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Abstract

In the context of mitigating climate change and increase energy security, the utilization of biomass in the energy sector is expected to play a major role. However, to estimate the possibility of fulfilling national goals concerning the future use of biomass sources and to estimate the future use of biomass sources in the energy sector, the current energy system models needs to be further developed to consider the high sub-national variances in the supply and cost of the biomass sources. In this paper we present a sub-national MARKAL/TIMES model for estimating regional utilization of biomass sources and the future development of the energy system. The proposed model is evaluated for two case studies, France and Sweden, for which the future utilization of biomass is evaluated utilizing numerous scenarios of the potential supply of biomass, cost of biomass, and end-use demand. Our results show that the limit of national biomass potentials for energy purposes in France is approximately 35 Mtoe, while all demand scenarios for Sweden could be fulfilled by national biomass potentials. Furthermore, the results show that there are large differences in the regional utilization level of biomass sources, even when the total utilization level of biomass sources is high.

1   Introduction

Renewable energy sources such as biomass and biofuels are increasingly being seen as important energy sources in Europe. To promote the usage of renewable energy sources and thereby mitigate climate change and increase energy security, the European Union (EU) has set the following targets: by 2020 the share of renewable energy sources on the final energy consumption should be 20% and the share of biofuels on the final consumption of energy in transport should be 10%. The long-term target is to reduce the green house gas emission (GHG) by 50% by 2050. To reach these targets, biomass is expected to play a major role and an increased use of biomass is considered essential [1]. Biomass is currently the main source of renewable energy accounting for 66% of the gross domestic consumption of renewables in the current 27 countries in EU (EU27) [2]. Most of the biomass currently being used for energy purposes is wood, and in absolute terms France (9.3 Mtoe) and Sweden (8.2 Mtoe) are the second and third largest users of woody biomass for energy purposes. Even though the usage of biomass has increased significantly during the last years, a number of studies suggest that there is a potential for further increasing the usage of biomass [3, 4, 5]. Sources of biomass that traditionally have not been utilized in the energy sector, for example unutilized agricultural land and forest residues, are starting to play an important role in the energy sector. However, there is still considerable uncertainty as to how commercially available the different sources of biomass are. Furthermore, existing energy system models that may be used to estimate the future use of biomass typically do not consider important divergences in the structural characteristics of the cost and supply of biomass. Also, the models are typically aggregated on national levels and thereby unable to consider sub-national or regional variances and unable to analyze regional differentiations in the development of the energy system.

The main objective of this paper is twofold. Firstly, to present a sub-national MARKAL/TIMES model specifically developed for estimating the future use of biomass in the energy system. Secondly, to study the future use of biomass in France and Sweden. The proposed model is a MARKAL/TIMES model which are based on a partial-equilibrium, linear-programming approach for which the short-, medium-, or long-term development of an energy system can be represented and analyzed. The model is driven by the demand of some commodities and is based on a technology rich, bottom-up approach in which typically a large number of technologies can supply the different demands. The proposed model considers the heat, electricity, and biofuel sectors, and can be utilized to analyze and estimate the national utilization levels of biomass, the mix of different sources of biomass to be utilized, the utilization of biomass in the different sectors, mix of technologies used to produce the demand as well as the introduction rate of new technologies. One of the main features of the proposed model is that it is sub-national and thereby able to consider aspects on both national and regional/county levels. The supply, cost, and demand of biomass and biofuels can thereby be expressed with enhanced precision, and the development of the energy system and the future use of biomass can be studies on several levels. Furthermore, the proposed model is able to consider important features of the cost and supply of biomass such as: regional and variable transport distances, numerous agricultural and forest biomass supply assortments, regional distributions of the size of forest clear-cutting areas, supply and exploitation cost of surplus agricultural land and forest biomass in mountainous, hilly, and flat landscape areas.

The proposed model was applied to two case studies, one for France and one for Sweden. These two countries were selected as they both are large users of forest biomass in the energy sector, and as

statistics at a very detailed level are available for the agricultural and forest sectors. The case studies demonstrate two methods for enhancing the expression of the cost and supply of biomass to include aspects having a major influence on the cost of supplying biomass to the energy system. For the case study of France, the available areas for production of biomass is divided into four land classes according to the difficulty of performing management activities due to aspects such as soil, land slope, and accessibility. The supply of each land classes is defined per region, thereby facilitating the differentiation of mountainous regions from regions with a flat landscape. For the case study of Sweden, the cost of supplying forest residues is modeled on a detailed level utilizing regional cost-supply curves. The cost considers numerous aspects having a major impact on the cost of supplying biomass such as cost of harvesting, cost of transporting to road, and cost of transporting the biomass to the factory. The regional cost-supply curves thereby represent the supply of biomass in the region and where they are located in terms of distances to the factories utilizing the biomass. Sources of biomass nearby and far from the factories are thereby differentiated.

Two sources of biomass are considered in the two case studies: surplus agricultural land and forestry biomass. The utilized sources of biomass are sources that are not utilized in other sectors and which utilization does not hinder the development of sectors such a food and livestock. They thereby do not hinder other sectors. The surplus agricultural land potential corresponds to the utilization of agricultural land that is no longer required in the food and livestock sectors, and can thereby be utilized for the production of biofuel and biomass production. The forest biomass corresponds to the forestry biomass that may be utilized for energy purposes and that is not utilized in other sectors.

The two case studies were used to study the mix of utilized sources of biomass and the amount of biomass utilized in the different energy sectors. A base case scenario as well as alternative scenarios was developed to analyze the future development of the energy system under aspects such as differences in the cost and supply of biomass as well as differences in the end-use demand of heating, electricity and biofuels. We are thereby able to study the stability of the mix of utilized sources of biomass, the demand level that can be fulfilled by national supplies, and the introduction rate of second generation conversion technologies. Furthermore, we look closely at regional differences and national trends in the utilization of the different sources of biomass and the development of the energy system. The paper is structured as follows. In section 2 we describe the proposed model. In section 3 we describe the data utilized for the two case studies and how the case studies were created. Section 4 presents the results of the case studies. A discussion of the results ends the paper in section 5.

2   Methodology

2.1   MARKAL/TIMES models

A MARKAL/TIMES (Market Allocation) model [6, 7, 8, 9] is a demand driven linear programming model that can be used to represent, optimize and analyze energy systems over a mid- to long-term planning horizon (20 to 100 years). The energy system may be on a local, regional, national or global scale and the planning horizon may be divided into multiple planning periods of variable length. It was developed and is being maintained by the international ETSAP (Energy Technology System Analysis Programme) [10, 11] organization, which is an implementation agreement with the International Energy Agency (IEA) [12].

The MARKAL/TIMES model represents the energy system via a set of technologies that are linked together by the flows of commodities. A technology, or process, is a typically a physical device that consumes and/or produces commodities, while a commodity is anything produced/consumed by the technologies. Examples of technologies are gas extraction, oil refinery, and coal-based electricity plant. Examples of commodities are gas, crude oil, electricity, and heat. Technologies are characterized by their input and output of commodities, efficiency, costs and environmental impacts, while commodities are characterized by their potential availability, cost of extraction, demand, and which technologies they can be produced and/or consumed by.

