Technical University of Denmark

DTU

Bioenergy yields in Denmark in the RES2020 Pan European TIMES model

Grohnheit, Poul Erik; Callesen, Ingeborg; Østergård, Hanne

Link back to DTU Orbit

DTU Library
Technical Information Center of Denmark

Poul Erik Grohnheit[1]*, Ingeborg Callesen[2,3], Hanne Østergård[3]

Bioenergy yields in Denmark in the RES2020 Pan European TIMES model

*Corresponding author [1]Systems Analysis Division, Risø DTU,
Technical University of Denmark, pogr@risoe.dtu.dk.

[2]DTU Management, Technical University of Denmark, inca@dtu.man.dk.

[3]Biosystems Division, Risø DTU, Technical University of Denmark, haqs@risoe.dtu.dk.

Abstract. The Pan European TIMES model that was developed as a part of the EU research projects NEEDS and RES2020 and the model now covers more than 30 countries. The projects are now finished, and results from the RES2020 project have become available online. Further applications of the model are now being developed under various projects, e.g. the present..

As biomass resources are limited, optimization of biomass production from land resources is desirable. The biological production potential of cultivated land is a combination of physiographic conditions (soil quality and climate), crop type, seed material, cultivation method, fertilizer and irrigation. Assessment of the potential sustained biomass supply is needed in order to evaluate the potentials of switching from fossil-based carbon to actual biomass sources for energy and goods.

Estimation of biomass feedstock potentials from energy crops and crop residues in future scenarios may be based on various modelling approaches, taking into account environmental concerns such as loss of biodiversity and water quality in the agricultural landscape. The aim of the work within the 3-year post doc project was to provide a simple transparent analysis of bioenergy yields from selected crops that are suitable for bioenergy in Denmark. The assumptions made for this static model will be implemented into the national model, which is included in the RES2020 Pan European model. In contrast to the model described above this is a dynamic model covering the period 2005-2020 with model calculations until 2025. The results of the static model are tested against the the final results from the RES2020 project.

Keywords: Biomass; Denmark: RES2020 project; Pan European TIMES.

1 Introduction

The Pan European TIMES model that was developed as a part of the EU research projects NEEDS (www.needs-project.org/) and RES2020 (www.res2020.eu/) now covers more than 30 countries. These projects are now finished, and results from the RES2020 project are available online. Further applications of the model are now being developed under various projects, e.g. REACCESS, PLANETS (www.feem-project.net/planets), and "Storage Utsira" on carbon capture and storage in the five countries around the North Sea.

This paper describes a national application focusing on the potential for bioenergy in Denmark, which is based on a simplified spreadsheet model (Callesen et al., 2010a,b, Grohnheit, 2008).

2 Using the RES2020-TIMES Pan European model as basis for national model studies

2.1 The EU RES2020 project

RES2020 (2006-09) aimed at analysing the present situation of the RES implementation, i.e., defining future options for policies and measures, calculating specific targets for the RES contribution that can be achieved by the implementation of these options and finally examining the implications of the achievement of these targets to the European economy.

The NEEDS-TIMES Pan-European model has been enhanced for the renewable technologies that are in the focus of the RES2020 project. These are

- Renewable electricity generation, including wind and distributed electricity generation

- Biomass for electricity and heat

In the original project plan it was assumed that the NEEDS-TIMES model should be run by the model teams with the enhancements country by country. This was changed, so that the Pan-European model, which has been taken over from NEEDS, was run centrally as a multi-regional model. This means that both enhancements and calibration of 2005 data from Eurostat have been made centrally. The final results, corrections and main sensitivity results were distributed May-July 2009, now available online via www.res2020.eu. A huge material covering all sectors of the energy system with consistent results for several policy scenarios and variants is available for further analyses.

2.2 Primary and final energy use in Denmark

The four scenarios analysed in Res2020 were (BAU) based on policies without the ingredients of the January 2008 energy and climate package and 3 policy scenarios: (RES) a reference scenario for the 2020 policies, in which the essentials of this package are implemented, (RES-T) where – next to physical trade of (renewable) electricity and bio-fuels – a virtual trade mechanism in RES production rights is in place, and (RES-30%) in which the greenhouse gas emission reduction objective for EU is 30% instead of 20%. These scenarios

were calculated for all countries (EU27 plus Norway, Iceland and Switzerland). For some countries further variants were analysed.

