CHAPTER 6:

Estimating GHG emission mitigation supply curves of large-scale biomass use on a country level*

Abstract

This study evaluates the possible influences of a large-scale introduction of biomass material and energy systems and their market volumes on land, material and energy market prices and their feedback to GHG emission mitigation costs. GHG emission mitigation supply curves for large-scale biomass use are compiled using a methodology that combines a bottom-up analysis of biomass applications, biomass cost supply curves and market prices of land, bio-materials and bio-energy carriers. These market prices depend on the scale of biomass use and the market volume of materials and energy carriers and are estimated using own-price elasticities of demand. The methodology is demonstrated for a case study of Poland in the year 2015. The case study applies different scenarios on economic development and trade in Europe that impact biomass supply and markets of land, materials and energy carriers. For the key technologies considered, i.e. medium density fibreboard, poly lactic acid, electricity and methanol production, and scenarios investigated in this study, GHG emission mitigation costs increase strongly with the scale of biomass production. It is found that the influence of a large-scale introduction on the development of biomass supply costs and market prices of land, materials and energy carriers, reduces the GHG emission reduction potential at costs below 50 €/Mg CO_{2eq} with about 13—70% depending on the different scenarios. Bio-material production accounts for only a small part of the total GHG emission mitigation potential at low costs. This is due to relatively small material markets and the subsequent strong decrease of market prices of bio-materials at large scale of production. GHG emission mitigation costs depend strongly on biomass supply curves, own-price elasticity of land and market volumes of bioenergy carriers. This analysis shows that these influences should be taken into account for developing biomass implementations strategies. However, literature estimates of own-price elasticities are highly uncertain and market volumes of biomass applications depend on their competitiveness. To counteract these uncertainties, a combination of a bottom-up analysis with an analysis of market effects is recommended.

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1 Introduction

The use of biomass for energy may contribute significantly to the reduction of greenhouse gas (GHG) emissions (IPCC, 2001b; Johansson, 2000). It has been shown in earlier bottom-up analyses, that the use of biomass for materials combined with the energy utilisation of residues and material wastes may increase the efficiency of GHG emission reduction—i.e. increasing the amount of GHG emissions per area of land used for biomass production and/or decrease the GHG emission mitigation costs—if suitable biomass applications are selected (Chapter 2 and 3 of this thesis). [1]

However, increasing the amount of biomass produced and subsequently the amount of bio-materials and biomass-based energy may lead to an increase of agricultural land prices and a decrease of material and energy prices, depending on the market volumes involved. Especially, markets for bio-materials are often quite small (ECCP, 2001) and therefore, expected decreases of material prices are relatively large; see e.g. Chapter 5 of this thesis. Market volumes and subsequent market price changes may decide which options are economically most attractive to reduce GHG emissions by large-scale introduction of bio-materials and bio-energy carriers. Furthermore, the use of agricultural land for biomass production may influence land prices significantly as the production of food and fodder on agricultural land will compete with the production of biomass for energy and materials; see e.g. Keith (2001). As a consequence, these effects may increase GHG emission mitigation costs of biomass systems with the scale of biomass utilisation.

Various biomass supply curves have been calculated for different geographical scales; see e.g. Hoogwijk et al. (2004a) and Walsh (2000). These calculations are based on the availability of land and its quality and, typically, do not consider changing market prices with increased biomass production. Beside, also supply curves for GHG emission mitigation costs by carbon sequestration in forests have been determined; see e.g. Sedjo et al. (2001) and Stavins (1999). Some of the GHG emission mitigation cost supply curves take increase of land prices due to increased sequestration activities into account by various approaches; see the review by Richards and Stokes (2004). One of these approaches is the use of a demand curve of land that specifies market prices in relation to demand by means of own-price elasticity[2] (Richards and Stokes, 2004). Also the relation

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[1] This increase of efficiency is in the range of avoiding about several tens of Mg CO_{2eq} per ha and yr additionally and lowering GHG emission mitigation costs about several hundreds of € per Mg CO_{2eq} compared to single bioenergy utilisation (see chapter 2 and 3).

[2] Own-price elasticity is the percentage change of demand divided by the according percentage change of price on the demand curve of a commodity.

between the amount of biomass use and its market price has been investigated. Otto and Gallagher (2001) estimate the market price of fodder by-products from ethanol production using own-price elasticity, if ethanol production is increased. De La Torre Ugarte et al. (2003) calculate the demand for agricultural crops depending on their prices using a.o. own-price elasticity.

For many different options, e.g. increases of energy efficiency, carbon capture and storage, and renewable energy supplies, GHG emission mitigation costs have been calculated. These calculations have been done using either bottom-up or top-down approaches including various market effects; see e.g. the review of studies in IPCC (2001b). Studies considering a relation between the demand and the price of goods that use a top-down approach typically start with prices. From these prices—e.g. material prices, energy prices or carbon taxes—the demands for goods are calculated from demand curves. The GHG emissions and costs of a system producing these demands of goods are than compared to those of other possible systems with different demands. Thus, various GHG emission mitigation scenarios have been developed; see e.g. RIVM (2001), Bollen et al. (2004) and Gielen et al. (2003).

Studies that calculate GHG emission mitigation costs of biomass systems starting from an exogenous demand, e.g. of biomass products, taking market effects into account could not be identified. Such an approach, however, may create new insights, because it could produce GHG emission mitigation cost curves for bio-material and bioenergy application by varying the amount of biomass utilisation exogenously. Also, biomass supply curves could be integrated into the analysis, leading to overall GHG emission mitigation cost curves of bio-material and bio-energy uses with growing biomass use considering effects on land, energy and material markets. Another advantage of this approach is that market effects for different biomass applications can be analysed explicitly, e.g. a GHG emission mitigation cost supply curve for bio-fuels may be different than that for bio-materials.

The objective of this study is, therefore, *to evaluate the possible influences of a large-scale introduction of biomass material and energy systems and their market volumes on market prices of land, materials and energy carriers and subsequently on GHG emission reduction costs.*

For this purpose, a methodology to estimate GHG emission mitigation supply curve for large-scale biomass use is proposed. The methodology incorporates (1) a bottom-up analysis of bio-material and bioenergy applications, (2) scenario-dependent biomass cost supply curves and (3) estimations of market prices of land, bio-materials and bio-energy carriers depending on the scale of biomass use and the market volume of materials and energy carriers using own-price elasticities of demand. Because biomass supply curves as well as markets of land, materials and energy carriers depend strongly on economic development and trade, these parameters are varied for different scenarios that follow the SRES scenario families of IPCC (2000).

The methodology is demonstrated for bio-material and bio-energy use on a country-level. Subject of this case study is Poland in the year 2015, because in a short term new Eastern European member states of the European Union may play an important role in European biomass production, as many of these countries have relatively large areas of available agricultural land and low biomass production costs. Poland is a representative example of a Central Eastern European country with a rather high biomass production potential.

We analyse GHG emission mitigation cost curves for four selected bio-material and bio-energy applications. Key criteria for the selection are that the application (1) has a potentially large market volume in the year 2015, (2) potentially reduces a large amount of GHG emissions per unit of biomass used and (3) has rather low initial GHG emission mitigation costs. Moreover, for the simplification of biomass supply curves and the calculation of GHG emission mitigation cost curves, only applications are selected that can use the same type of biomass, i.e. short rotation wood. From earlier reviews of GHG emission reduction of bio-materials and bioenergy carriers (see Chapter 2, 3 and 5 of this thesis), the following four bio-material and bio-energy applications are investigated:

- Poly lactic acid (PLA) with waste-to-energy recovery
- Medium density fibreboard (MDF) with waste-to-energy recovery
- Methanol
- Electricity

In Section 2, an overview of the approach is given, while Section 3 presents input data on the biomass supply and the selected biomass applications based mainly on scientific literature, market statistics, and agricultural production data. Section 4 presents GHG emission mitigation costs of the different biomass systems and finally, Section 5 and 6 finish with discussion and conclusions.

2 Method

To calculate GHG emission mitigation cost supply curves, various calculation steps are necessary. In Figure 6.1, the various steps to calculate GHG emission mitigation supply curves are presented.

1. Biomass supply curves describing the possible amount and costs of biomass production in Poland are determined.
2. The effects of increased biomass production on the market prices of agricultural land are investigated.
3. The GHG emission mitigation costs of selected bio-materials and bio-energy applications are calculated.
4. The changes of market prices of materials and energy carriers due to an increased production of bio-materials and bio-energy are estimated.
5. The results of these four steps are combined in a GHG mitigation supply curve.

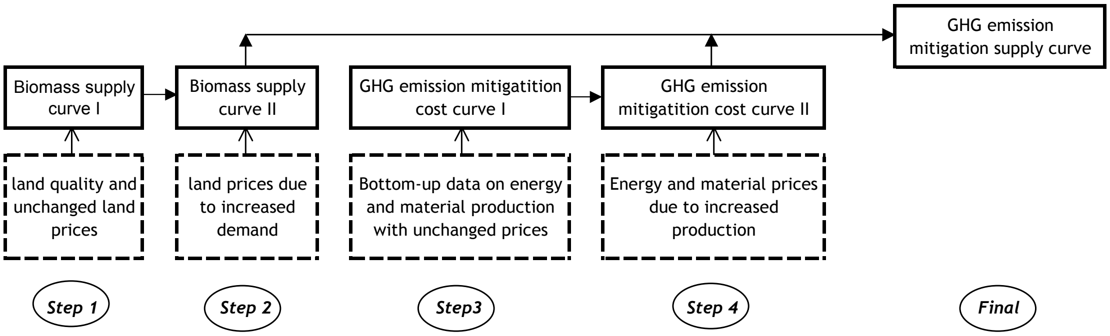

Figure 6.1: Overview of the main steps to calculate GHG emission mitigation supply curves of bio-material and bioenergy applications in which price elasticity effects are incorporated

The first step leads to the '*biomass supply curve I*' describing biomass production costs (€/Mg $_{\text{biomass}}$). It is based on the production costs per ha, the available agricultural land of different qualities with different crop yields and land rents. However, with a growing production of biomass for energy and material applications, agricultural land rents rise. In step 2, these increased land rents lead in combination with the production costs to the '*biomass supply curves II*'. Step 3 results in the '*GHG emission mitigation cost curve I*' describing the basic GHG emission mitigation costs (€/Mg CO_{2eq}) of the bio-material and bio-energy applications. These costs are determined from the difference between production costs and market prices of the bio-material applications and from the difference between the GHG emissions of biomass application and a reference application. As for the land rents, an increased production of bio-materials or bio-energy may increase their market prices.[3] With these new market prices of bio-materials and bio-energy and the data from

