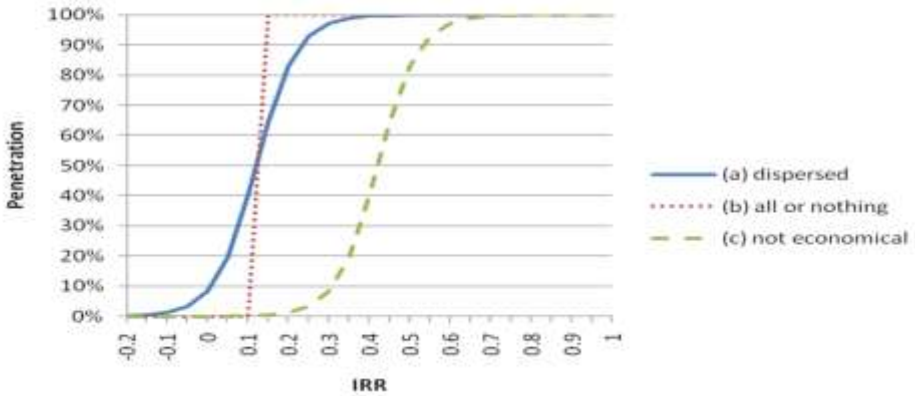
5

Resolve-H

5.1 Introduction

RESolve-H is a simulation model that calculates the penetration of RES-H options based on a *dispersed S-curve* description of consumer's behaviour, Figure 10(a).

Figure 10: Penetration vs. Internal Rate of Return (IRR) in RESolve-H



Each RES-H option has a cost to the consumer, but it also brings some benefits, namely the avoided costs of using non-RES fuels. When the benefits for a certain option are comparable to the costs, the option starts to become economically attractive for the consumer. This is modelled by considering the Internal Rate of Return (IRR) of a certain option, taking explicitly into account the avoided costs of not using fossil fuels. In the example of **Σφάλμα! Το αρχείο προέλευσης της αναφοράς δεν βρέθηκε.** (b) all consumers immediately switch to RES-H as soon as the IRR is higher than 0.12. This *all or nothing* case is obviously not very realistic, and the real consumer behaviour is better modelled by a *dispersed* S-curve such as the one in Figure 10(a): early adopters would invest even at 'uneconomical' levels of the IRR (cf. the range below 0.12), whereas some players ('laggards') do not even invest as higher levels of the IRR (cf. the range above 0.12) because other, non-financial barriers prevent them from doing so.

The influence of policies on consumer's behaviour can be modelled by:

- direct relations between policies and the cost-benefit ratio (for example investment subsidies or feed-in tariffs)
- shifting the S-curve (**Σφάλμα! Το αρχείο προέλευσης της αναφοράς δεν βρέθηκε.** (c)) or changing its shape, to simulate other impacts of policies on consumer behaviour: increased awareness, targets, measures on suppliers

5.2 Potentials and production

The potentials in RESolve-H are calculated starting from the total heat demand per member state in the Industrial, Residential and Tertiary sector in 2008 (the model's *base-year*). The demand data are taken from the Odyssee database (www.odyssee-indicators.org, sourced August 2011), projected to 2020 by applying growth factors derived from NREAPs, and then extrapolated towards 2030. To determine to what extent this demand can realistically be fulfilled by RES-H technologies a series of constraints is applied to the initial heat demand, effectively narrowing it down to a realizable potential. This potential should be interpreted as a *substitution potential*, i.e. how much of a certain fossil fuel-based heating technology can be replaced by a RES-H technology.

The constraints that are applied to the initial heat demand are:

- constraints on the *fuel supply*: availability of biomass feedstock, coming from RESolve-biomass
- constraints on the *equipment growth*: upper limit on how much each RES-H technology can be expected to grow in the future
- constraints on the *demand side*: upper limit on how much of a certain fossil fuel-based heating technology can be replaced by a RES-H technology

After potentials have been determined, the extent to which the technology will penetrate the market is limited by:

- *cost-benefit ratio*: the Internal Rate of Return (IRR) of a certain replacement option
- *consumer behaviour*: the shape of the S-curve

In practice, in order to determine the penetration of RES-H technologies, a cash-flow analysis is carried out for each possible replacement option. The analysis is based on knowledge of techno-economic parameters of each RES-H technology (i.e. investment and operation and maintenance costs, conversion efficiency, full load hours and lifetime), and price series of fossil fuels and biofuels used for heating. The avoided costs of *not* using a certain fossil fuel are explicitly taken into account in the calculation. From the cashflow analysis the IRR of each possible replacement option is calculated, and via the S-curve the final penetration is obtained.

5.3 Conversion technologies

The technologies considered in the RESolve-H model are summarized in **Σφάλμα! Το αρχείο προέλευσης της αναφοράς δεν βρέθηκε.**Table 2.

Table 2: RESolve-H technologies

Technology type	Technology	Used in Biomass Futures
Biomass	Combustion (Heat Only) of wood and residual streams in all demand sectors	✓
	Direct Firing	
	CHP	
Geothermal	Direct use in Residential, Industrial and Tertiary sector	✓
Solar Thermal	Direct use in Residenatial, Industrial and Tertiary sector	✓

Among the biomass technologies, *Direct Firing* and *CHP* have not been included in the present study. The former technology has a limited potential in only a few industrial subsectors and has therefore been excluded. The latter is already covered by RESolve-E.