For Denmark the share of renewable was 9 % in 2000. This figure will increase to 24 % by 2020 in the BAU scenario, and 27 % in the policy scenarios, with very little variations among these scenarios, mainly due to the planned increase in off-shore wind and biomass in the electricity and heat sector. Also for primary and final energy, the three policy scenarios give very similar results. The most important development of renewables is the further penetration of wind power, which is policy driven. Further, there is a significant increase in bioenergy from 2000 to 2020 in the BAU scenario and some additional increase in the policy scenarios, but little difference among these three scenarios (Figure 1). Some small variations among the policy scenarios are found in the central electricity and heat sector for 2020.
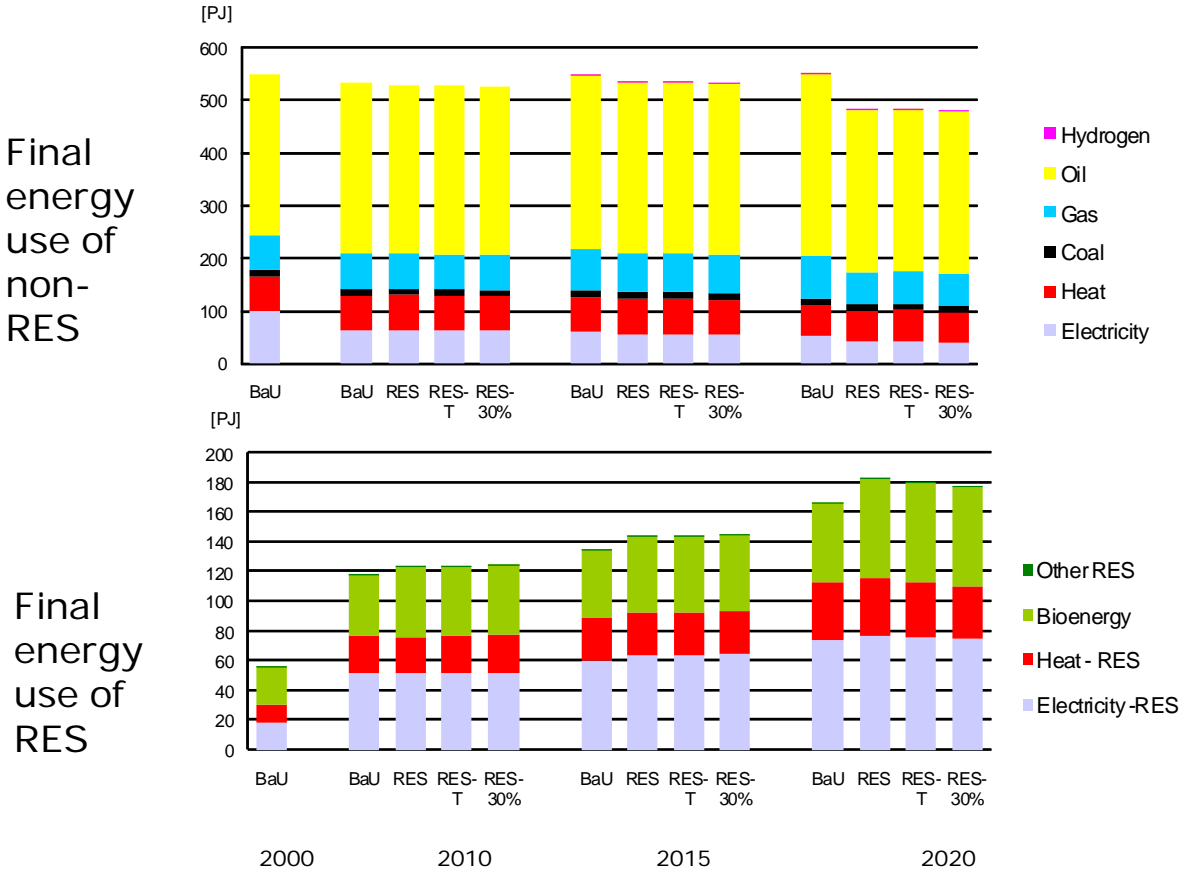
Figure 1. RES2020 Results: Final Energy use of renewable and non-renewables

For Denmark the RES and RES-T scenarios mean 30 % share of RES in final energy by 2020 and for all sectors, which do not fall under the European Emissions Trading scheme, a CO_2 emissions cap of 21.2 Mtons.