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[3] An increased production of a good typically leads to a decrease in market prices, because selling the additional production necessitates an additional demand and the relation between an increase in demand and market prices is

the GHG emission mitigation cost curve I, GHG emission mitigation costs of the *'GHG emission mitigation cost curve II'* are calculated in step 4. Step 5 then determines the final *'GHG emission mitigation supply curve'* by summing the costs of the biomass supply curve II and the GHG emission mitigation costs II. GHG emission mitigation supply costs are calculated as *marginal costs* for avoiding an additional unit of GHG emissions, see also equation 1. By comparing the marginal GHG emission mitigation costs of the different biomass application and selecting the respective lowest costs at each additional amount of biomass used, an overall GHG emission mitigation cost supply curve can be composed.

$$C_{GHG}\ (S) = (C_{bios}\ (S) + C_{land}\ (S) + C_{bioa} - R_{bioa}(S))/(-GHG_{bios} - GHG_{bioa} + GHG_{sub}) \qquad (1)$$

C_{GHG}: Marginal costs of GHG emission mitigation (€/kg CO_{2eq})
S: Scale of biomass system (kg $_{biomass}$/yr)
C_{bios} (S): Marginal costs of biomass production in relation to scale due to the quality of available land (€)
C_{land} (S): Marginal costs of agricultural land in relation to scale due to land demand (€)
C_{bioa} : Marginal costs of the production of bio-materials and bioenergy (€)
R_{bioa}(S): Revenues of bio-material and bioenergy sales in relation to the market size and their subsequent market prices
GHG_{bios}: GHG emissions during biomass production (kg CO_{2eq})
GHG_{bioa}: GHG emissions during production of bio-materials and bioenergy (kg CO_{2eq})
GHG_{sub}: GHG emissions during production of reference applications that are substituted by bio-materials and -energy (kg CO_{2eq})

Possible biomass supply curves as well as the bio-energy and material markets depend strongly on the trade of food, materials and energy and technological developments in the agricultural sector, which are difficult to predict. To accommodate this variability in a bottom-up calculation, biomass supply curves and market developments are differentiated for four scenarios that reflect possible political developments in Eastern Europe. Following, the methodology used in the various steps of our approach is discussed.

2.1 Biomass supply curve I

The biomass supply curve I is estimated for the production of short rotation coppice (SRC) in Poland in the year 2015.[4] The methodology for the calculation of this biomass supply curve I is summarised in figure 6.2. Food demand and international trade determine the demand for food production in Poland. The available agricultural land in Poland is divided into four different quality categories with subsequent different crop yields and land

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usually negative. However, if an additional demand can be created without lowering market prices—e.g. by substituting fossil reference energy carriers—market prices may also stay constant, see Section 2.4.

[4] The methodology and the data used to estimate the biomass supply curves I are based on research on possible future biomass supplies in Central Eastern Europe (CEE) carried out at the Copernicus Institute, Utrecht University. This research is carried out in the context of the European Commission supported research project: *VIEWLS - Clear Views on Clean Fuels, Data, Potentials, Scenarios, Markets and Trade of* Biofuels (NNE5-2001-00619).

costs. These categories are: very suitable (VS), suitable (S), medium suitable (MS) and marginally suitable (mS). This agricultural land is allocated to food production in order to achieve a most efficient land use in terms of total hectares; see Smeets et al. (in press).[5] Following, agricultural land that is available for energy crop production in the four different quality categories, i.e. land that is not used for food production, is determined. From the available land, biomass yields, land costs, and assumptions on the agricultural production system, amounts and costs of biomass production are calculated.[6] The amount and costs of biomass are finally summarised in the biomass supply curve I.[7]

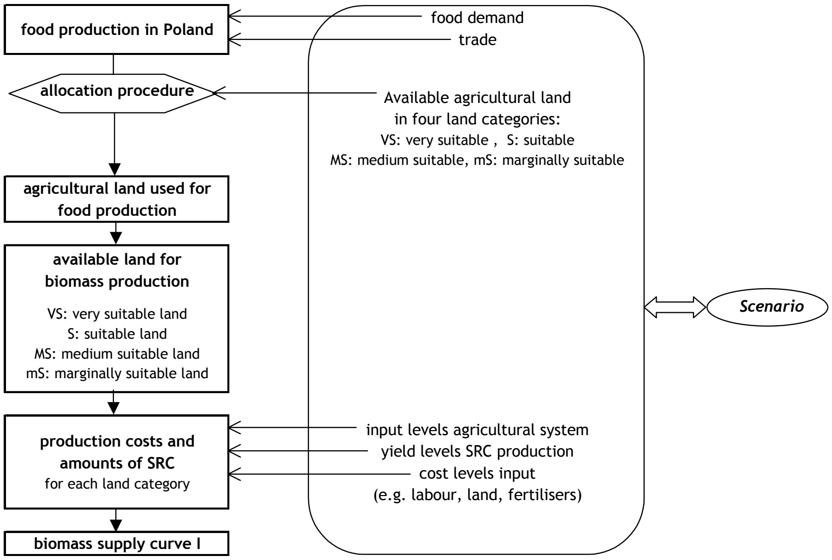

Figure 6.2: Schematic overview of the calculation of biomass supply curves I

Because agricultural production and the demand for food are strongly related to economic and demographic trends, we determine the biomass supply curve I for four different scenarios. These scenarios are related to the SRES emission scenarios (IPCC, 2000) and are translated for Europe. The scenarios differ with regard to an economic (V1, V2) versus an environmental orientation (V3, V4) and with regard to a global (V1, V3) versus a regional orientation (V2, V4). In table 6.1 the main characteristics of these scenarios and the most important assumptions for the calculation of biomass supply curves are presented. (In brackets the most closely related SRES scenario family is indicated.)

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[5] Note, that the suitability of land is crop dependent.

[6] In the V1 and V4 scenario, also a small part of agricultural land is reserved for the growth of forestry and urban areas. In the V3 scenario, part of agricultural land (0,5% per land suitability type) is reserved for energy crops before the allocation procedure.

[7] Input data on available land, biomass yields and production costs are summarised in table 6.3 in Section 3.1.

Table 6.1: Characteristic of scenarios for the analysis of biomass supply

Characteristic	**V1 (A1)**	**V2 (A2)**	**V3 (B1)**	**V4 (B2)**
Main economic characteristic	Fast growing economy, international trade	Slow economy, CEE lacks behind Western Europe	EU economy, scenario based on CAP reforms	EU economy, high level of self-sufficiency in protected market
Trade of agricul. products	Liberal trade on world market	Market oriented CAP reform	Market oriented CAP reform	Self-sufficiency, import reduced substantially
Agricul. production system	High – tech advanced	Intermediate	High input	High –tech advanced
Machinery and labour input	Advanced machinery, low labour input	Current situation CEE	SOTA machinery, low labour input	SOTA machinery, low labour input
Yield levels SRC	+30% of high input system yields	-30% high input system yields	high input system (Data from IIASA)	+30% of high input system yields
Cost level production inputs	Decrease of EU prices (increased competition)	Current cost levels CEE	Current cost levels EU	Increase of EU prices (protected market)
Land costs	Current land rents USA (open market)	Current land rents CEE	Current land rents EU	Increase of EU prices (protected market)
Labour costs	Increased costs (strong economy)	Current cost levels CEE	Current cost levels EU	Increased costs

SRC: short rotation coppice; CEE: Central Eastern Europe; CAP: Common Agricultural Policy of EU; SOTA: State of the Art; IIASA: International Institute of Applied System Analysis

2.2 Biomass supply curve II

The costs of biomass in the initial biomass supply curve I am calculated using fixed land prices differentiated by the quality of the agricultural land and varying per scenario. In the biomass supply curve II, we take into account that the price of agricultural land increases if the demand for land increases, e.g. due the production of biomass.

In an ideal market, the price of a good, e.g. agricultural land, and the demand for it are related negatively. This relation can be described by a demand curve and the ratio between the percentage change of demand and the percentage change of price is the so-called own-price elasticity. This own-price elasticity can vary for different demand levels of a good, but often demand curves are simplified by assuming constant own-price elasticity. This assumption is used in this chapter, too. Equation (2) shows such a demand curve for agricultural land.

Biomass production can be regarded to lead to an additional demand for agricultural land apart from food production. We assume that at the given land rents—used for the calculation of the biomass supply curve I—all agricultural land is used for non-biomass production. Furthermore, it is assumed that in the short term, the amount of agricultural land is fixed and that every increased demand for agricultural land leads to an increased price. The new price of agricultural land can be calculated depending on the own price elasticity of land; see equation (3).[8] This formula describes, in fact, a movement of the original demand curve of agricultural land to a new demand curve. In this new demand curve, the demand of land for a certain price is higher than in the original one, and the difference is about the additional demand of land due to biomass production. For the fixed amount of available agricultural land, the price on this new demand curve then is higher than in the original demand curve; see chapter 5 of this thesis.

$$P_{\mathrm{L}\text{-}curr} = C_L * Q_{\mathrm{L}\text{-}T}^{\;1/\varepsilon L} \qquad (2)$$

$P_{\mathrm{L\text{-}curr}}$: current price of agricultural land rents [€/(ha*yr)]
C_{L}: Constant [€*(ha*yr)$^{(-1/\varepsilon L-1)}$]
$Q_{\mathrm{L\text{-}T}}$: total amount of agricultural land available per year [ha*yr]
εL: own-price elasticity of agricultural land

$$P_{\mathrm{L}\text{-}new} = P_{\mathrm{L}\text{-}curr} * (Q_{\mathrm{L}\text{-}T}/(Q_{\mathrm{L}\text{-}T}+ Q_{\mathrm{L}\text{-}add\text{-}bio}))^{1/\varepsilon L} \qquad (3)$$

$P_{\mathrm{L\text{-}new}}$: new price of agricultural land rents [€/(ha*yr)]
$Q_{\mathrm{L\text{-}add\text{-}bio}}$: additional demand for land due to biomass production [ha*yr]

2.3 GHG emission mitigation cost curve I

For each of the biomass applications, i.e. MDF, PLA, methanol and electricity, the GHG emission mitigation cost curve I is calculated. The GHG emission reduction is determined by comparison of the biomass application system with a non-biomass reference system. In the reference system, the same functions are fulfilled as in the biomass system. Costs are calculated from the difference between the production costs of the bio-materials and bio-energy carriers and their market prices. This approach to calculate GHG emission mitigation costs and the type of input data necessary has been demonstrated in Chapter 5 of this thesis. For the GHG emission mitigation cost curves I, the market prices are fixed. Because we are mainly interested in the market effects of bio-material and bio-energy introduction instead of in the development of biomass applications, no scenario-dependent technology developments or subsidies are taken into account. Also other dynamics such as technological learning and the developments of new markets during large-scale implementation of biomass technologies are not considered; the timeframe until the year 2015 is too short for these effects to be pronounced and, moreover, world markets in general are hard to predict.