The MARKAL/TIMES model is driven by the demand of some commodities and is based on a technology rich bottom-up approach in which typically a large number of technologies can supply the different demands. To fulfill the demands, available energy resources are extracted or imported, and in a series of steps, converted from one commodity into another commodity, finally resulting in the availability of the demanded commodities. The commodities can be divided into three general groups according to the chain of conversion of commodities: primary commodities that are extracted (or imported) and that previously have not been subjected to any conversion or transformation process, secondary commodities which are the processed or transformed commodities, end-use commodities that are the commodities that are demanded. An example of a primary commodity is rapeseed, which can be processed into the secondary commodity bio-oil, which in turn can be refined into the end-use commodity bio-diesel. Each conversion of a commodity into another commodity occurs through a technology and the link between the different technologies is represented by a special type of network diagram, known as a Reference Energy System (RES). The RES provides a representation of the energy system by presenting the link between the technologies and the commodities. For a general example of an RES, see Figure 1. For a more detailed description of the RES concept, we refer to [13].
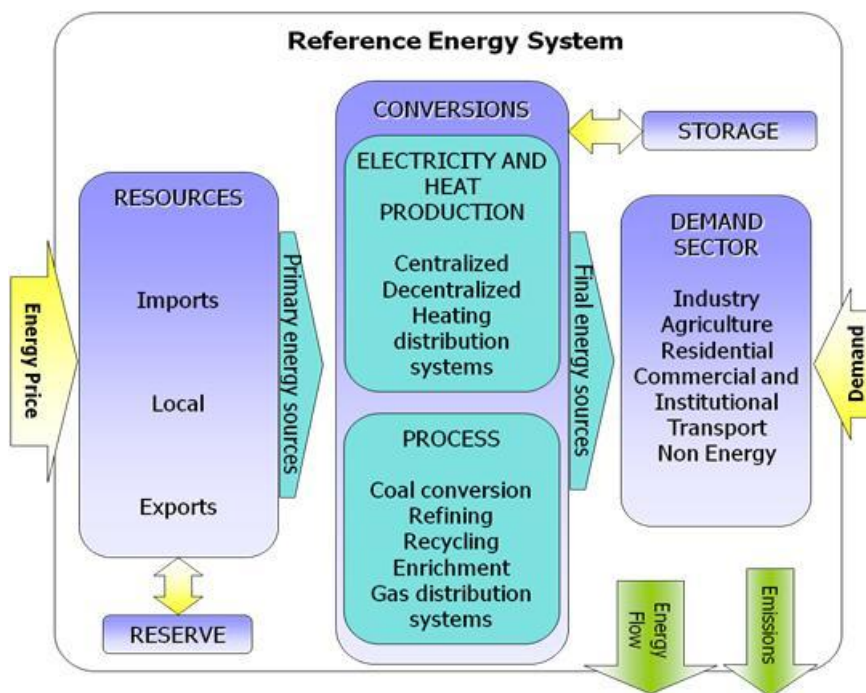

Figure 1 : A general view of the reference energy system.

Each transformation step is a linear input/output process and the RES provides an extended linear model of the whole energy system. The second dimension of the MARKAL/TIMES model is that it is a linear programming model that optimizes the fulfillment of the demands to the least total discounted cost of the system, via decisions concerning the activity of the technologies, trade between regions, technological investments to increase capacity and lifetime of the technologies, etc. The objective function being minimized represent aspects such as fixed and variable utilization costs of the technologies, investment and/or dismantling costs, taxes and subsidies, salvage values, costs and revenues due to import and exports of commodities etc. The constraints cover a large number of aspects, ranging from fulfillment of demands, to maximal available of resources for extraction, maximal production capacities of the technologies, lifetime of the technologies, bounds on the utilization rate of technologies, environmental and policy goals etc. The model is commonly based on a perfect foresight assumption for which the input energy prices, the end-use demands, and the development of the technologies are known. The long-term development of the energy sector is estimated according to a deterministic future development, and the development of the energy sector is commonly analyzed according to numerous scenarios of the future development of the system. The MARKAL model can thereby evaluate the effect of a range of aspects, for example the effect of different supply levels of commodities, climate policies, trading opportunities between countries etc. The MARKAL/TIMES model is formulated in the GAMS language and is operated with the help of an interface implemented in the IEA/ETSAP framework.

In MARKAL/TIMES, the user provide projections of the current and future demand of the end-use commodities, the supply of primary commodities, characteristics of the technologies, currently installed capacities of the technologies, political and environmental policies etc. Supply of the primary commodities is described in the form of cost-supply curves, expressing the cost of supplying a specific amount of the commodity. Renewable energy resources are commonly expressed in terms of annual production potentials, while fossil fuel resources are commonly expressed in terms of cumulative potentials over the planning horizon.

2.2   Sub-national MARKAL/TIMES model

As there are large sub-national/regional differences in both the potential supply and cost of utilizing sources of biomass, we propose the utilization of a regional MARKAL/TIMES model in order to evaluate the future utilization of biomass and the development of the energy system. The proposed model contains a detailed description of numerous sources of biomass, ranging from agricultural crops, agricultural waste, and forestry harvesting products. Each source of biomass is defined per region in terms of supply, cost, and geographical location. Regional cost and supply levels of the different sources of biomass are thereby considered. The general outline of the model is that the biomass resources are extracted on a regional level, thereafter through a series of steps, converted to fulfill demands on an aggregated national level. The proposed model considers the heat, electricity, and biofuel sectors. Extracted sources of biomass can thus be utilized in these three sectors, and a detailed description of the possible conversions and utilization of the different sources is considered in the model. For a general overview of the model, see Figure 2.
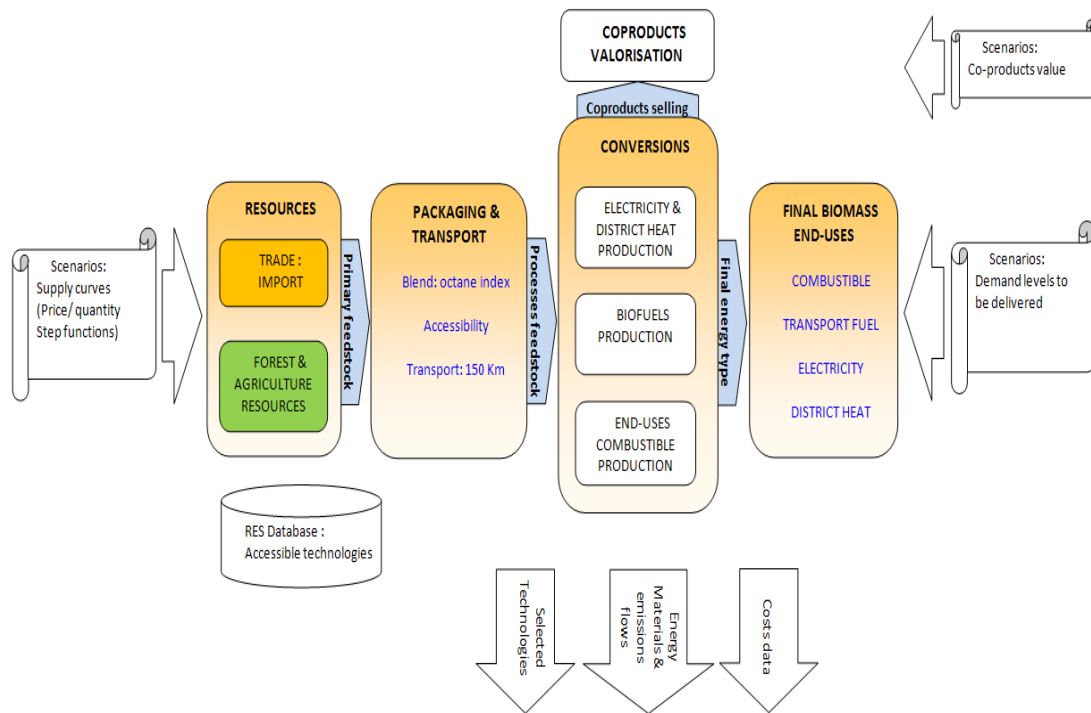
Figure 2: The RES of the proposed model