2.3 Use of renewable energy sources

Analysed by sector, the use of renewable energy in the scenarios reveal that bioenergy (wood) based central heat & power is the dominant source. Renewables in agriculture are mainly based on agricultural waste, in particular straw and biogas in a small scale. However, the preferred use of agricultural waste is in the district heating sector, mostly for CHP supplying

small district heating systems, although straw is also used in large-scale CHP units. The model results for industry are uncertain.

There is little tradition for optimization modeling of large energy consuming industries in Denmark, because there are only few plants, i.e., one cement plant and one steel work which has operated only in short periods during recent years. The central electricity and heat is by far the most important user of renewables.

2.4 Electricity and heat

In the 1980s nearly all new capacity was medium-sized extraction-condensing units for large-scale CHP; in the 1990s a significant share was small-scale gas-fired CHP units for decentralised district heating systems. Wind power covers about 20% of the electricity demand in the years 2004-2008 on an annual basis. 2.8 GW installed capacity and 6.6 TWh of wind generation covers approximately 20% of the nation's demand (2005-2008). The Government's new energy strategy supports the expansion of wind energy capacity for on- and offshore. Prospects for micro CHP are limited due to the large role of district heating in heating of single-family houses. Industrial autoproducers have generated about 9 % of the total demand after 2000.

The district heating infrastructure covers all the more densely populated urban areas, including small towns and villages (22% of the heat supply for single family houses and 66% for multi-family houses). Base load heat in nearly all district heating networks is supplied CHP plants, ranging from less than 1 MW gas motors to large-scale power plants. In urban areas with interconnected district heating systems incineration of urban waste for energy have priority over other sources for heat supply. Natural gas covers individual homes in areas less suitable for district heating (18% of the heat supply for single family houses and 9% for multi-family houses in 2005). All densely build up areas are zoned for district heating or natural gas depending on heat densities and access to networks. Electric resistance heating (about 5 % of the heat market) is being phased out in areas zoned for district heating or natural gas. Outside these areas heat pumps or biomass renewables are encouraged. Expanding the district heating systems with flexibility using heat storages will be one of the measures to accommodate much larger amounts of wind power.

2.5 Transport fuels

The available biomass resources may be used for either transport or electricity and heat. The infrastructure for the use of biomass for electricity and heat is available, and it is being further developed. The key priority for new transport fuels is electricity for charge of batteries for electric vehicles. This technology will be needed for an efficient further penetration of wind power. Thus, electric cars supplied by wind power are seen as an important means to achieve the target of 10 % renewable in transport. Biofuels for transport is an important Danish research priority.

2.6 Trade and import dependency

Currently, the only import of fossil fuels to Denmark is coal for the central electricity and heat sector. The current oil and gas production exceeds the national demand, so the surplus is

exported. However, both oil and gas production has peaked about 2005 and is expected to decrease over the next decade.

The trade pattern for electricity is determined by the variations in hydro power in Norway and Sweden and wind energy in Denmark. The remaining fossil electricity-only production has become the 'swing producer' on an annual basis, and in recent years this production has become larger than gross export. The current RES2020 Pan European model is not designed to model this trade or the intermittency of wind power.

2.7 Impacts of policies on emissions and costs

The model results for 2020 show reductions of CO_2 emissions for both the ETS sectors and the Non-ETS sectors for the policy scenarios compared to the BAU scenario. The reductions in the residential and industry sectors are mainly due to increased use of RES in these sectors, which is the same for all policy scenarios. For the central electricity and heat sector increased use of wind power and biomass as combustible renewable lead to reduction of CO_2. The reduction is largest in the scenario with the most ambitious CO_2 reduction target.

The total investment costs and operational costs of renewable technologies are calculated by the model between 500 M€ and 1000 M € by 2020, or about 0.01 % of GDP with no significant difference among the BAU scenarios.

2.8 Conclusions of RES2020 for Denmark

The BAU scenario for Denmark shows a significant increase in renewable energy sources until 2020 as shown in Figure 1. This leaves little room for further penetration of renewables in the policy scenarios, and even less room for optimisation results of different policy scenarios. However, the results, which are now available online, may be explainable within the logic of the optimisation model.