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[8] In this chapter, different land quality classes are used for biomass production. As it is assumed that a demand for agricultural land in any of the classes will lead to increased prices on the whole land market, the increase of the average land price is calculated. From the new average land price and the ratio between the current average land price and the current land price of the land class, the new land price of the land class is calculated.

Figure 6.3 gives an overview of the biomass and the references systems considered in this study. For agricultural land, the biomass supply curves are based on the assumption that necessary food/fodder is produced and that on the remaining land biomass can be produced for other purposes. Therefore, it is assumed that the reference land use of agricultural land is set aside. In the reference system, forestry land is used for the production of plywood, which is utilised as construction material. However, if in the biomass system agricultural land is used to produce an alternative construction material, i.e. MDF board, the conventional forestry land is assumed to produce wood for electricity production.[9]

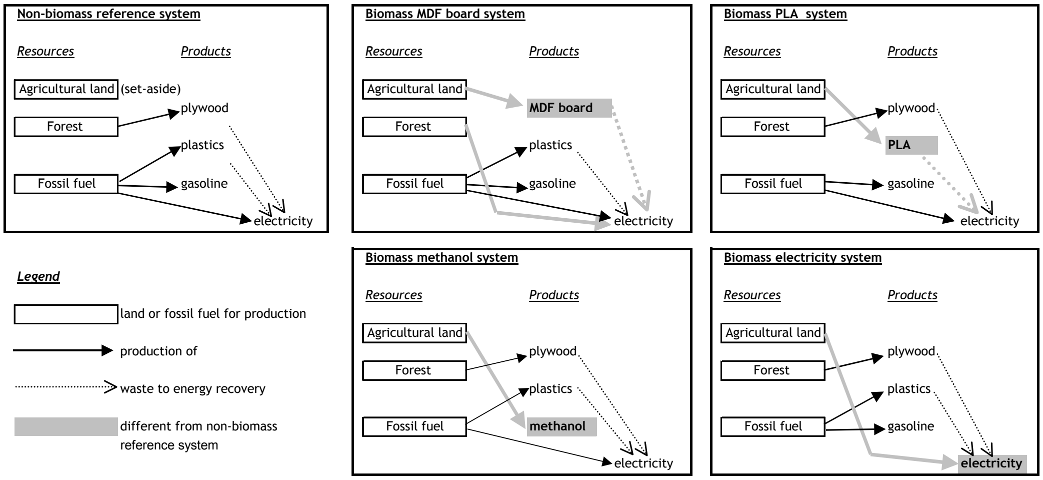

Figure 6.3: Selected biomass systems and the non-biomass reference system to determine GHG emission reductions

Bio-materials in the biomass system are produced and used in a ‘multi-functional’ way. This means that besides the bio-materials, bio-energy is produced by the utilisation of residues and waste materials. Both bio-materials and bio-energy carriers are then compared to reference materials and energy carriers. In the *MDF biomass system*, MDF board is produced from ligno-cellulosic biomass. This MDF board replaces plywood from softwood produced in conventional forestry on a board volume basis. After utilisation both plywood and MDF board are incinerated with electricity recovery; see Chapter 3 of this thesis for a description of MDF and plywood production. In the *PLA biomass system* bio-based PLA replaces polyethylene (PE) on a weight basis; see also Chapter 4 of this thesis for a description of PLA and PE production. Like in the MDF production system it is assumed that

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[9] In fact, the forestry land could be used for the production of other forest products, for the production of energy, converted to agricultural land or not harvested at all. With our assumption of electricity production, the material and energy carriers in the different systems can be easily compared.

both PLA and PE are incinerated for electricity recovery after use. Finally, in the *electricity and methanol biomass systems*, electricity from the grid and gasoline are replaced on the basis of energy content of the energy carriers.

2.4 GHG emission mitigation costs II

In the GHG emission mitigation cost curve II, market price changes of materials and energy carriers are incorporated. The lower the market price of a good, the larger the demand for this good. In an ideal market, the market price is equivalent to the costs of supply and the quantities sold are equivalent to the demand of the respective market price. However, if a larger amount of a good is produced, e.g. through government interventions to reduce GHG emissions, the market price of the good will decrease until the demand equals the amount of production.

This decrease of market prices applies for the bio-materials investigated in this study, i.e. MDF board and PLA. However, for bio-energy carriers, i.e. methanol and electricity, the situation is different. Currently, a large amount of transportation fuels and electricity are produced from other (mainly fossil) resources. If bio-energy is produced, it substitutes the production from these sources.[10] Thus, the production of bio-energy carriers does not lead to an increased supply of energy carriers. As a consequence, market prices stay constant. However, if no more energy carriers from other sources can be replaced, because the total energy consumption is supplied from biomass, increased production of bio-energy carriers leads to a decrease of market prices. This decrease of market prices is described in a similar way as the decrease of market prices for bio-materials. The consequences of this approach are evaluated in the sensitivity analysis.

The decrease of market prices due to an increased supply of a good can be described by a simplified demand curve with constant own-price elasticity, see Section 2.2. If the amount of bio-material or bio-energy production is increased, the new market price of the good $P_{G\text{-new}}$ can be calculated from the total current market volume of the commodity $Q_{G\text{-T},}$ the current price $P_{G\text{-curr},}$ the own-price elasticity εG and the additional production of the commodity $Q_{G\text{-add-bio}}$; see equation (4). Also this approach has been described in Chapter 5 of this thesis.

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[10] This substitution depends of course on whether bioenergy carriers can compete with alternative energy carriers. In a real market, the amount of bioenergy carriers produced will be limited to the amount that can compete with other energy sources. However, in this study we want to illustrate the effect of increased bioenergy production on GHG mitigation cost and, therefore, higher amounts of bioenergy production and substitution of alternative energy carriers are assumed.

$$P_{G\text{-}new} = P_{G\text{-}curr} * ((Q_{G\text{-}T} + Q_{G\text{-}add\text{-}bio})/Q_{G\text{-}T})^{1/\varepsilon G} \qquad (4)$$

Thus, to estimate the new market price of a bio-material or bio-energy carrier at an increased production level, we need to know three parameters, i.e. the elasticity, the total current market volume of the commodity and the current market price of the commodity.

The own-price elasticity of a good refers to a specific market, i.e. the type of good (e.g. agricultural land, forestry land) and the size of the market (e.g. only Poland or European Union). Own-price elasticity is often derived by econometric analysis from historical data on quantities sold on the market and their prices; see e.g. van Driel et al. (1997). Two main uncertainties are inherent to this methodology. First, factors that influence the own-price elasticity—like the availability of goods for substitution or income—may be different in the future. Second, often the historical data used do not refer to the specific market investigated in our analysis referring to other geographical scopes or products. For example, food demand may have been investigated instead of agricultural land demand, or global demands for gasoline may have been analysed instead of gasoline demand restricted to the European Union.

The total current market volume and the current market price depend on the assumptions about market size and trade. These assumptions are made for the different scenarios in accordance to the assumptions made for the production of biomass; see Section 2.1. Moreover, for each biomass application considered, assumptions are adapted to the specific market of that application; see Table 6.2. MDF board is currently traded globally. However, regional markets for forest products differ, as can be seen from the differences in market prices; see FAO (2004). Therefore, assumptions on MDF markets in the scenarios follow the assumptions for food markets in Section 2.2, i.e. a world market in scenario V1 and V3 and a limited market to Central Eastern Europe and the EU-25 in scenario V2 and V4. Plastics and transportation fuels are typically traded on a global market with global market prices. Because these commodities are usually produced from crude oil, a limitation of markets to Europe seems unrealistic. As a consequence, a world market is assumed for PLA and methanol in all scenarios. Electricity, finally, is traded on regional markets, for example within Europe, due to transportation constraints. As largest market, therefore, a limited market to the EU-25 is assumed in the V1, V3 and V4 scenario. In the V2 scenario, the market is limited to Central Eastern Europe. Input data for market volumes and prices are discussed in Section 3.

Finally, the market volumes of Polish bio-material and bio-energy production also depend on assumptions about the development of markets in other countries. While the additional production of biomass application in Poland is analysed, other countries may also increase their production of biomass application. For bio-materials, this increased production of all countries in the respective market is the additional amount of production leading to a changed market price. For bio-energy carriers, the production of all these countries replaces alternative energy carriers and, finally leads to a decrease of market prices. It seems unrealistic to assume that the growth of bio-material or bio-energy production is exclusively limited to Poland. Therefore, we assume that all countries increase their production of biomass applications. As an approximation for the share of Poland of this increased production, we assume that the current market share of Poland for a certain good stays constant.

Table 6.2: Scenarios and their influence on the biomass energy and material markets

	V1 (A1)	**V2 (A2)**	**V3 (B1)**	**V4 (B2)**
Basic characteristic	Fast growing economy, international trade	Slow economy, CEE lacks behind Western Europe	EU economy, scenario based on CAP reforms	EU economy, high level of self-sufficiency in protected market
MDF market	World	CEE	World	EU-25
PLA market	World	World	World	World
Methanol market	World	World	World	World
Electricity market	EU-25	CEE	EU-25	EU-25

3 Input data

3.1 *Biomass supply and land markets*

For the calculation of food production in the different scenarios, background data on food demand, GDP growth and trade are data from SRES scenario projections (IPCC, 2000; RIVM, 2001) combined with projections from the FAO on food demands and GDP growth in Eastern Europe (FAO, 2003). Yield data of agricultural crops on a grid cell level (50 km x 50 km) are based on data from IIASA combined with agricultural production data from FAO and EUROSTAT statistics.

Key parameters for the production of biomass, i.e. short rotation willow, are crop yields, amounts of suitable agricultural land in Poland, land rents and biomass production costs; see Table 6.3.[11] Crop yields depend on the intensity of the production system in the respective scenarios. Base data on crop yields are taken from studies of Nonhebel (2002), Londo et al. (2004) and REU and FAL (1996). The suitable areas for energy crop

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[11] The input data discussed here are also used in research carried out at the Copernicus Institute, Utrecht University in the project *VIEWLS - Clear Views on Clean Fuels, Data, Potentials, Scenarios, Markets and Trade of Biofuels.* A more detailed report on biomass supply curves is forthcoming.

production are also from IIASA and have been adapted to water stresses for willow production. Land rents for Europe and the U.S. are taken from Eurostat (2003) and USDA (2003), while Polish land rents are obtained from the Institute of Agricultural and Food Economics (IAFE) in Warsaw. Finally, production costs are calculated from a reference case of willow production on a current input level in Poland (EC-BREC, 2004). These production costs are adapted to different intensities of agricultural production and different qualities of agricultural land by assumptions on the amount of agricultural production inputs used, e.g. fertilisers based on Kaltschmitt and Reinhardt (1997) and labour based on ILO (2001).