A current concern is that the increased demand of bioenergy will induce land use change, resulting in agricultural land currently utilized for food and livestock production instead being utilized for growing crop specifically dedicated for energy purposes. A number of issues have been raced concerning land use change. To avoid conflicting land use issues, the proposed model only considers land not utilized in the food and livestock sectors as potential land for energy purposes. The potential land for energy purposed thereby does not conflict with the food and livestock sectors. The land utilized in the food and livestock sectors has in the last years been decreasing in both France and Sweden, thereby freeing up land for energy purposes. Furthermore, agricultural land is also likely to become available for energy crops and biofuels production due to future changes in the production intensity, trade of agricultural products as well as development in food demand. Assuming that the self-reliance level of agricultural products will be kept in the future, the amount of freed up agricultural land that can be utilized for growing crops for energy purposes can be estimated. Note that the same underlying assumption is also utilized for the potential forest biomass for the energy sector. The forest potential considered in the model is only forest biomass that is not utilized in other sectors (pulp/paper, construction, industry, etc).

A number of technologies to convert the biomass sources into biofuels, heat, and electricity are considered in the model. A set of "mean" technologies were created to represent the rich and diverse set of current and future technologies. Each implemented technology thereby represented a specific type or a specific size of a transformation technology. A total of eleven technologies for biofuel conversion and five for heat and electricity cogeneration production were available in the model to choose between. The possible conversions of the biomass sources can be seen in Table 1.

Potentials			Generation of conversion technology	Bio-diesel	Bio-ethanol	FT-diesel	Bio-HVO
Agricultural crops	Oil crops	Rapeseed	1st, 2nd	X			X
		Sunflower	1st, 2nd	X			X
		Soy bean	1st, 2nd	X			X
		Palm oil	1st, 2nd	X			X
		Jatropha	1st, 2nd	X			X
	Sugar crops	Sugar beet	1st		X		
	Starch crops	Maize grain	1st		X		
		Maize straw	2nd			X	
		Wheat grain	1st		X		
		Wheat straw	2nd			X	
		Triticale grain	1st		X		
		Triticale straw	2st			X	
	Woody crops	Eucalyptus	2nd		X	X	
		Poplar	2nd		X	X	
		Willow	2nd		X	X	
		Locust tree	2nd		X	X	
	Grassy crops	Switch grass	2nd		X	X	
		Miscanthus	2nd		X	X	
		Reed canary grass	2nd		X	X	
Forestry products			2nd		X	X	
Agricultural waste			2nd		X	X	

Table 1: The modeled conversions for the biomass sources

To get an accurate picture of the economy of the different conversion technologies and thereby which technologies that will be utilized, the byproducts of the various conversion technologies were considered in the model. The price of the different byproducts were set according to current prices and assumed to be fixed over the planning horizon. The byproducts considered in the model were: glycerin, brewer's spent grain, press cake, propane, naphtha, carbon dioxide, wine product, and electricity.

The proposed MARKAL/TIMES model allows for international import of commodities such as wood and biofuels, this in order for the model to always be able to fulfill national demands for bioenergy. As the main aim of the proposed model is to identify possible national production levels, the cost of importing sources of biomass were arbitrarily set to be higher than domestic prices. Domestic sources of biomass were thereby always utilized before import of biomass was selected.

3　Case studies

The planning horizon of the proposed models was from the year 2000 until the year 2050, divided into time periods of five years. The years 2000 and 2005 were used as reference periods, according to which the model was calibrated. The model had no freedom in the selection of the variables for these two periods as the variables in the linear-programming are fixed. The calibration of the model

to reference periods is important as it calibrated the capacity of the technologies, commodities in storage, trade between regions, emissions etc.

3.1   Case study of France

The model of France was created utilizing nine regions, dividing the national biomass potential and cost of harvesting the potential into regional potentials and costs (see Figure 3). The regional potential and cost of the different sources of biomass were that of the data collected and compiled for the VALERBIO project [14]. In the VALERBIO project, data concerning both the agricultural and forestry sectors were collected, cost and potential of the different biomass sources, as well as scenarios of the end-use demand. For the cost of agricultural crops, the cost of transport varied between the different crops, while a fixed national average transport distance of 150 km was utilized for all crops. The costs (harvesting and transport costs) of the agricultural crops were set to be constant over the planning horizon.
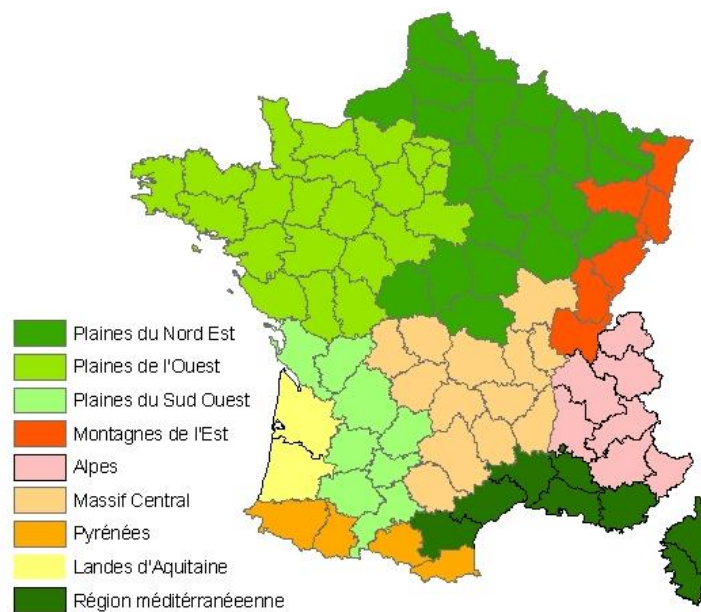

Figure 3: Regional division of biomass sources in France

The representation of the regional potentials of forestry biomass was further enhanced utilizing four types of accessibility groups (Easy, Medium, Difficult, Very Difficult) and three types of woody products (Big wood, Medium wood, Small wood). The potential and cost of forestry biomass was thereby defined per region, accessibility group, and woody product. The accessibility groups represent the accessibility and the difficulty of performing management activities in the stands, while the woody products represent the different part of a tree that may be utilized. Big and medium wood represents the stem of the tree, while the small wood represents the crown and branches. For energy purposes, small wood is more interesting as it is currently not utilized in other industrial sectors and is therefore highly available. While big and medium wood can be utilized in the energy sector, they are also demanded in other industrial sectors, resulting in a lower potential for energy purposes. As the management of the stands varies between the accessibility groups, the potential of forestry biomass also varied between the accessibility groups. The cost of harvesting biomass was estimated as a linear function of the cubic meters of biomass harvested for each accessibility group and woody product. For each region, an average transport distance was utilized to represent the

distance between the forest collection site and the plant utilizing the forest biomass. Chipping of forest residues was assumed to always be performed at roadside. The costs (harvesting and transport costs) of the different forestry products were set to be constant over the planning horizon.