The first set of results from the Pan European model – as a result of the NEEDS project – from the autumn of 2007 was presented primarily as European totals as a long-term reference until 2050 for the selection of new technologies (see Grohnheit, 2008). The next step has been the enhancements of some of the model sectors and the much shorter time horizon until 2020, which gives much less room for large-scale penetration of new technologies. These results are now being improved by further analyses of the assumptions and results in the individual national models. The common structure of models for 30 European countries will allow accumulation of model experience, and thus improve the conclusions that may be drawn from the results – mainly using the national models individually. The current results for biomass trade indicate that the Pan European model may be used to disclose a trade pattern that will benefit from the differences in infrastructure and existing equipment among the European countries.

3 Bioenergy yield from cultivated land in Denmark

To further resolve the sources and potentials of bioenergy supply in Denmark the framework of the TIMES model was used in a much simpler model for a fuel mix of bioenergy and fossil

energy with more elaborate data for cultivation of bioenergy and based on an economical optimisation of the choice of crops grown. The biological production potential of cultivated land is a combination of physiographic conditions (soil quality and climate), crop type, seed material, cultivation method, fertilizer and irrigation. Assessment of the potential sustained biomass supply is needed in order to evaluate the potentials of switching from fossil-based carbon to actual biomass sources for energy and goods.

For Denmark, energy policy goals have been set by the Danish Government (Danish Energy Agency, 2009). By 2011, the Danish energy supply from renewable energy sources should be 20%. The utilization of biomass is closely linked with the structure of the Danish bioenergy sector. The combustion of biomass for district heating and combined heat and power (CHP) is well developed as technology and infrastructure. There is no pulp and paper industry in Denmark, and by 2005, a fuel ethanol industry was non-existing.

3.1 Biomass in energy models

Estimation of biomass feedstock potentials from energy crops and crop residues in future scenarios may be based on various modelling approaches, taking into account environmental concerns such as loss of biodiversity and water quality in the agricultural landscape (EEA, 2008). Biomass is all kinds of photosynthetic tissue, and for simplicity potential bioenergy crops may be grouped into starch, oil, sugar, grassy and woody biomass products like in two recent projects under Intelligent Energy Europe, REFUEL (Fischer et al. 2010a,b) and RES2020 (2009). REFUEL includes an assessment of biomass potentials for biofuel feedstock production in Europe, which is based on IIASAs agro-ecological zones modeling framework.

Technologies for use of biomass for energy are considered in RES2020. In contrast, the upstream technologies, i.e. cultivation of crops, were not considered in RES2020 TIMES. However, these technologies were in the focus of the work within a project to provide a transparent analysis of bioenergy yields from crops that are suitable for bioenergy in Denmark, which is reported in Callesen et. al., 2010a,b.

An optimisation model in an Excel workbook was used to explore links between energy demand, bioenergy and food&feed supply via the price of fossil oil. This approach serves the purpose of creating overview of primary bioenergi potentials, food&feed production and consequenses for land use. Constraints to biomass production are included in modelling of bioenergy potentials e.g. by reservation of crops for food and feed or excluding biomass extraction from protected nature types. The outcome of the model is a crop area distribution of Danish cultivated land and an assessment of the biomass feedstock available for conversion to heat, electric power and transport fuels. The model is purely static with no endogenous investment in conversion technologies.

The energy efficiency of plant based bioenergy depends on land productivity, cultivation, and conversion methods. The question now remains in what quantity and at what cost bioenergy from different crop types can be supplied from cultivated land, and how the fossil oil price interacts with biofuel costs.

3.2 Materials and methods

The analysis is based on a static cost minimization model for bioenergy feedstocks grown in Denmark in a single year using currently grown crop classes and yield levels, Table 1. For each feedstock type a crop representative was selected, e.g winter wheat represents all starch crops. The model uses linear programming for providing solutions to an objective function that minimizes the cost of a fuel mix of bioenergy and fossil oil, represented by diesel oil, by changing the crop area distribution. Data on crop yields, input factors and input prices from the year 2005 were used. A key issue in the model, comparing the results using 2005 parameters with alternatives, is the changes in real fossil fuel prices and its influence on other costs of inputs used in the cultivation. Higher future cost price in proportion to the real oil price increase was based on an evaluation of the direct and indirect energy used in the production of these input factors: seeds 25%, fertilizers 50% (nitrogen and potassium) or 75% (phosphorus), lime 50%, machines 25%, fuels and lubricants 100%, pesticides 25% .