Table 6.3: Key input data on biomass production in the different scenarios

	Short rotation wood yield Mg/ha*yr	**Suitable agricultural land for biomass production**[a] Million ha	**Land rents** €/(ha*yr)	**Production costs**[b] €/(ha*yr)
Scenario V1				
Very suitable land (VS)	15.0	7.20	116	314
Suitable land (S)	11.2	4.58	54	267
Medium suitable land (MS)	7.6	3.01	43	233
Marginally suitable land (mS)	2.4	2.20	25	166
Scenario V2				
Very suitable land (VS)	10.5	8.43	113	112
Suitable land (S)	7.9	3.15	35	89
Medium suitable land (MS)	5.3	3.44	29	68
Marginally suitable land (mS)	1.7	3.58	10	39
Scenario V3				
Very suitable land (VS)	12.8	7.74	165	496
Suitable land (S)	9.5	4.16	111	433
Medium suitable land (MS)	6.5	3.03	100	374
Marginally suitable land (mS)	2.1	2.13	84	303
Scenario V4				
Very suitable land (VS)	15.0	7.45	235	680
Suitable land (S)	11.2	4.41	177	601
Medium suitable land (MS)	7.6	2.93	164	528
Marginally suitable land (mS)	2.4	2.20	145	443

VS very suitable land, S: suitable land, MS: medium suitable land, mS: marginally suitable land.

[a] Total amount of agricultural land without subtracting land for food demands.

[b] Production costs stated here exclude land rents. The production costs are based on data from EC-BREC (2004) in which production costs are about 281 €/(ha*yr) and have been adapted for the different scenarios, characterised by different land qualities and production systems. Main assumption is that the intensive production systems require a high input of machinery and relatively less labour input. The V2 scenario is based on the current situation in Poland. Input data for the total production costs as presented in this table are: (1) interest rates, ranging from 6% for V1 to 4% for V2 (Eurostat, 2004); (2) rotation periods (ranging from 21 years for VS land for V1 and V4 to 25 years for S land for the V2 scenario) and harvest cycle (G. Kunikowski EC-BREC, personal communication 2004; Szczukowski et al., 2002a, Larsson and Lindegaard, 2003); (3) fertiliser use, which is related to yield levels based on the formulas from Kaltschmitt and Reinhardt (1997); (4) cuttings per ha, ranging from 18.000 cutting / ha for S land for the V1 and V4 scenario to 12.000 cuttings / ha for S land for the V2 scenario (Ledin, 1996; DEFR, 2003; Szczukowski et al., 2002a); (5) pesticide use is based on Szczukowski et al. (2002a), Kaltschmitt and Reinhardt (1997) and Stańczyk and Ludwik (2003), and only differentiated for V2 scenario assuming a decrease of inputs; (6) fertiliser costs are € 0.44 / kg for V2 (current cost level in Poland), € 0.52 for V1 (assumption is that cost levels go down with an open market compared to average EU price level

because of increased competition), € 0.60 / kg for V3 (average EU price level) and € 0.75 / kg for V4 (assumption is that cost levels increase because of decrease of competition for European manufacturers), ranges are based on data from EC-BREC (2004) and Eurostat (2003); (7) pesticide costs range from € 3.37 to € 13.28 / litre for *Roundup*, based on the same assumptions as mentioned for fertiliser costs, data are from Stańczyk and Ludwik (2003), PAV (2000) and G.V. Roman (University of Agronomic Sciences and veterinary Medicine in Bucharest, personal communication 2004); (8) labour costs range from € 2.52 / hour for V2 scenario (current wages in Poland) to € 12.22 / hour for V3 scenario (average EU level) and € 14.63 for V1 and V4 scenario (increase compared to average EU level because of strong economy and more efficient production system), data are from ILO (2001) and EC-BREC (2004); (9) Machinery and labour input for harvesting are based on data from EC-BREC (2004), WSRC (2004) and Ledin (1996) and differentiated per scenario based on yield levels and costs for wages and machinery. Input data range for machinery from 3.75 €/t_{dm} per rotation for V2 to 11.06 €/t_{dm} per rotation for the V1 and V4 scenario); (10) Insurance and miscellaneous costs are based for the V3 scenario on data from EC-BREC (2004), assuming a 10% increase for the V1 and V4 scenario and a 5% decrease for the V2 scenario.

Finally, the available agricultural land for energy production depends on the suitability of land for energy crop production and the amount of land that is already used for food production. The available agricultural land for willow production in the different scenarios is summarised in Figure 6.4 (as resulting from the bottom-up approach described in Smeets et al., in press).

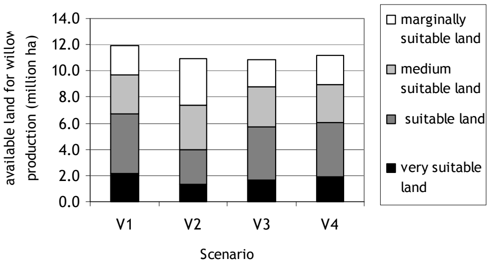

Figure 6.4: Projected available agricultural land in 2015 for the production of biomass (i.e. short rotation wood) after subtracting land for food demands

In the analysis of land markets, new rents of agricultural land are calculated. Input data for these calculations are the base rents, the total amount of agricultural land (see Table 6.3) and the elasticity of agricultural land. In scientific literature, no estimates for own-price elasticity of land could be identified. Rather, own-price elasticity of food is used for the agricultural sector; see Ciaian et al. (2002). This is due to the fact that the demand for agricultural land is closely related to the demand for food. Estimates for the own-price elasticity of food vary considerable.[12] Based on the results of Finke et al. (1984), Ciaian et al. (2002) estimates elasticities of –0.18, -0,24 and –0.3 for the Czech Republic, Poland and Slovakia, respectively. We use the medium value of –0.24 as estimate for Central Eastern Europe in the V2 scenario. In the V4 scenario, we assume a slightly higher value of about –0.2 as presented for the Netherlands by van Driel et al. (1997) to be applicable for the EU-25. Finally, no global estimates for food demand could be identified. As in the global V1

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[12] Finke et al. (1984) estimate elasticity factor between -0.03 and 0.64. For the U.S., the authors estimate an elasticity of –0.03, while Driel et al. (1997) determine this elasticity to be –0.45.

scenario current U.S. land rents are assumed, we assume an elasticity factor for food demand in the U.S. of –0.45 (van Driel et al., 1997) in the global land markets of the V1 and V3 scenario.

3.2 Biomass applications and their markets

In this section, input data on the four bio-material and bioenergy systems i.e. medium density fibreboard (MDF), poly lactic acid (PLA), methanol and electricity production are described. Key parameters for the characterisation per unit of biomass application are the input of short rotation wood, the production costs and the GHG emission reduction in relation to the reference system; see Table 6.4. Furthermore, MDF and PLA and their reference materials, i.e. plywood and PE, are converted to electricity after their use. The resulting electricity is assumed to replace electricity from the grid and, thus, to contribute to GHG emission reduction and revenues from sales.

Data on material and energy markets are summarised in Table 6.5. These are market volumes, market prices and Polish market shares of the biomass applications based on statistics and own-price elasticities. While the growth of GDP may lead to developments of the consumption of materials and energy carriers in 2015, in this chapter no changes of material and energy demands are assumed, but current market volumes are used. On the one hand, this is because the demand for materials and energy carriers does not develop one by one with the growth of GDP, since energy efficiencies increase. Also the growth of GDP may cause sectoral changes influencing material and energy intensities, see Groenenberg (2002). On the other hand, keeping market volumes of materials and energy carriers constant, enables us to investigate market effects on GHG emission mitigation costs without disturbing influences. However, in the sensitivity analysis the influence of this assumption is evaluated, see Section 4.5.

In general, GHG emissions are calculated with carbon emission factors representing indirect and direct greenhouse gas emissions of average European energy use in 2000.[13] For fuel, the average EU oil product mix for production of 83 kg CO_{2eq}/GJ and for electricity, the average EU mix of electricity production of 126 kg CO_{2eq} /GJ are used (UBA, 2003). The GHG emissions of biomass production are derived from production inputs of short

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[13] GHG emission factors of energy use vary within geographical regions and are likely to change in the future. Moreover future specific GHG emissions are depending on economic developments and governmental policies and are, therefore, scenario specific; see e.g. Bollen et al. (2004). In our analysis, GHG emission factors of energy use are kept constant in order to investigate market effects on GHG emission mitigation costs without disturbing influences of varying GHG emission factors.

rotation willow production in Poland (Szczukowski et al., 2000a) and generic GHG emissions for machine uses, fertilisers, etc. mainly from a study from Biewinga and van der Bijl (1996). The resulting GHG emissions are about 0.23 kg GHG per ha; see Chapter 2 of this thesis for a more detailed description of GHG emissions from biomass production.[14]

MDF

The input of wood for MDF is based on a study of hardboard (Richter et al., 1995). Concerning GHG emission reduction, it is assumed that MDF replaces plywood with the volume of board as functional unit.[15] The GHG emission reduction is then calculated from the GHG emissions during plywood and MDF production[16] (Kaltschmitt and Reinhardt, 1997; Forintek, 1993; Hekkert and Worrell, 1998; Haygreen and Bowyer, 1996). Also, the GHG emissions that could be saved if forestry wood for plywood production would be used for electricity production are added to the GHG emission reductions. Production costs of MDF are estimated to be the difference between the prices of the raw material, i.e. wood chips, and the export prices of MDF board in Europe derived from statistics on wood products trade (FAO, 2004). Data on the production and GHG emission reduction of MDF as summarised in Table 6.4 have already been discussed in a study of short rotation wood cascading; see Chapter 3 of this thesis.

The market volume, i.e. the consumption of MDF boards is currently (in 2002) about 23.3 million m^3 in the world, 8.0 million m^3 in Europe and 1.5 million m^3 in Central Eastern Europe (FAO, 2004). Market volumes in Table 6.3 are converted to Mg with an average density of MDF board of 0.65 Mg/m^3 (Haygreen and Bowyer, 1996). Polish market shares of MDF board production in comparison to MDF board consumption have been 5.3% globally, 15.6% in whole Europe and 84.6% in Central Eastern Europe (FAO, 2004). Market prices are based on the import prices for fibreboard in the world, Europe and Central Eastern Europe, respectively, in 2002 (FAO, 2004).[17] The own-price elasticity of MDF board demand has been estimated from historical MDF board import prices and consumption by regression analysis; see Figure 6.5. These data are available for 1995—2002 (FAO, 2004).