To evaluate the impact of the cost and supply of the biomass sources on the development of the energy sector, a number of scenarios were developed. The scenarios reflect different future developments as well as high volatility in the costs. Note that all these scenarios were developed under the previously defined assumptions. The developed scenarios are as follows: three scenarios for the potential of woody products, three scenarios for the potential of short rotation coppice (SRH), two scenarios for the potential of agricultural crops, and two scenarios for the price of agricultural crops.

Potential of forestry products:
- Business as usual (BAU).
- All for energy (AFE): assumes that a high degree of wood can be used for energy purposes as the wood industry is not growing fast.
- All for industry (AFI): assumes that a low degree of wood can be used for energy purposes as the wood industry is growing fast. The wood potential is 20% less than that of the business as usual scenario.

Potential and price of agricultural crops:
- Business as usual (BAU).
- All for energy (AFE): assumes that a high amount of agricultural crops can be used for energy purposes.
- Average cost: assumes average costs of the agricultural crops.
- High cost: assumes high costs of the agricultural crops.

Potential of short rotation coppice:
- Not available.
- Average availability.
- High availability.

Six combinations of the different scenarios were created as seen in Table 2.

Global scenario name	Forestry potential			Agricultural potential		Agricultural cost		SRC potential		
	BAU	AFE	AFI	BAU	AFE	Average	High	No	Average	High
P1	X			X		X		X		
P1b	X			X			X	X		
P2			X		X		X			X
P2b			X	X		X				X
P3		X			X		X			X
P3b		X			X		X		X	

Table 2: Scenarios for development of the agricultural and forestry products

3.2   Case study of Sweden

For the model of Sweden, the forestry potential was defined for each of the 21 counties in Sweden, while the agricultural potentials were defined on an aggregated national level. The national potential of agricultural crops was defined according to the RES2020 project [15], while the costs were set

according to a literature study of the current costs of agricultural crops [16, 17]. The cost of the forestry and agricultural biomass sources were assumed to be fixed over the planning horizon. As the potentials of agricultural crops collected and computed in the RES2020 project were for each general type of crop (oil, sugar, starch, woody, and grassy) and not in terms of each species of the crop (rapeseed, sunflower soy bean, palm oil, jatropha), the cost and potentials in the case study of Sweden were expresses in terms of the general types of crop.

The potential and cost of forestry biomass for energy purposes was enhanced utilizing two wood assortments: pulpwood and woody chips produced from forest residues. Woody chips are in Sweden almost exclusively utilized for energy purposes and is most commonly produced from forest residues such as crown and branches of the tree. While short rotation coppice are also chipped and may also be sold as woody chips, the two assortments are in the proposed model separated with different potentials and costs. Pulpwood is a wood assortment commonly produced from either small trees or parts of the stem that cannot be sold as timber. For energy purposes, forest residues is more interesting as it is commonly cheaper than pulpwood, and while there is a high demand for pulpwood in the industry and construction sectors, the demand of forest residues for non-energy purposes is small.

A detailed description of the potential and cost of forest residues on a county level was utilized, while the potential and cost of pulpwood was defined on a national level. The potential and cost of forest residues was defined for each of the 21 counties in Sweden according to detailed linear cost-supply curves [18]. A cost-supply curve was thus defined for each county (see Figure 4). Each cost-supply curve was estimated according to geographical estimation where in the county harvesting operations would occur and how much forest residues it would result in. Environmental, technical and economical restrictions were utilized when evaluating the harvesting potentials in the counties. The cost of harvesting biomass considered aspects such as: harvesting operations, compensation to forest owner, chipping, transport to forest collection site, and transport to factory. The cost of road transport of the biomass was computed utilizing the distance between the forest collection site and the nearest population centre of at least 10000 inhabitants. Chipping of forest residues was assumed to always be performed at roadside and was estimated as a linear function of the amount of harvested biomass. Note that forest residue was only considered from final felling and that after chipping, no differentiation was made between the biomass provided from different tree species.
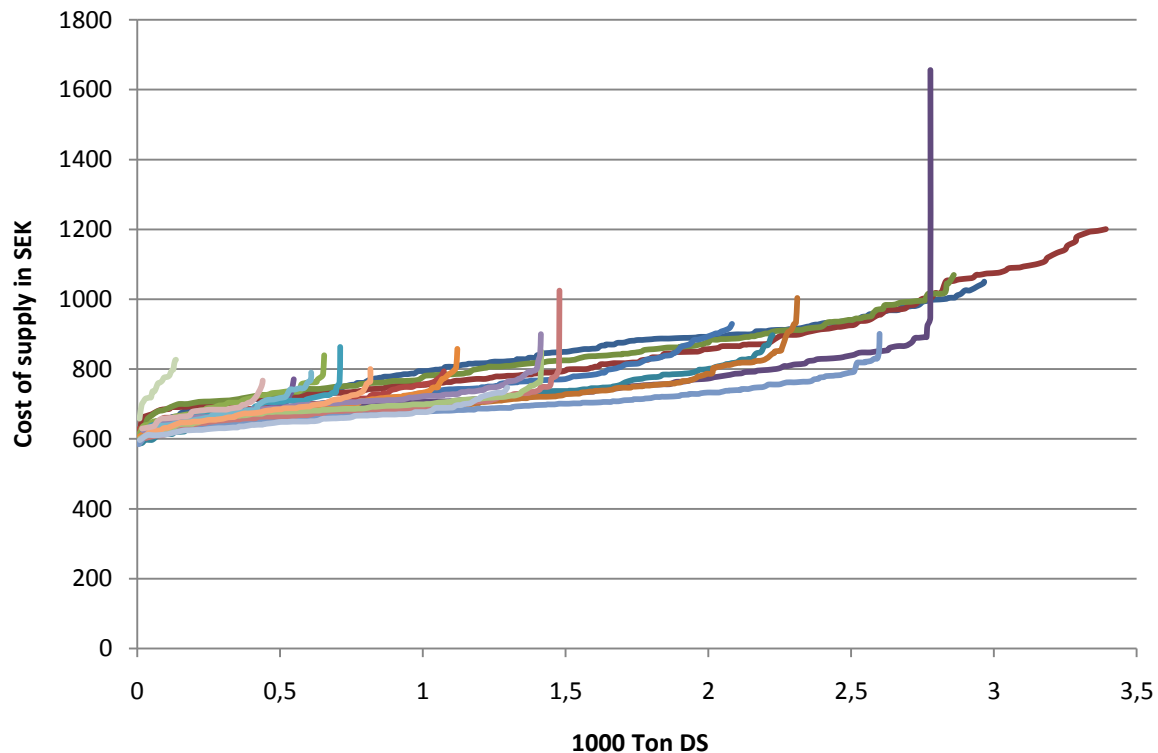
Figure 4: Regional cost-supply curves for forest residues [18]

To evaluate the impact of the cost and supply of the biomass sources on the development of the energy sector, a number of scenarios were developed. The scenarios reflect different future developments of the industrial and energy sectors as well as high volatility in costs. Note that all these scenarios were developed under the previously defined assumptions. The developed scenarios are as follows: two scenarios for the potential of woody products, two scenarios for the potential of short rotation coppice (SRH), two scenarios for the potential of agricultural crops, and two scenarios for the price of agricultural crops.