Constraints on crop area use were delineated based on land data, limitations due to crop rotation requirements, protection of forest area (600 kha evenly distributed on average and low productive soil), permanent grassland (175 kha) and other constraints set by biological requirements of the crops.

Table 1. Feedstock types, crop representatives, conversion methods and efficiencies used in the model.

Feedstock type	Crop representative	Conversion method and efficiency
Woody lignocellulosic	Norway spruce, yield level PK8 and PK12 in 60 yr rotation Willow in short rotation forest (22 yr) on sandy and loamy soils.	Heat and combined heat and power (69-81%)
Grassy lignocellulosic	Grass-clover ley with 30-50% clover	Biogas (54%)
Oil crops	Oil seed rape on sandy (JB1-3) and loamy soils (JB5-6)	RME, Rape Methyl Ester (70%)
Starch crops	Winter wheat on sandy (JB1-3) and loamy soils (JB5-6)	1st generation bioethanol (57%), straw used in combustion (90%)
Sugar crops	Sugar beet on loamy soils	1st and 2nd g. bioethanol (54%), tops used for biogas (54%)

3.3 Key scenario parameters: Food and feed requirement and fossil fuel prices.

In this application of the model we analyzed two sets of scenarios each with fossil oil prices ranging from index 25 to index 200 in intervals of 25 (<oil index 100) or 10 (>oil index100), and cost levels were as experienced in the year 2005. The food, feed and timber demand was set to 167 PJ starch crop yields, 6 PJ oil crop yields, 11 PJ sugar crop yields, 38 PJ grass for feed based on 2005 crop yields. The reservation of timber for wood products was 5 PJ corresponding to about 25% of wood fellings. The main difference between the two sets of scenarios is the reservation for food and feed and some corresponding constraints on the area for short rotation forest (willow for energy use) and permanent grass.

(a) A set of scenarios based on the food&feed production in 2005 (=100%). The area with willow was 0.2% of the available land area.

(b) A set of scenarios with only 50% food and feed reservation as a variant of the scenario (a). Constraints on area use were due to prioritization of bioenergy and the environment. The short rotation willow was restricted to a maximum of 25% of the land area.

The feedstock cost reflected the combination of yield level (soil quality) and crop type and the cultivation intensity applied.
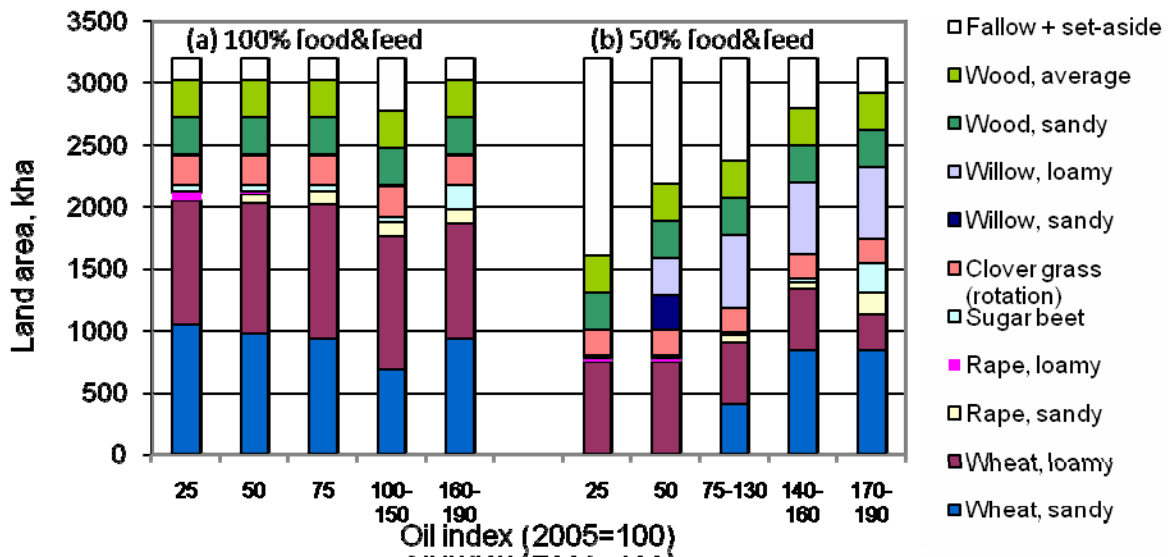