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[14] Different biomass production systems for Poland, i.e. 'current input', 'high input' and 'high advanced input' are assumed in the scenarios. These production systems use different levels of inputs per hectare, e.g. machinery and fertilisers, but also lead to different levels of short rotation willow yields per hectare. Due to a lack of data on GHG emissions of the various production systems, it is assumed that GHG emission per unit of biomass produced is constant. This assumption can be justified by findings for miscanthus for which the share of energy input (including drying) at the end use energy varies only about 8 – 14% for different production systems (Lewandowski and Heinz, 2003).

[15] This is equivalent to 1 kg of MDF board replacing about 0.71 kg of plywood (Haygreen and Bowyer, 1996).

[16] Data on MDF board and plywood production take into account that processing residues are used for process heat generation.

[17] Exchange rate used for conversion to € is the average rate in 2002 of 1.06 US$/€.

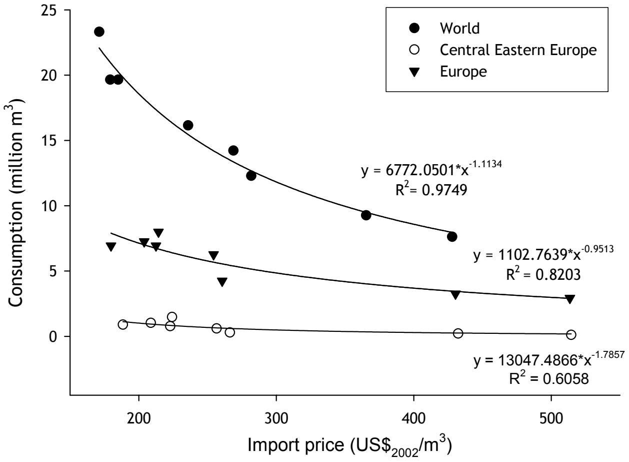

Figure 6.5: Historical data on demand and prices of MDF board used for the estimation of own-price elasticity; data from FAO (2004)

PLA

The efficiency of PLA production is based on current ligno-cellulose pre-treatment (Wooley et al. 1999; Mc Aloon et al., 2000) and current estimations about PLA production from ligno-cellulose (Vink et al., 2003). It is assumed that 1 kg of PLA replaces 1 kg of HDPE. GHG emissions are the emissions of PLA production caused by energy uses (Vink et al., 2003) but accounting for the fact that lignin from short rotation wood is used for process heat and electricity production. Subsequently, net emissions are determined by subtracting GHG emissions of HDPE production APME (2003). Production costs of PLA are taken from projections of Cargill Dow planning to produce PLA from corn stover (Crank et al., 2004). Because HDPE has a much higher heating value than PLA, the net electricity recovery from waste is negative for PLA production. All analyses on energy and GHG balances of PLA production are reported in a study of a PLA bio-refinery; see Chapter 5 of this thesis.

The global market volume of PLA is the current global production of PLA in 2003 of about 0.14 million Mg (Crank et al., 2004). Current global market prices are taken from a study on bio-based polymers (Crank et al., 2004). At the moment no PLA is produced in Poland. Therefore, we use Polish market shares of polyethylene production as fictive market shares of PLA production (UN, 2002). Because the production of PLA (and other bio-based polymers) is a rather new development, no historical data on market prices and production volumes are available. However, as PLA has the potential to substitute PE on a large scale, the own-price elasticity of PE is used in this analysis for PLA. This own-price elasticity is estimated from historical figures of global PE production and market prices by regression; see Figure 6.6 (UN, 2002; Crank, et al., 2004).

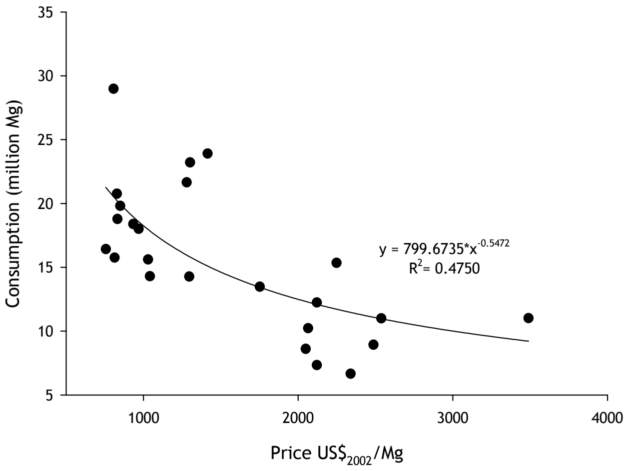

Figure 6.6: Historical data on global demand and prices of Polyethylene used for the estimation of own-price elasticity; data from UN (2002) and Crank, et al. (2004).

Methanol

Data on methanol production refers to an advanced methanol production concept without electricity co-production and a conversion efficiency of 57% (HHV) as investigated by Hamelinck and Faaij (2002). Production costs include distribution costs in order to make the production costs comparable to the market prices for end-users used in this analysis.[18] To determine GHG emission reduction, it is assumed that 1 GJ_{LHV} methanol replaces 1 GJ_{LHV} gasoline.

The methanol is assumed to be sold for market prices of gasoline in advanced economies without taxes.[19] The market volume for methanol is the global consumption of petroleum products for road transport, i.e. 58.8 EJ in 2000 (IEA, 2003a). In 1999, the Polish gasoline production was about 0.3 EJ (UN, 2002).

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[18] The methanol production technology considered is currently under development and is likely to be commercial in 2015-2020. The selected concept uses an atmospheric indirectly fired gasifier, wet gas cleaning, steam reforming and liquid phase methanol production (Hamelinck and Faaij, 2004). Production costs are based on an interest rate of 5%, a scale of 400 MWth, a base load of 8000 h/yr, an economical lifetime of 15 years and a technical lifetime of 25 years. Assuming biomass costs of 2 US$/$GJ_{HHV}$, methanol production costs of 7.2 US$/$GJ_{HHV}$ result (Hamelinck and Faaij, 2004). Distribution costs of 2.1 €/GJ_{HHV} (Hamelinck, 2004) are added to the production costs.

[19] Market prices are averaged from prices in USA, Canada, Japan, France, Germany, Spain, Italy and the UK in 2003-2004 (IEA, 2004b).

Espey (1998) compares more than 300 estimates of short-run own-price elasticity of gasoline demand, i.e. describing the relation between prices and demand in the short to medium term. These estimates are derived from economic models as well as time series analysis. The median of all estimates is –0.23 and is used in our analysis.[20]

Electricity

The data for electricity production are based on state-of-the-art IG/CC plant (about 150 MW_e) with a net electric efficiency (LHV) of 43.5% (Faaij et al., 1998). Also for electricity, production costs include distribution costs.[21] Electricity from short rotation wood replaces electricity from the European grid on a kWh basis.

The market volumes of electricity are the consumption of electricity in the year 2000, in the EU-25 and Central Eastern Europe, respectively (IEA, 2002a; IEA, 2002b). Market prices for electricity vary between consumers and countries.[22] In our analysis we use about average market prices without taxes that apply to large-scale household and medium industrial-scale users. In the EU-25 these are about 0.07 €/kWh and in Central Eastern Europe about 0.05 €/kWh (Goerten and Beranek, 2004a and 2004b). Polish electricity consumption in the year 2000 was about 0.35 EJ_e (IEA, 2002a).

Own-price elasticity estimates in economic literature are usually given for limited markets but not for whole regions as the EU-25 or global. However, estimates for elasticity of electricity in scientific literature are in a comparable range. Kamerschen and Porter (2004) estimate the elasticity of total electricity demand in the U.S. between –0.13 and –0.15 and find that this value is within the same range as other US based studies. Wolfram (1999) analyses the British spot market, concluding that the data suggest a price elasticity of approximately –0.1. SEO (1998) investigates industrial electricity use in the Netherlands resulting in an own-price elasticity of –0.2. Given this information, own-price elasticity of electricity is not differentiated between the scenarios, but a value of –0.15 is assumed.

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[20] The estimates of the short-term elasticity range from 0 to –1.36 (Espey, 1998).

[21] The lower heating value of short rotation wood is assumed to be 17 GJ/Mg. Production costs of electricity are calculated from the investment costs of the IG/CC plant, i.e. 1.97 million €/MW_e investment costs (Faaij et al., 1998), a lifetime of 25 years, an interest rate of 5% rent and a load factor of 80%. Also for electricity, distribution costs are added to the production costs as market prices used are for end-users. In Western Europe, i.e. in DK, D, F, the Netherlands, UK distribution costs for large-scale consumers are about 0.01-0.02 €/kWh (ECN, 2001). In this study, distribution costs of 1.5 cent/kWh (4.2 €/GJ) are assumed.

[22] For example, in the EU-25 market prices without taxes vary from 0.035 €/kWh for large-scale industrial users in Latvia and 0.350 €/kWh for small-scale household users in Norway (Goerten and Beranek, 2004a and 2004b).

Table 6.4: Input data of biomass options for the use of SR wood to reduce carbon emissions

	MDF		**PLA**		**Methanol**		**Electricity**	
SR wood input (dm)	1.3	kg_{wood} /kg	0.68	kg_{wood} /kg	0.10	kg_{wood}/GJ	0.13	kg_{wood}/GJ
GHG em. reduction	0.82	kg $CO_{2\,eq}$/kg	3.97	kg $CO_{2\,eq}$/kg	42.6	$kgCO_{2eq}$/GJ	94.2	$kgCO_{2eq}$/GJ
Production costs[a]	250	€/kg	1210	€/kg	6.2	€/GJ	14.6	€/GJ
Electricity recovery[b]	1.62	GJ_e/kg	-7.65	GJ_e/kg	-		-	

[a] Production costs are without costs of biomass inputs, because biomass costs vary within the different scenarios.

[b] In the A1 and B2 scenarios, electric efficiency of waste incineration is 30% (LHV), which is State-of-the-Art in Europe. Lower heating values are 15 GJ/Mg for MDF, 13.5 GJ/Mg for plywood, 43.4 GJ/Mg for HDPE and 17.9 GJ/Mg for PLA.