Potential of forestry products:
- Business as usual (BAU).
- All for industry (AFI): assumes that a low amount of wood can be used for energy purposes as few forest owners are willing to sell the forest residues for energy purposes. The forest residue potential in each harvesting site is 20% less than that of the business as usual scenario.

Potential and price of agricultural crops:
- Business as usual (BAU).
- All for energy (AFE): assumes that a high amount of agricultural crops can be used for energy purposes. The potential is 20% higher than that of the business as usual scenario.
- Low cost: assumes low costs of the agricultural crops.
- High cost: assumes high costs of the agricultural crops.

Potential of short rotation coppice:
- Average availability.

- High availability. The potential is 20% higher than that of the average potential scenario.

Four combinations of the different scenarios were created as seen in Table 3.

Global scenario name	Forestry potential		Agricultural potential		Agricultural cost		SRC potential	
	BAU	AFI	BAU	AFE	Average	High	Average	High
P1	X		X		X		X	
P1b	X		X			X	X	
P2		X		X		X		X
P2b		X	X		X			X

Table 3: Scenarios for development of the agricultural and forestry products

3.3 End-use energy demand from biomass source in France and Sweden

The proposed model considers contribution of biomass sources to the heat, electricity, and biofuels sectors. An end-use demand was specified for each of these three sectors. While both France and Sweden are large users of biomass for energy purposes, there are large differences between the countries in the end-use energy demand from biomass sources and what the different sources of biomass are utilized for. While two thirds of the woody biomass harvested in France is utilized for direct heating of private houses, the major part of woody biomass harvested in Sweden is utilized in the industry sectors (pulp/paper, construction, industry, etc) and only a small portion of the woody biomass harvested in Sweden is directly utilized for heating of private houses. Of the roughly 40 millions of ton dry mass of wood (MTon DS) harvested in Sweden during 2007, only roughly 3 MTon DS were utilized for direct heating of private houses [19]. In Sweden, heating generated from CHP plants instead constitutes to a major part of the end-use heat demand from biomass energy sources. As there are large differences between the countries end-use demand, the demand of heat was separated into two demands, one corresponding to heat from CHP and one corresponding to heat from private biomass heating. The end-use demand of electricity was specified as single demand. For Sweden, the end-use demand of the four sources of biofuels was expressed in term of one demand for ethanol and one aggregated demand for diesel. For France, the demand for biofuels was aggregated over the four sources of biofuels and expressed as a single demand for biofuels.

To evaluate the effect of the end-use demands on the development of the energy sectors, numerous scenarios concerning the development of the end-use demand were created. For France, three scenarios of the end-use demands were defined. The scenarios were created based on the objectives announced in the 10th operational comity for renewable energy development with environmental high quality (ComOp 10). The ComOp 10 was provided in the framework of the French "Grenelle de l'environnement" (environment round table), and announced that by 2020, the total end-use demand of biomass in the heating, electricity and biofuel sectors could be 20 Mtoe. The defined scenarios are as follows:
- **D1**: Total end-use demand of biomass by 2050 is 20 Mtoe. The scenario corresponds to a pessimistic extension of the ComOp 10 targets, following that the targets should instead be met by 2050.
- **D2**: Total end-use demand of biomass by 2050 is 40 Mtoe. The ComOp 10 targets are reached in 2020, after which the demand for bio-energy continues to grow up to 2050. The demand after 2020 incorporates demand for bio-electricity due to the penetration of electric vehicles.

- **D3**: Total end-use demand of biomass by 2050 is 40 Mtoe. The ComOp 10 targets are reached in 2020, after which the demand for bio-energy continues to grow up to 2050. The demand after 2020 incorporates demand for bio fuel jet. The demand for biofuels is assumed to cover 20% of the total demand of fuels in the transport sector (air and road).
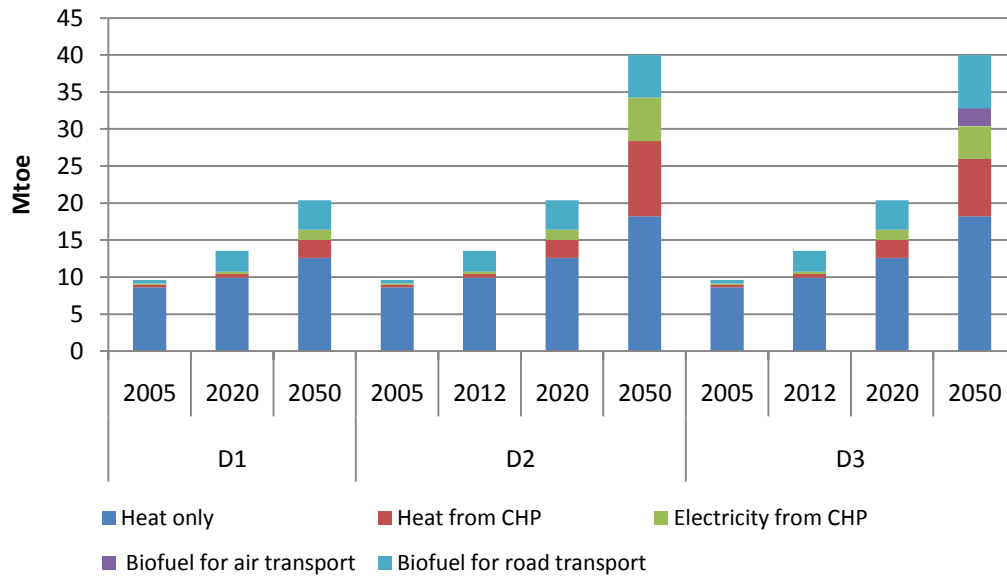

Figure 5: Structure of the demand scenarios for France

For Sweden, three scenarios of the end-use demands were defined. The scenarios were created based on the Swedish Energy Agency's long-term energy projection 2008 [20], which provide long term projections of the end-use energy demand in Sweden up to 2030. The scenarios were defined as follows:

- **D1**: Business as usual (BAU).
- **D2**: High economic growth. The scenario corresponds to a higher economic growth than that of the BAU scenario, resulting in a slightly higher demand for heating.
- **D3**: High prices of fossil fuels. The scenario corresponds to a future projection in which the prices of fossil fuels are higher than those in the BAU scenario. The higher fossil fuels were assumed to decrease the economic growth and give a higher demand for electricity, heating, and biofuels.
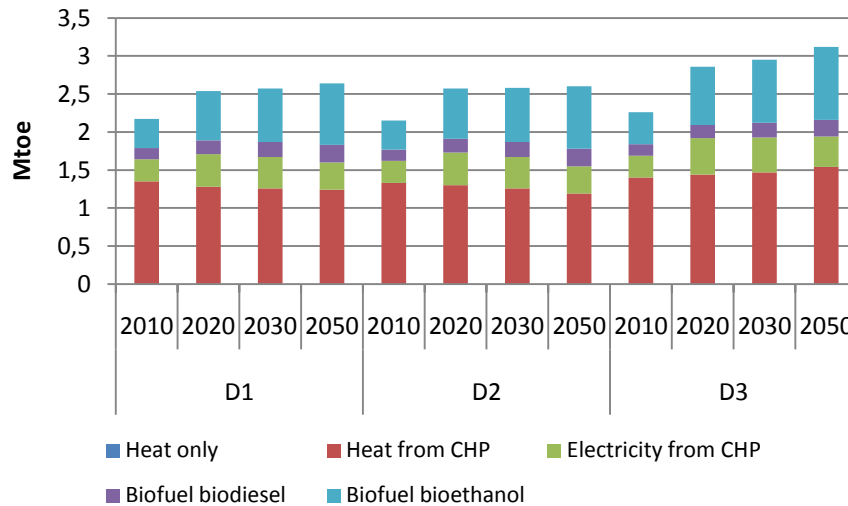
Figure 6 : Structure of the demand scenarios for Sweden

4   Results

We will now present and discuss some of the results that were attained from the MARKAL/TIMES models of France and Sweden. Our discussion will be focused on the differences between the results for the two countries and on regional differences within the countries.