Figure 2. Area distribution of the (a) scenarios with 100% food&feed and the (b) scenarios with 50% food&feed for oil index 25 to oil index 190. Willow is allowed to occupy 25% of the crop area in the (b) scenarios.
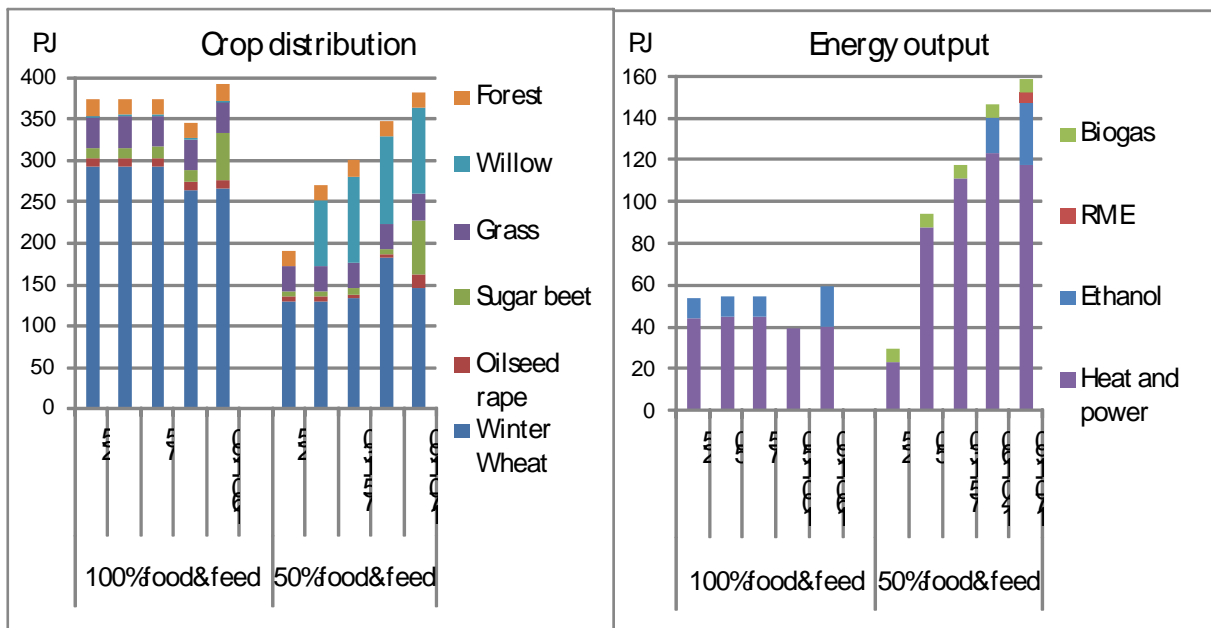

Figure 3. Scenario results for Cropdistribution in PJ and biomass energy output. Oilindex range from 25 to 190 (2005=100).

In the (a) scenarios the cost minimized crop area distribution reflected the food constraints laid down in the model and the very limited constraints on willow plantations. Oilseed rape was grown on a very limited area, and sugar beet was only relevant for bioenergy beyond oil index 160 (Figure 2). In the oil index range from 75 to 150, the biofuel costs for wheat per GJ final energy were quite close to the fossil oil index. Different crop area distributions as solutions to the cost minimization may therefore result in quite similar values of objective function. The suggested optimized wheat area is a range, since fallow land, wheat and fossil oil compete in this price range.

In the (b) scenarios with much less crops reserved for food and feed, no or very limited crop area was allocated to energy crops at oil index 25. With increasing fossil oil index the effect of the low yield level was evident since willow on sandy soil was only present at oil index 50. In the remaining price range the maximum willow area was grown on the high yielding loamy soils. Oilseed rape on sandy soil and sugar beet exceeding the mandatory area reserved for food did occur, but only at a relatively high oil price beyond oil index 160 with a concurrent reduction in wheat on loamy soils. The areas shown in Figure 2 are converted into energy units in Figure 3 (left), while Figure 3 (right) shows the energy output after conversion of the biomass availabel. The lower reservation for food and feed means thar more biomass will be available for energy use. The total bioenergy supply across fossil oil prices in the (a) scenarios in Figure 2 ranged between 40 PJ and 60 PJ per year, and the (b) scenarios between 30 PJ and 160 PJ per year.