Table 6.5: Input data of biomass options for the use of SR wood to reduce carbon emissions

	MDF	**PLA**	**Methanol**	**Electricity**
Market volume				
V1	15.2 million Mg (World)	All scenarios:	All scenarios:	8.9 EJ (World)
V2	1.0 million Mg (CEE)	0.14 million Mg (World)	58.8 EJ (World)	1.3 EJ (CEE)
V3	15.2 million Mg (World)			8.9 EJ (World)
V4	5.2 million Mg (EU-25)			8.9 EJ (World)
Market price				
V1	279 €/Mg	All scenarios:	All scenarios:	19.4 €/GJ
V2	453 €/Mg	3000 €/Mg	8.9[b] €/GJ	13.8 €/GJ
V3	279 €/Mg			19.4 €/GJ
V4	366 €/Mg			19.4 €/GJ
Market share Poland				
V1	5%	All scenarios:	All scenarios:	4%
V2	85%	0.3%	0.5%	27%
V3	6%			4%
V4	16%			4%
Own-price elasticity				
V1	-1.11	All scenarios:	All scenarios:	All scenarios:
V2	-1.79	-0.55	-0.23	-0.15
V3	-1.11			
V4	-0.95			

4 Results

For each scenario, all steps of the calculation, i.e. the biomass supply curves I+II, the GHG emission mitigation costs curves I+II and the resulting GHG emission mitigation supply curves for PLA, MDF board, methanol and electricity are shown in figure 6.7 to 6.10.

4.1 *Biomass supply curves*

The biomass supply curves I show biomass production costs in Poland. In the V1 scenario, a large amount of biomass of about 88 million Mg_{dry} is available at relatively low prices below 36 €/Mg_{dry}.[23] Production costs, like labour and land, are even cheaper in the V2 scenario in which economic development of Eastern Europe stagnates. However, as yields are

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[23] 1 Mg_{dry} of biomass, i.e. short rotation willow has a higher heating value of about 18.4 GJ/Mg. Biomass costs of about 2 €/GJ_{HHV} are, therefore, equivalent to about 36.8 €/Mg_{dry}.

also lower and food production is in principle self-sufficient, a total amount of biomass of 59 million Mg_{dry} are available at costs below 28 €/Mg_{dry}. In the V3 scenario biomass production is quite expensive as levels of input, i.e. machinery, labour, fertilisers, etc. and their costs per unit are high. Thus, only 21 million Mg_{dry} of biomass can be produced at lowest possible costs of about 51 €/Mg_{dry}. The V4 scenario is characterised by even higher production costs and high average land rents. As a consequence, the lowest biomass production costs are 60 €/Mg_{dry} for which about 28 million Mg_{dry} of biomass are available.

The biomass supply curves II, also take into account that land rents will increase if biomass for material and energy is produced on a larger scale. Adding the increase of land costs to the biomass supply curves increases the biomass production costs considerable, especially at large scales of biomass production. The higher the basic land rents in a scenario, the higher is the increase of land rents by increasing biomass production. For example in the V2 scenario with low land rents, the increase of biomass production costs is relatively small, not exceeding 70 €/Mg_{dry} even at large scale.

4.2 GHG emission mitigation cost curves

The GHG emission mitigation cost curves I show these costs not considering variable market prices of products and land. Also, biomass supply curves are not taken into account for the calculation of the GHG emission mitigation cost curve I. Thus, the results are indifferent to the volumes of biomass application produced and represent the GHG emission mitigation costs without the possible influences of a large scale introduction of biomass material and energy system.

The GHG emission mitigation cost curves I are depicted for the fixed amount of available biomass given in the biomass supply curves. PLA production has the technical potential to avoid by far the largest amount of GHG emissions using the available biomass. In decreasing order, MDF board production, electricity production and methanol production have lower technical potentials to avoid GHG emissions.

PLA production at current market prices results in all scenarios in low GHG emission mitigation costs of about –500 €/Mg CO_{2eq}. In the V2 scenario, high market prices of MDF board and low market prices of electricity in a Central Eastern European market are assumed. These assumptions result in GHG emission mitigation costs of about

–200 €/Mg CO_{2eq} for MDF production.[24] In the V4 scenario, biomass production costs are assumed to be relatively high. As a result GHG emission mitigation costs of electricity production are with 100 €/Mg CO_{2eq} relatively high, too. The remaining options in the different scenarios have GHG emission mitigation costs of around zero.

The GHG emission mitigation cost curves II show the influence of material and energy markets on these costs by changing bio-material and bio-energy prices depending on the volume produced.

In all scenarios, the GHG emission mitigation costs of PLA production first increase strongly and then stay nearly constant, with increasing amount of GHG emissions avoided. This is due to the relative small market volumes of PLA. With increasing PLA production, market prices of PLA decrease rapidly until the demand curve becomes nearly constant.[25] For MDF board, methanol and electricity, a similar but less pronounced effect can be observed in figures 6.7 to 6.10. The smaller the market volumes of the bio-material or bio-energy carrier are, the larger is the increase of GHG emission mitigation costs with the amount of GHG emissions avoided. For methanol and electricity, however, in the first part of the curves II, the GHG emission mitigation costs are constant, because it was assumed that alternative energy carriers are replaced at constant market prices; see Section 2.4. In all scenarios, the amount of GHG emissions that can be avoided without an increase of GHG emission mitigation is larger for electricity than for methanol.

4.3 GHG emission mitigation supply curves

In the GHG emission mitigation supply curves, costs of biomass production from the biomass supply curve II are combined with costs of the GHG emission mitigation cost curves II. Only GHG emission mitigation costs curves up to 300 €/Mg CO_{2eq} are depicted, as measures with higher costs are very unrealistic to be implemented.[26] Because MDF, PLA, methanol and electricity production technologies use different amounts of biomass per unit of GHG emission reduction, the influence of the biomass production costs on these options varies.

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[24] Negative GHG emission mitigation costs result from the fact, that revenues from material and energy sales are higher than production costs of these materials and energy carriers.

[25] This increase is not visible at the scales in Figure 6.7 to 6.10, but the GHG emission mitigation costs appear as constant.

[26] According to the IPCC, costs of promising GHG emissions reduction options are at present in a range of up to 60 US$/Mg CO_{2eq} (IPCC, 2001b). However, at costs of 60 US$/Mg CO_{2eq}, only a small part of the total GHG emission mitigation supply curve would be visible. Therefore, costs of up to 300 €/Mg CO_{2eq} are shown.

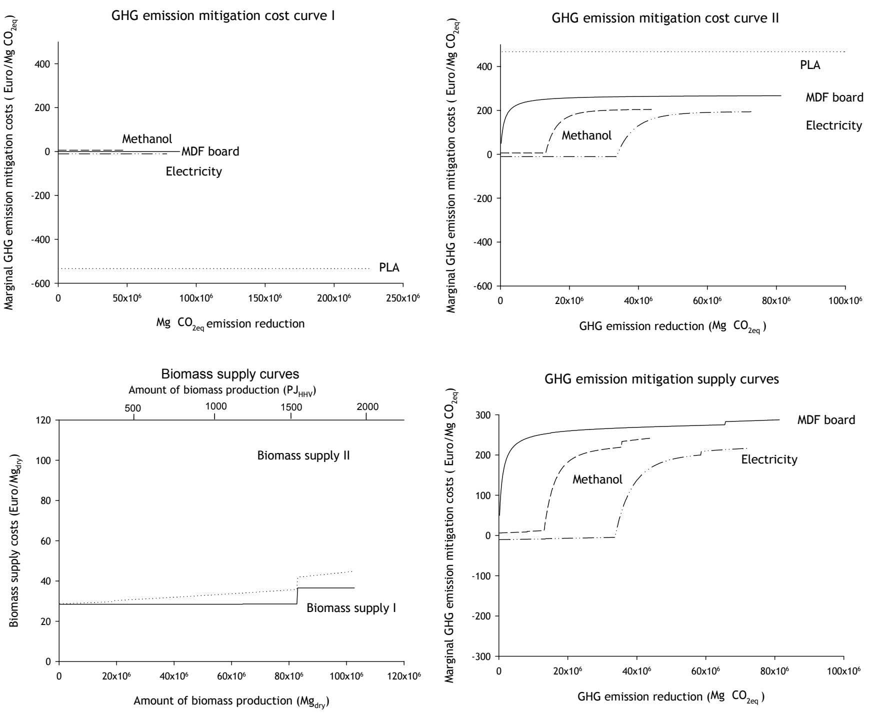

Figure 6.7: GHG emission mitigation cost curves, biomass supply curves and overall supply curves for GHG emission mitigation assuming scenario V1

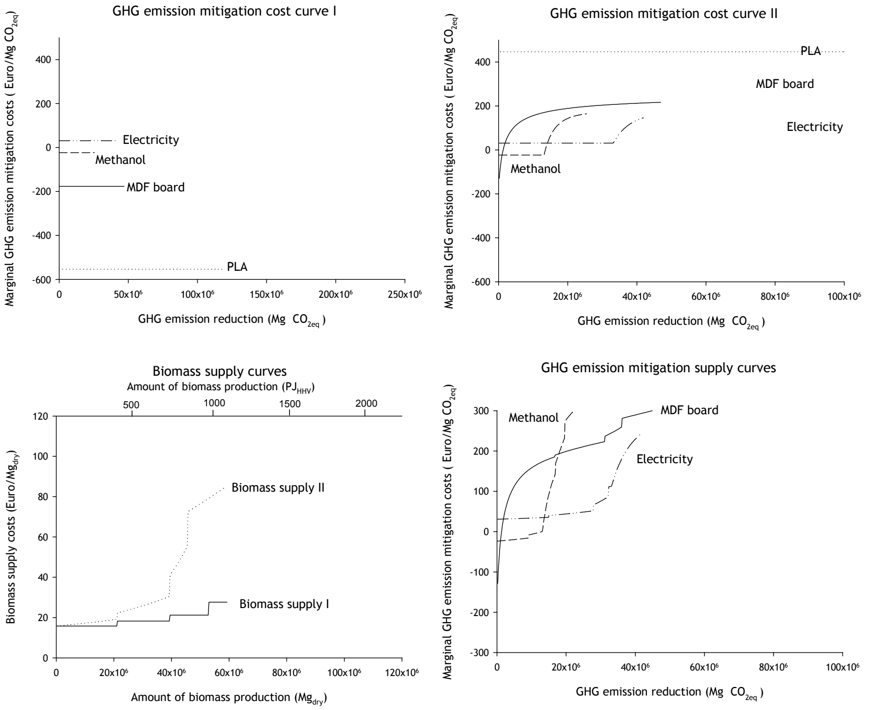

Figure 6.8: GHG emission mitigation cost curves, biomass supply curves and overall supply curves for GHG emission mitigation assuming scenario V2