4.1   Production of biofuels

Our results show that while national potentials are sufficient to fulfill the demand for biofuels in Sweden, import of ethanol is required to fulfill the demand for biofuels in France (see Figure 7 and Figure 8). The amount of imported ethanol varies between the demand scenarios and while the amount of import is relatively small for demand scenario D1, it is high for scenarios D2 and D3. As the import price for ethanol was set to be higher than the national production cost of biomass, import was only selected as a last resource to fulfill the demand. The demand levels for France thereby show the limits of the French production.

Biodiesel production from oil crops shows to an important source of biofuels in both France and Sweden. The production levels are fairly stable over the scenarios and after 2020, the production level of biodiesel increases over time. However, while the production of biodiesel increases by time, its share of the total production of biofuels decreases in Sweden. Biodiesel's share of the total production is fairly stable in France for demand scenarios D1 and D2, but decreases in the case where there is a demand for national production of bio jet fuels (D3).

Ethanol from cereals is a very important conversion technology for biofuel production in Sweden, consisting of a major part of the total production of biofuels. Ethanol production from cereals increases over the years in both Sweden and France. Ethanol from cereals takes a growing share of the total production of biofuels in France in all the scenarios. However, ethanol's growing share of the total production of biofuels is in Sweden reduced by the second generation ethanol production from wood. In particular 2050, second generation ethanol production technologies may substitute a large share of first generation ethanol production technologies from cereals.

For France, the BTL conversion technology shows to be an important technology for production of biofuels. The technology is based on a multistep process in which the biomass is gasified after which a Fischer-Tropsch process is used to produce the diesel fuel. Our results show that the technology is especially important in France when the demand for biofuels is high (D2 and D3). For Sweden, however, second generation ethanol technologies producing ethanol from lignocelluloses straw/woody material is important while the BTL conversion technology is not utilized. The BTL conversion technology is not utilized as biodiesel conversion of oil crops is in Sweden sufficient to produce the demanded diesel level. Introduction of the second generation ethanol production technologies in Sweden varied with the demand scenarios: for demand scenarios D3, the conversion technology is already utilized 2020, while for demand scenarios D1 and D2, the conversion technology is not utilized to a high degree until the 2050.
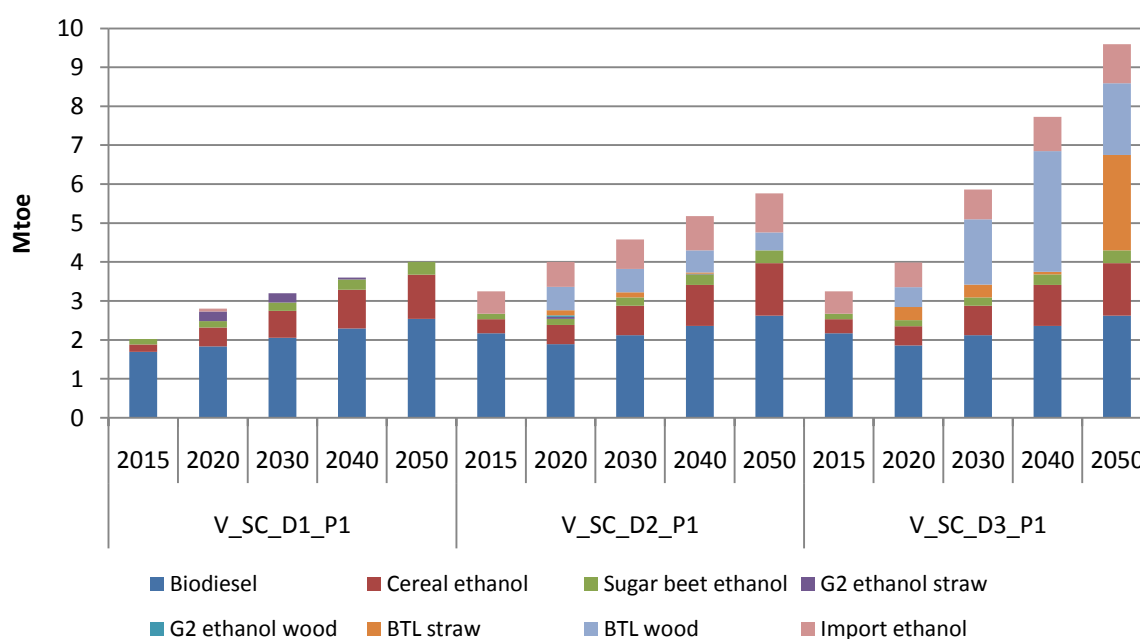

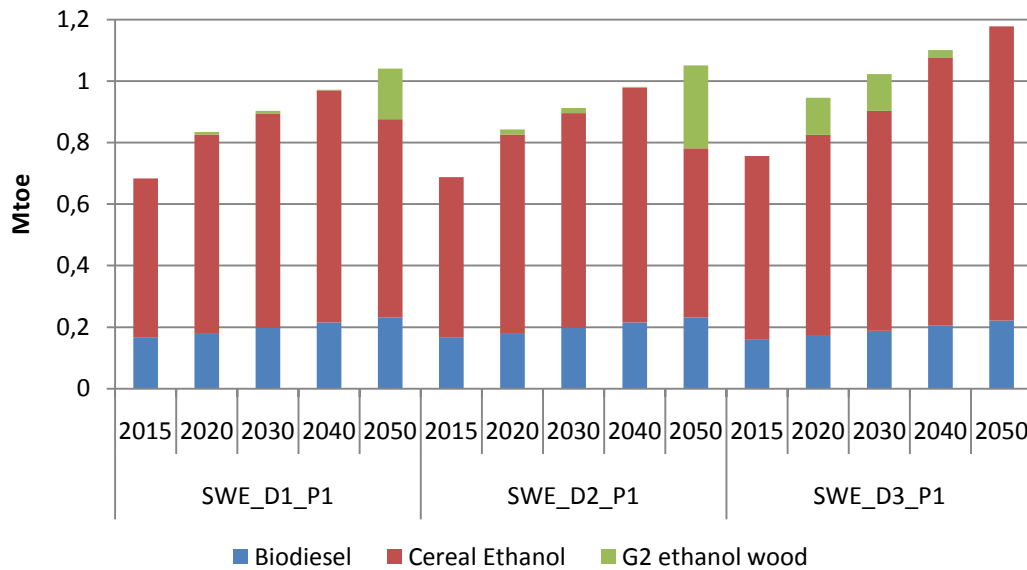**Figure 7: Conversion technologies for production of biofuels in France**

Figure 8: Conversion technologies for production of biofuels in Sweden

4.2 Utilization of SRC and forestry biomass

Our results show for both France and Sweden, that when short rotation coppice is available, it is utilized to a high degree and thereby reduces the utilization of standard forestry biomass sources for energy purposes (see Figure 9 and Figure 10). The utilization of SRC is stable over the three considered demand scenarios for both France and Sweden. Furthermore, for demand scenarios where the total use of woody biomass is small, the utilization of forestry biomass decreases rather than the utilization of SRC. The utilization of SRC increases over the years in both France and Sweden. When the demand for biomass sources is small in France (D1), the utilization of SRC becomes larger than the utilization of forestry biomass by 2040. The utilization of SRC becomes larger that the utilization of forestry biomass in Sweden by 2040 in all the demand scenarios. This shows the importance of SRC and its possible future contribution to the energy systems in both France and Sweden.