3.4 Short rotation forest

If the reservation of land for food supply is decreased, much more land would be set-aside or planted with forest in short or long rotation. The environmental benefits for the environment by reducing nitrogen loads (Erisman et al., 2008) through cultivation of perennial woody crops or setting land aside are obvious. Guesses of the potential available area for willow are 100 kha – far lower than the 581 kha that occur in the model result, Figure 2. There is no knowledge base for large-scale willow cultivation in Denmark indicating if the actual yields and costs can be sustained over time, and if it is accepted by the public. Willow plantations may be a way of increasing the forest area in the long term. The energy sector and the agricultural sectors are regulated, taxed and subsidized in numerous ways. The analysis indicates that volatile oil prices are contributing to the uncertainty of price developments for both food&feed and bioenergy markets. The market for solid biofuels, such as wood chips and energy grain, is well established and flexible. Switching between different biofuels and co-firing with fossil fuel in both small and large heat and heat and power plants is possible. In comparison with an annual total primary energy use of 800-850 PJ the bioenergy supply would range from 4% to 19%.

Domestic bioenergy feedstock production is very limited in comparison with the energy consumption. The possibilities of a substantial increase e.g. by cultivation of willow, even up to 25% of the available crop area, will not increase the bioenergy supply substantially, but the landscape would change dramatically. Biomass imports are needed if the contribution of bioenergy to the total energy production is to increase above current levels.

Apparently, willow in short rotation is a cost effective solid biofuel alternative to annual crops, but issues like actual future yields, landscape planning perspectives, environmental performance, and landuse flexibility need further consideration.

4 Implementation into the RES2020 TIMES model

The assumptions made for the static optimisation model described above will be implemented into the national model, which is included in the RES2020 Pan European model. In contrast to the simple model, the latter is a dynamic model covering the period 2005-2020 with model calculations until 2025. The results will be tested against the simple model and the final results from the RES2020 project.

4.1 Exploring the online results

Comparing Figure 3 (right) with Figure 4, which is extracted from the online results of the RES2020 TIMES model shows that the results of the static model with 50% food&feed restrictions for high prices on fossil fules are very similar to the results from RES2020 for Denmark.

The price index for diesel oil in the RES2020 scenarios with 2005=100 is 147 in2010, 155 in 2015, 168 in 2020 and 177 in 2025.

The similar results from the two different model approaches mean that both models are suitable for further analyses and comparisons.
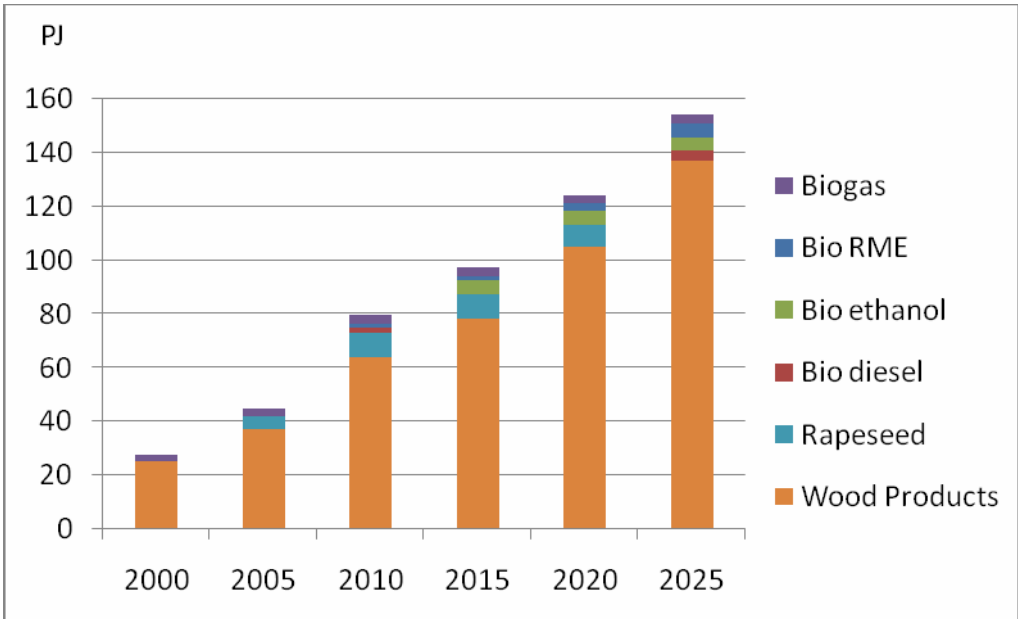

Figure 4. RES2020 Scenario 2020 for Denamrk. Biofuels except municipal waste.