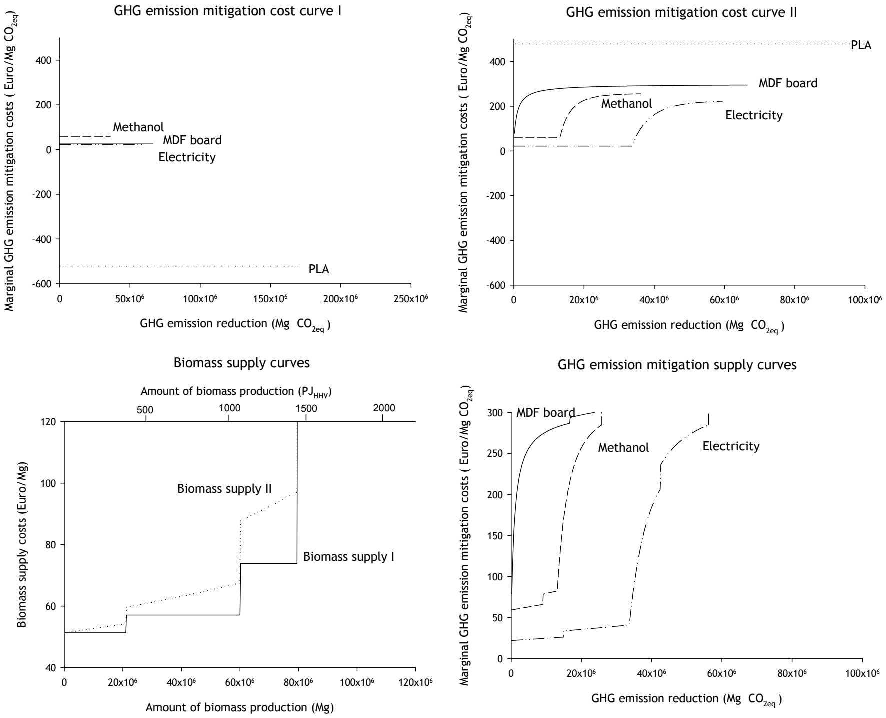

Figure 6.9 GHG emission mitigation cost curves, biomass supply curves and overall supply curves for GHG emission mitigation assuming scenario V3

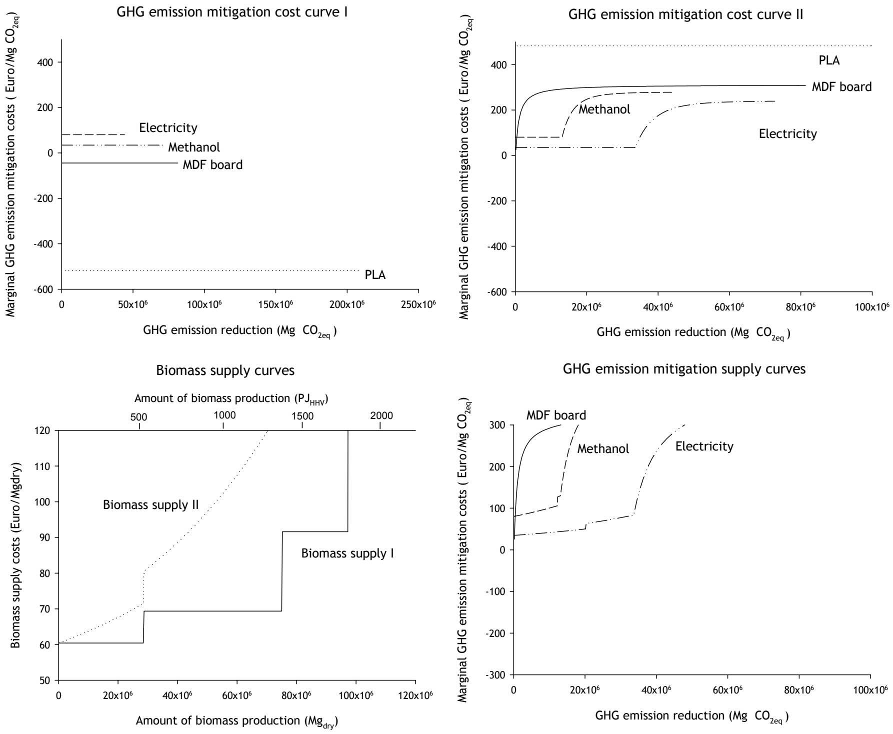

Figure 6.10: GHG emission mitigation cost curves, biomass supply curves and overall supply curves for GHG emission mitigation assuming scenario V4

4.4 Comparison of scenarios

Figure 6.11 depicts the 'integral' GHG emission mitigation cost supply curves for the different scenarios, i.e. for each amount of biomass used, the cheapest biomass material or energy option of the considered technologies is applied.

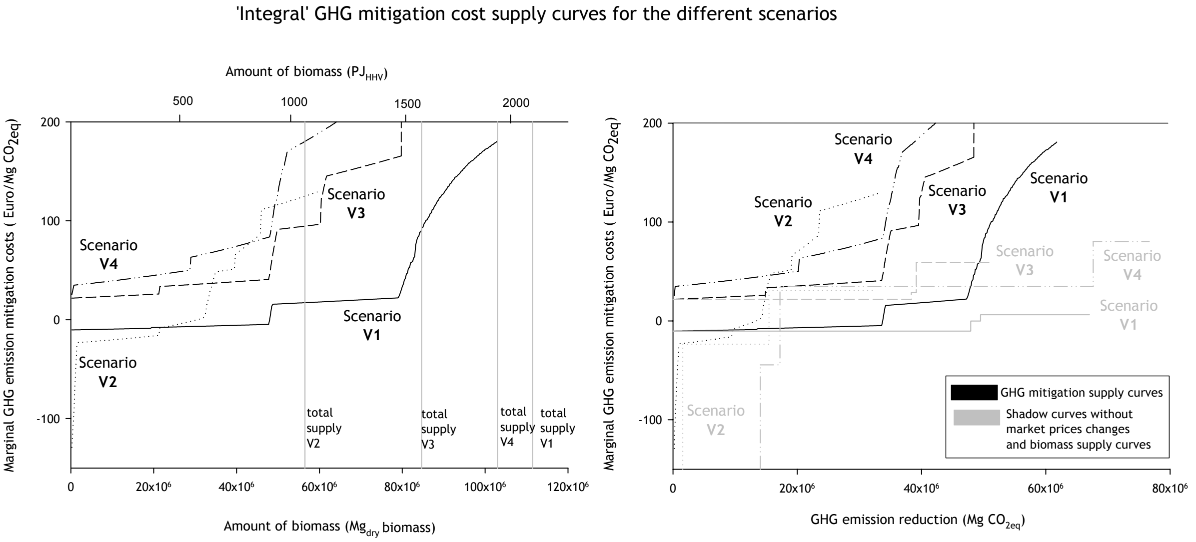

Figure 6.11: Comparison of overall GHG emission mitigation supply curves for the different scenarios

The specific GHG emission reduction, i.e. Mg CO_{2eq} avoided per unit of biomass use, differs only slightly between the technologies used for GHG emission mitigation in the scenarios. Therefore, the shape of the 'integral' GHG emission mitigation supply curves per unit of biomass used (left part of Figure 6.11) and per unit of GHG emissions avoided (right part of Figure 6.11) differs hardly.

In the V1, V3 and V4 scenario, in the first instance electricity production from biomass is preferred for GHG emission mitigation as long as electricity prices stay constant. Second, methanol production from biomass is used for the part of the market volume in which methanol prices stay constant. Finally, MDF, electricity and methanol production are applied in the last part of the integral GHG emission mitigation supply curve. The use of the different technologies alternates. This is due to the fact that with increasing use of one technology its GHG emission mitigation costs increase and, finally, exceed the GHG emission mitigation costs of another technology. In the V2 scenario, first MDF production is applied for a small part of GHG emission mitigation. Second and third, methanol and electricity production are used.

GHG emission mitigation costs in the V1 and V2 scenario are relatively low. In the V1 scenario about 49 and 34 million Mg CO_{2eq} are avoided for costs below 50 and 0 €/Mg CO_{2eq}, respectively. In the V2 scenario, these amounts are about 18 and 13 million Mg CO_{2eq} avoided. In the V3 and V4 scenario, however, biomass production costs are relatively high, especially at large scales of biomass production. As a consequence, GHG emission mitigation costs in these scenarios are higher and no GHG emissions are avoided at costs below 0 €/Mg CO_{2eq}. Moreover, in the V3 and V4 scenario about 34 and 20 million Mg CO_{2eq}, respectively, are avoided at costs below 50 €/Mg CO_{2eq}.

To show the impact of the large-scale introduction of biomass, shadow curves of GHG emission mitigation costs are depicted in the right part of figure 6.11. These curves show the GHG emission mitigation costs in the different scenarios without considering market price changes of materials, energy carriers and increasing costs of biomass supply. The same amount of each technology, i.e. MDF, PLA, methanol or electricity, is used for the shadow curves as in the respective scenarios. The shadow curves show, that market mechanisms and increasing biomass supply costs lowers the GHG emission reduction potential at low costs considerable. The potential GHG emission reduction at costs below 50 €/Mg CO_{2eq} decreases from 67 to 49 million Mg CO_{2eq} in the V1 scenario, from 33 to 18 million Mg CO_{2eq} in the V2 scenario, from 39 to 34 million Mg CO_{2eq} in the V3 scenario and from 68 to 20 million Mg CO_{2eq} in the V4 scenario.

Poland is a country with large biomass production potential. While the total primary energy consumption of Poland in 2000 is about 3.8 EJ (IEA, 2002a), the total biomass supply (short rotation wood) in the different scenarios varies between 1.1 and 2.0 EJ. [27]However, at relatively low GHG emission mitigation costs of below 50 €/Mg CO_{2eq} only about a half to two third of this biomass can be used with the options considered in this study. As biomaterials have only a small potential of GHG emission mitigation at low cost, the production of other bio-energy carriers, e.g. heat, would be necessary to use a larger part of this biomass potential.

4.5 Sensitivity analysis

In a sensitivity analyses, the influences of assumptions about the material and energy market on the integral GHG emission mitigation costs supply curves are analysed. Also, many other factors influence the final GHG emission mitigation supply costs, e.g. biomass

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[27] In these potentials agricultural and forestry residues are not included, which amount to about 0.2 to 0.6 EJ.

production costs, efficiency of material production, the reference system and market prices. In this study, however, our main interest is the possible change of GHG emission mitigation costs through the variability of market prices if biomass material and/or energy uses are introduced on a large scale. Therefore, only the main factors influencing these markets, i.e. elasticity, the total market volume and the Polish market shares are investigated here. An overview of the variation of parameters in the sensitivity analysis is given in Table 6.6. For illustration, this sensitivity analysis is carried out for the V1 scenario that has the largest GHG emission mitigation potential at low costs.