Depending on the sector and the input feedstock, *Biomass Combustion (Heat Only)* has been further split into 6 different technologies that can be directly matched with processes within RESolve-biomass, therefore allowing for interaction between the two sub-models. The matching is summarized in Table 3.

Table 3: Matching between RESolve-H and RESolve-biomass

RESolve-H Technology	Sector	Input Feedstock	RESolve-biomass Process
Biomass Combustion (Heat Only)	Industry	Verge Grass	Waste combustion - heat only
		Wood Chips	Local heating plant for wood chips - large scale (5 MW)
	Residential	Wood Pellets	Residential wood pellet boilers - small scale (35kW)
		Wood Chips	Residential wood chips boilers - small scale (35kW)
	Tertiary	Wood Pellets	Local heating plant for wood pellets - medium scale (0.5MW)
		Wood Chips	Local heating plant for wood chips - medium scale (1 MW)

5.4 Output

Given techno-economic and cost data of RES-H technologies, fuel prices, policy measures, and a representation of consumer behaviour (shape of S-curve), RESolve-H calculates the penetration of renewables in the heating sector (residential, services and industry). As an example, modelling results for the 'Reference scenario' of Biomass Futures have been presented in **Σφάλμα! Το αρχείο προέλευσης της αναφοράς δεν βρέθηκε.** and **Σφάλμα! Το αρχείο προέλευσης της αναφοράς δεν βρέθηκε.**, in which for the years 2020 and 2030 the biomass final heat demand is close to 80 Mtoe for EU-27.

Figure 11: Penetration of biomass according to RESolve-H in various cross-sections for the reference scenario

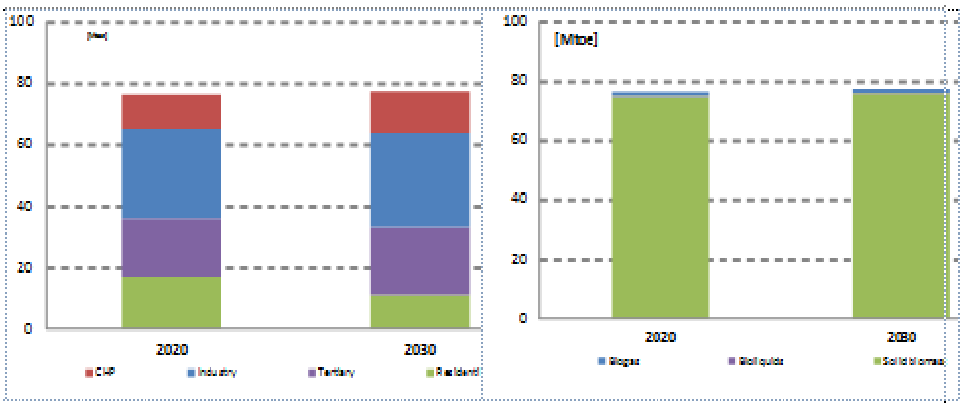
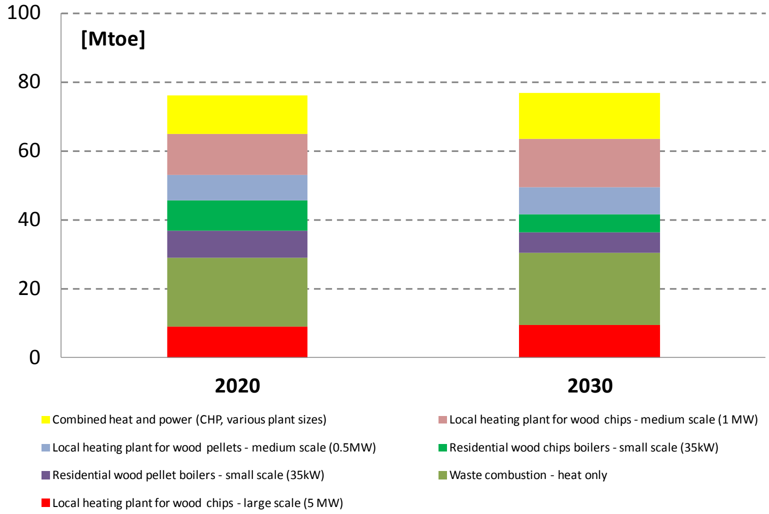


Figure 12: Contributions from various biomass technologies according to RESolve-H for the reference scenario



6

Conclusions

In this report a set of ECN models, used within Biomass Futures, to quantitatively estimate how the different biomass sources can be allocated in a cost-effective way to the different energy uses is described. This biomass allocation is based on an interaction between three ECN submodels within an iterative scheme. The RESolve-biomass model is the central model for biomass allocation, covering bio-electricity, bio-heat and biofuels. However, RESolve-E and RESolve-H deal with the electricity and CHP sector and the heating sector respectively in a more dedicated way. Therefore an interaction between the three models is necessary for a robust quantitative assessment of the bioenergy deployment in the EU27.

7 References

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