4.2 Exogenous variables

In RES2020 TIMES the commodity set "ALLBIO" includes waste incineration for energy, which is not shown in Figure 4, because the results would be misleading.

Investment in incineration of urban waste is driven by the need for environmentally optimal treatment of urban waste rather than the demand for energy. Thus, it does not make sense to consider all these technologies in the same optimisation. In the current RES2020 results waste for energy is phased out for nearly all countries. This result is most visible for Denmark, where waste incineration is used for treatment of nearly all urban waste that is not recycled. (Grohnheit et al. 2008).

For the same reason the food and feed requirement is exogenous in the static bioenergy model and not included in the optimisation.

4.3 Conclusion and perspectives

The static bioenergy model contains the structure of processes for an upstream module for RES2020 and the data that is needed for a national application for Denmark. A similar module for other countries will require a similar study of national agricural and forestry statistics, However, similar to the original development of the Pan European model, a common base-year template may be developed – starting from international statistics on cultivated areas and crops – to develop a harmonised set of processes and parameters.

The most important metholodical conclusion of this study for the further development of the RES2020 TIMES model is that requirements on food and feed from agriculture and non-energy material from forestry must be exogenous to an optimisation model driven by the demand for energy services.

References

Callesen, I., Grohnheit, P.E., & Østergård, H. (2010a) Biomass & Bioenergy 34: 1348-1362 doi:10.1016/j.biombioe.2010.04.020.

Callesen, I., Grohnheit, P.E., & Østergård, H. (2010b) Extended abstract**.** In: Proceedings of the International Conference on Energy, Environment and Health – Optimisation of Future Energy Systems May 31   June 2, 2010 Carlsberg Academy, Copenhagen, Denmark. REBECa, CEEH and CEESA.

Danish Energy Agency (2009), Danmarks energifremskrivning frem til 2030 [Denmarks Energy Projection up to 2030]. Copenhagen: [In Danish]. Available from www.ens.dk.

Danish Energy Agency. Energy statistics 2005. Copenhagen, Danish Energy Agency; 2006. Available from http://193.88.185.141/Graphics/Publikationer/Statistik_UK/Energy_statistics_2005/index.htm

EEA. (2006), How much bioenergy can Europe produce without harming the environment. Report no.7/2006. Copenhagen: EEA; .

Erisman, J.W., Sutton, M.A., Galloway, J., Klimont, Z., & Winiwarter, W. (2008) *Nature Geoscience*, 1, 636-639.

European Commission (2003). Directive 2003/30/EC of the European Parliament and of the Council of 8 May 2003 on the promotion of the use of biofuels or other renewable fuels for transport.

European Commission. Directive 2001/77/EC of the European Parliament and of the Council of 27 September 2001 on the promotion of electricity from renewable energy sources in the internal electricity market. Brussels: Commission of the European Communities; 2001.

Fischer G, Prieler S, van Velthuizen H, Lensink SM, Londo M, de Wit M. (2010a), Biofuel production potentials in Europe: Sustainable use of cultivated land and pastures. Part I: Land productivity potentials. Biomass and Bioenergy 2010; 34(2):159-72. DOI: 10.1016/j.biombioe.2009.07.008

Fischer G, Prieler S, van Velthuizen H, Berndes Gr, Faaij A, Londo M et al. (2010b), Biofuel production potentials in Europe: Sustainable use of cultivated land and pastures, Part II: Land use scenarios. Biomass and Bioenergy 2010; 34(2):173-87. DOI:10.1016/j.biombioe.2009.07.009

Grohnheit, P.E. (2008), Using the IEA ETSAP modelling tools for Denmark, Risø-R-1656.

Grohnheit,P. E:; Karlsson, K.. Münster, M. (2008), Waste-to-energy technologies in TIMES models, ETSAP Semi-Annual Workshop, Paris 3 July 2008.

RES2020 (2009),Monitoring and evaluation of the RES directives implementation in EU27 and policy recommendations for 2020. Deliverable D.4.2. Intelligent Energy Europe.

RES2020 Project, /www.res2020.eu/

OECD-FAO (2009). Agricultural outlook 2009-2018. Rome: OECD-FAO.