In all the demand scenarios for France, the utilization of forestry biomass peaks by 2030, and thereafter decreases to give way for SRC. In demand scenarios D2 and D3, the amount of forestry biomass utilized for energy purposes increases drastically until 2030. Even though the amount of forestry biomass utilized for energy purposes decreases after 2030, the utilization rate is still high in comparison to current utilization rates. For demand scenarios D1 and D2 for Sweden, the utilization of forestry biomass peaks by 2030, and thereafter decreases to give way for SRC. However, the increase in the utilization of forestry biomass is relative small while the decrease after 2030 is high, resulting in 50% decrease in the utilization level during the period 2030-2050. However, in demand scenario D3 for Sweden, the utilization of forestry biomass continues to increase up to 2050.
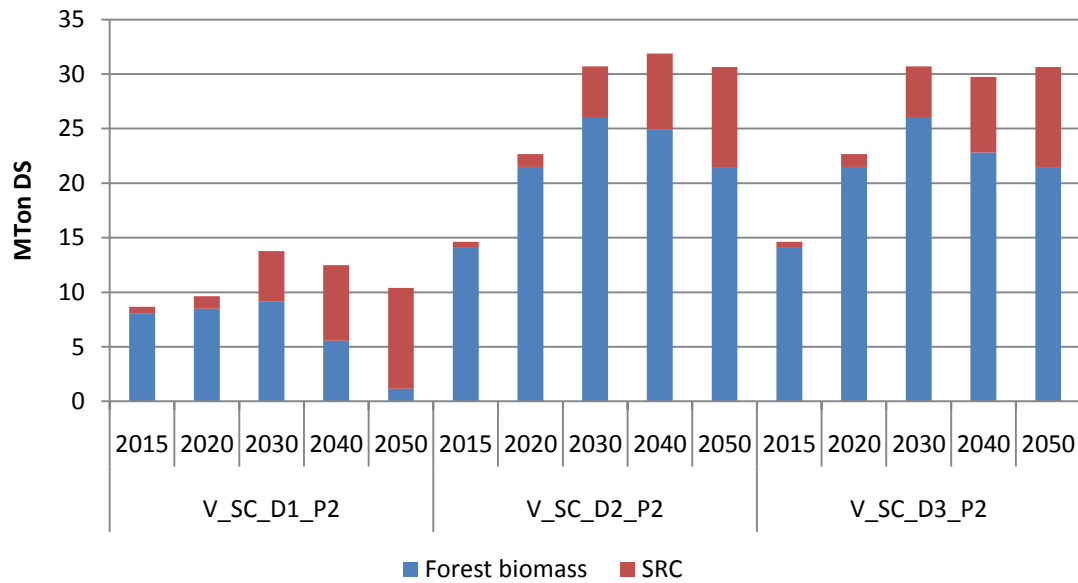
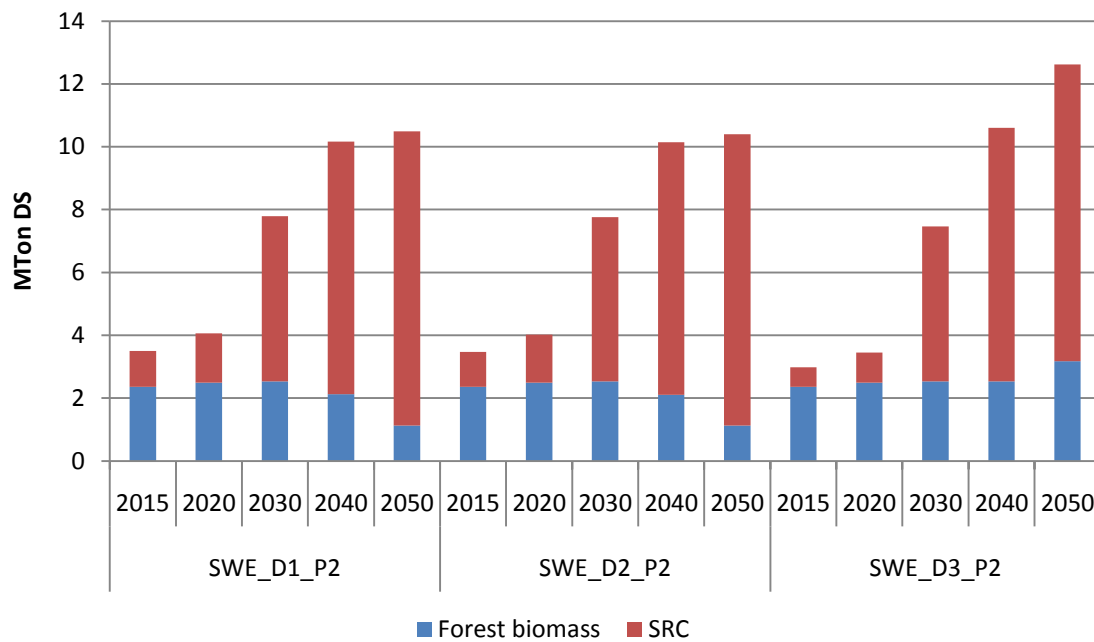**Figure 9: Utilization of forest biomass and short rotation coppice (SRC) in France**

Figure 10: Utilization of forest biomass and short rotation coppice (SRC) in Sweden

4.3 Regional differences in harvesting of forest residues in Sweden

As the potential of forest residue in Sweden was defined individually for each of the 21 counties, we were able to study the difference in the harvesting levels of forest residues between the counties. Figure 11 shows the percentage harvest of the total potential of forest residue in the counties. Our results show that there is a difference between the counties in the harvest level of forest residues and that generally the difference between the counties increases as the marginal price of forest residues decreases. Furthermore, there are three counties that stand out with a lower percentage outtake of forest residue (Norrbotten, Västerbotten, Jämtland).

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When the national harvesting level of forest residue is high and close to the total potential (for example year 2020 and 2030), we observe that the differences in the harvesting level of the resources in the counties is relatively small, only the counties Norrbotten, Västerbotten, and Jämtland do not have a 100% harvesting rate. The harvesting level in these three counties is consistently lower than the harvesting level of the other counties as the harvesting cost of the most expensive harvesting sites in these counties is high. The demand for forest residue thus has to be high for there to be an economical insinuative to harvest forest residue from these sites.