Table 6.6: Variation of elasticity factors and market volumes in the sensitivity analysis of scenario V1

	Land	**MDF board**	**PLA**	**Methanol**	**Electricity**
Base elasticity	-0.45	-1.11	-0.55	-0.23	-0.15
Range elasticity	-0.03 to –0.64	-0.5 to –1.8	-0.5to –2.5	-0.05 to –1.36	-0.1 to –0.2
Base market volume	N/a	15.2 million Mg	0.14 million Mg	58.7 EJ	45.6 EJ
Range market volume	N/a	±10% of volume	±10% of volume	±10% of volume	±10% of volume
Range market share	N/a	+100%/-50% of share	+100%/-50% of share	+100%/-50% of share	+100%/-50% of share

As discussed in Section 3, values of elasticity for the different markets are quite uncertain and various estimates exist. These often-broad ranges are used for the sensitivity analysis. For land markets the range of elasticities presented in Finke et al. (1984) is assumed. For all kind of bio-materials, Gielen et al. (2000) estimate own-price elasticity to be –0.5. This value is used as higher range for MDF board and PLA. The lower range of elasticity for MDF is the lowest value derived from historical data. For PLA, the lower value has been derived from price and volume forecast from producers in Crank et al. (2004); see also Chapter 5 of this thesis. For methanol, the range of elasticity found in the meta-analysis of Espey (1998) is used.[28] Finally, for electricity the values estimated by Wolfram (1999) and SEO (1998) are used as ranges.

Market volumes of materials and energy carriers in our analysis may vary because the total demand changes without related market price changes, e.g. by income variations. Also the market share of Poland on the respective market may increase or decrease depending strongly on the competitiveness of Polish production. To account for these possible changes, a variation of the market volume of 10% and a variation of market shares from half to twice the value is considered for the sensitivity analysis.

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[28] The lowest value of gasoline elasticity is zero (Espey, 1998). However, we use a value of -0.05 close to zero that allows for calculation with the elasticity function.

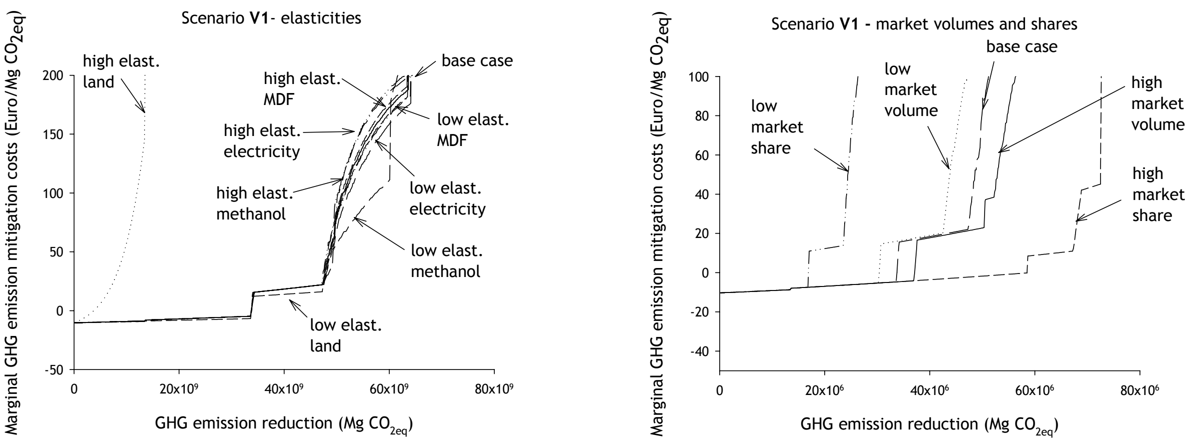

Figure 6.12: Variation of integral GHG emission mitigation cost supply curves (of scenario V1) due to the variation of elasticity factors and market volumes

In Figure 6.12, the influence of the variation of elasticities (left part of Figure 6.12), market volumes and market shares (right part of Figure 6.12) on the integral GHG emission mitigation costs in scenario V1 is presented. The sensitivity analysis shows that the own-price elasticity of the land demand has a strong influence on the GHG emission mitigation costs. If this elasticity is in the upper range, GHG emission mitigation costs increase rapidly reducing the potential of GHG emissions that can be avoided at costs below 50 €/Mg CO_{2eq} by 80%. The influence of elasticity factors on the integral GHG emission mitigation costs is limited to the part of the curve in which market prices are not constant. With low own-price elasticities, the increase of GHG emission mitigation costs with increasing scale of biomass use is slightly less than in the base case, while the opposite applies to high own-price elasticities. At GHG emission mitigation costs of about 100 €/Mg CO_{2eq} the GHG emission potentials varies about 0.01 to 10% through the variation of own-price elasticities of materials and energy carriers. The variation of market volumes and market shares has a large influence on the integral GHG emission mitigation costs. A higher market volume or share increases the amount of GHG emissions that can be reduced without a decrease of market prices of bioenergy carrier significantly, while a lower market volume decreases this amount of GHG emissions. If the Polish market share is doubled, the potential GHG emission reduction at costs below 50 €/Mg CO_{2eq} also doubles.

5 Discussion

The method used in this chapter is suitable to highlight the possible influences of large-scale introduction of biomass material and energy systems on market prices of materials and energy carriers and their feedback to GHG emission reduction costs. To determine the amount of GHG emission reduction costs for various scenarios, input data on technology performance and biomass production costs play a crucial role. The data used in this study give an estimation of possible costs. Even though technology development until 2015 will be limited and the possible differences in the developments of biomass production systems have been included in the scenario analysis, uncertainties in these input data may remain. For example, CO_2 intensities of electricity generation may change in the medium-term future due to e.g. the increased use of renewable energies and the replacement of less efficient fossil energy uses. These uncertainties, however, have not been explored in this analysis.

Instead, our analysis concentrates on the influence of market volumes, market shares and own-price elasticity of demand on the GHG emission mitigation costs. It has been shown in the sensitivity analysis that own-price elasticities of demand of agricultural land and market volumes of bioenergy carriers influence the GHG emission mitigation costs of bio-material and bioenergy utilisation strongly.

However, not all uncertainties in the developments of markets could be addressed. Elasticity factors in literature for land, materials and energy carriers show a very broad range. Moreover, own-price elasticity for MDF and PLA had to be estimated by a simple regression analysis. The influence of other factors than own-price elasticity on demand and market prices—e.g. developments in markets of substituting goods—could not be identified in this regression analysis. For this purpose, an econometric analysis would be necessary, which is beyond the scope of the study. For PLA, the results for PLA production may be pessimistic as the market is still developing and may grow.

For market volumes and Polish market shares of bio-energy carriers it has been assumed that the current volume of alternative energy carriers can be substituted. However, this substitution depends on the competitiveness of bio-energy production with other energy carriers and on the competitiveness of Polish bio-energy production with the production in other countries. This competitiveness may be evaluated by establishing supply curves for energy production. However, such an analysis is beyond the scope of this study.

While in principle the effects of increased bio-material and bio-energy production on their market prices have been included in our approach, other interactions between the large-scale introduction of biomass systems and GHG emission mitigation costs have not been included. For example, with increasing agricultural land prices, food prices increase as well, which may lead to a loss of welfare. Also, it has been assumed that bio-materials and bioenergy carriers substitute reference materials and energy carriers without accounting for any net effects of consumer or producer surpluses.

It may also be possible that the production of reference materials and energy carriers do not equally decrease with the production of biomass applications. Moreover, reference systems may change at large scales of biomass utilisation. For instance PLA may substitute poly(ethylene) first, and if this substitution potential is used, PLA may substitute paper packaging. As a result, the amount of GHG emissions reduced by biomass utilisation changes. Finally, the substitution of different amounts and kinds of reference materials and energy carrier may influence the shape of demand curves for biomass applications. To include these types of interaction a more detailed top-down model would be necessary, which is beyond the scope and objective of this study.

Also the time dimension of the large-scale introduction of biomass use has not been included in our study. The results depict the GHG emission mitigation costs in relation to the scale of biomass production at a certain fictive moment in time, i.e. the year 2015. To implement biomass systems on a large scale, however, will take a certain time span. During this implementation period, technological learning is likely to take place, lowering the resulting GHG emission mitigation costs. These effects have not been considered, because the main objective of this study was to analyse GHG emission mitigation cost changes due to a large-scale utilisation of biomass in a country rather than technological development during implementation strategies. Moreover, the time until the year 2015 is a rather short period for substantial learning to take place.

6 Conclusions

This study evaluates the possible influences of a large-scale introduction of biomass material and energy systems and their market volumes on market prices of land, materials and energy carriers and subsequently on GHG emission reduction costs. In first instance, it can be concluded that GHG emission mitigation costs from biomass on a country level may increase considerable with the scale of biomass production and utilisation. The potential for GHG emission mitigation below costs of 50 €/Mg CO_{2eq} for the four biomass applications considered is 49 million Mg CO_{2eq} in the V1 scenario (related to SRES scenario family A1), 18 million Mg CO_{2eq} in the V2 scenario (related to SRES scenario family A2), 34 million Mg CO_{2eq} in the V3 scenario (related to SRES scenario family B1) and 20 million Mg CO_{2eq} in the V4 scenario (related to SRES scenario family B2). Without the influence of a large-scale introduction on the development of biomass supply costs and market prices of land, materials and energy carriers, the GHG emission reduction potential at costs below 50 €/Mg CO_{2eq} would be about 13-70% higher, depending on the scenarios.

The increase of GHG mitigation costs depends mainly on biomass supply curves, the increase of agricultural land costs and the decrease of market prices of material and energy carriers. Biomass supply costs increase between 20 and 100 €/Mg_{dry} in the different scenarios, if all land that is not necessary for food production is used for biomass production. Additionally, the increase of agricultural land rents due to increased biomass production adds up to 50 to 100 €/Mg_{dry} to biomass production costs at large scales. At large scales of biomass use that exceed the volumes of current markets for energy carriers, GHG emission mitigation costs increase rapidly due to changes of market prices of material and energy carriers. At these scales, GHG emission mitigation cost levels rise to very high values.

Bio-material production covers only a small part of GHG emission mitigation at low costs. This is due to relatively small material markets and the subsequent strong decrease of market prices of bio-materials at large scale of production. Instead, mainly bio-energy production is applied for GHG emission mitigation as energy markets are comparably large and alternative energy carriers can be substituted at a large scale without decreasing market prices. Therefore, both supply and demand of materials and especially energy carriers should be analysed jointly to quantify the amounts that realistically can be used in a country/region.

GHG emission mitigation costs depend strongly on own-price elasticity of land and market volumes of bio-energy carriers. To a lesser degree, GHG emission mitigation costs also depend on the own-price elasticity of materials and energy carriers and market volumes of bio-materials. However, literature estimates of own-price elasticities are highly uncertain and market volumes of biomass applications depend on their competitiveness.

This analysis shows the importance to consider both biomass supplies and potential demands and markets simultaneously to get a more realistic picture of optimal biomass utilisation strategies for GHG emission mitigation. Hence, it would be ideal to combine the bottom-up approach demonstrated here with an analysis of market effects using top-down modelling.