When the national harvesting level of forest residues is low in comparison to the total potential (for example year 2040 and 2050), we observe a high difference in the utilization rate between the counties. This is specially the case in year 2050 for demand D1 and scenario P2, for which we observe that the utilization rate of the counties ranges between 4% and 100%. The high difference in the harvesting levels between the counties can be explained by the high differences in the cost-supply curves. The MARLAL/TIMES model assumes that forest residue is only harvested from areas with a harvesting cost lower than the marginal price of forest residues. As seen in Figure 12, for the marginal price of forest residue year 2050 (scenario P1 and P2), there is a large variance between the counties in the portion of their cost-supply curves that is above the marginal price and thus will not be harvested.
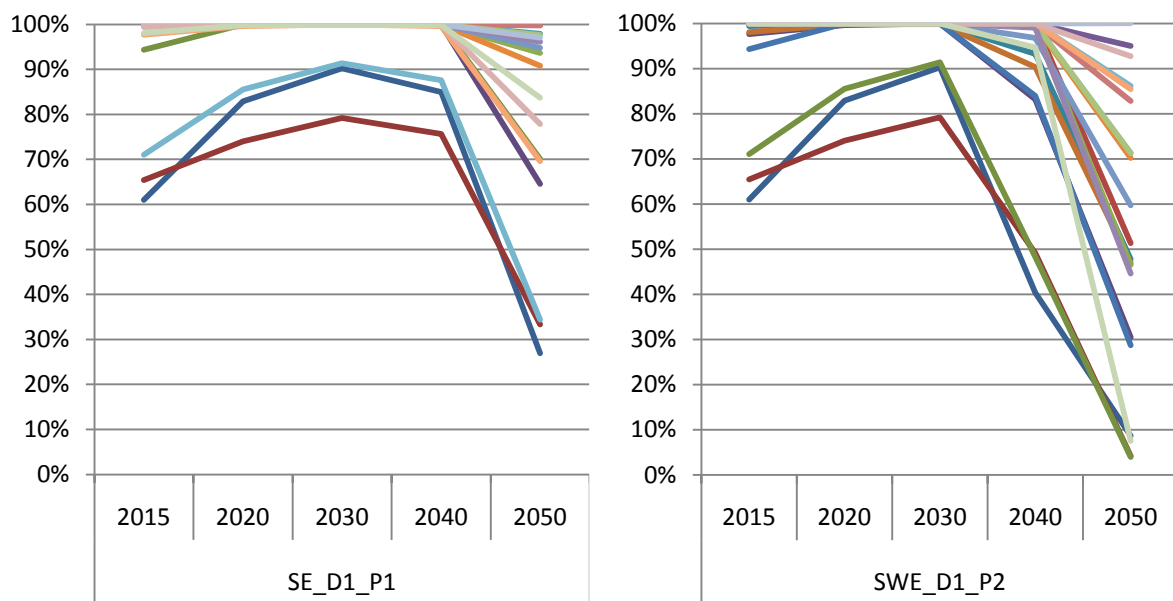

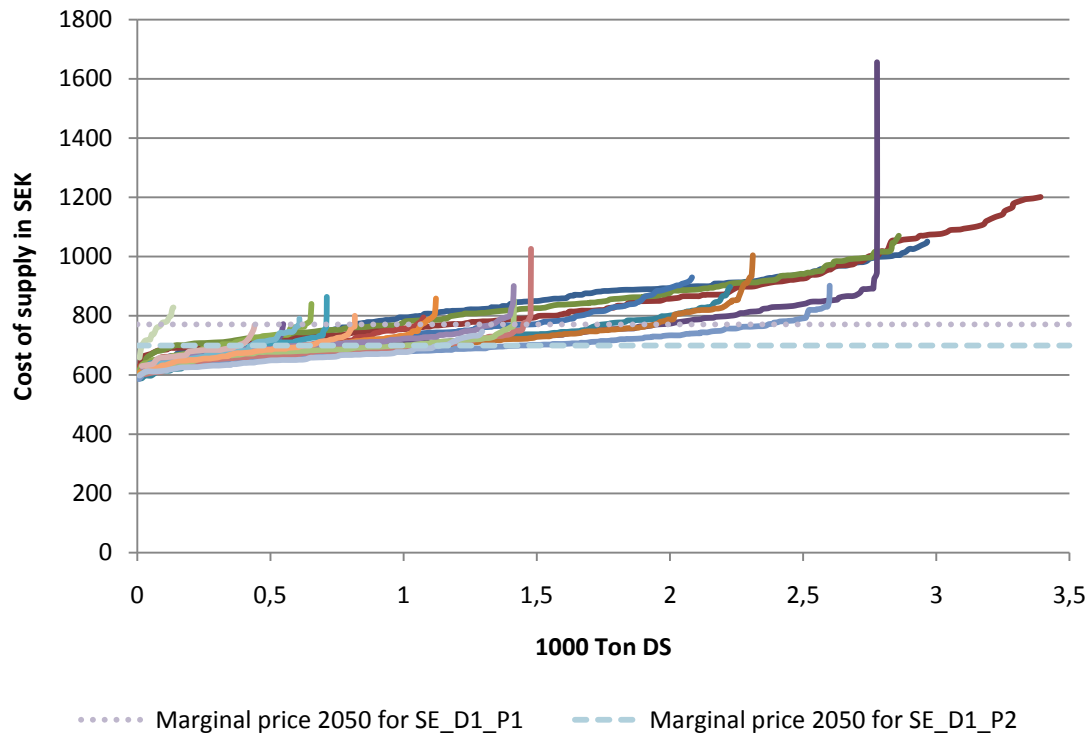Figure 11: Percentage utilization of forest residues in the counties in Sweden

Figure 12 : Cost-supply curves of forest residue in the counties and the marginal price of forest residue for scenarios SE_D1_P1 and SE _D1_P2

5 Conclusions

We have in this paper presented a MARKAL/TIMES model that can be used to study and analyze the possible fulfillment of national objectives concerning the utilization of biomass sources, mix of biomass sources to be utilized, development of the energy system, and the introduction and mix of utilization of first and second generation conversion technologies. As the proposed model is sub-national and considers the biomass potentials on a regional level, the potentials and harvesting costs can be expressed utilizing detailed information. Furthermore, the model enables the study of regional differences in the mix of utilized biomass sources and in the regional utilization levels.

The presented model was utilized to study the utilization of biomass resources in France and Sweden. Utilizing numerous scenarios concerning the potential and demand of biomass sources, we were able to analyze the development of the energy system and the fulfillment of national biomass objectives. While all the demand scenarios for Sweden could be fulfilled by national production potentials, import was required to fulfill the 40 Mtoe demand of biomass in France. The considered scenarios of national biomass potentials and technology availabilities shows that while the 20 Mtoe demand of biomass in France can be fulfilled by national potential, import is required to fulfill the 40 Mtoe demand of biomass in France. Our results show that the limit of national biomass potentials for energy purposes in France is approximately 35 Mtoe.

Our results show that there will be a high demand for forest residue in Sweden. Also, there are large differences between the counties in the utilization levels of forest residues. Norrbotten, Västerbotten, and Jämtland consistently had a lower percentage outtake of forest residue in comparison to the other counties in Sweden. While the transport cost corresponds to a large part of

the harvesting cost of forest residues, the transport cost differs heavily between the counties and between the harvesting sites and is therefore difficult to approximate with a single transport distance. As the harvesting costs varies heavily between the harvesting sites, it is important to consider sub-national cost-supply curves for biomass sources. This especially when comparing the utilization of biomass sources to sources such oil and gas which cost-supply curves are approximately linear. From our results, one can see that while the counties are can be seen as price takers on commodities such oil and gas as they cannot dictate the price of the commodity but have to buy the commodities at the market price, they can be seen as price setters for biomass sources and can dictate the price of the commodity. This as the price of the biomass is highly dependent on the harvest levels, which can be selected by the counties.

Acknowledgement

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