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Market-mediated impacts on emissions and costs

Juha Forsström | Kim Pingoud | Johanna Pohjola | Terhi Vilén | Lauri Valsta | Hans Verkerk



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Biodieseliä puusta. Päästö- ja kustannusvaikutukset Suomessa.

Juha Forsström, Kim Pingoud, Johanna Pohjola, Terhi Vilén, Lauri Valsta & Hans Verkerk.

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Abstract

Renewable energy targets create an increasing demand for bioenergy and transportation biofuels across the EU region. In Finland, forest biomass is the main bioenergy source and appears to be the most promising source for transportation biofuel production.

In this study, a biodiesel strategy based on domestic forest biomass is analysed using an integrated modelling framework. A market-oriented framework is applied to estimate the potential greenhouse gas impacts of achieving a national transport biofuel target (10% vs. 20% of total consumption) under the current climate and energy policy obligations. The cost-minimising adaptation of the energy system to policy targets, the demand for wood biomass and emissions from the energy system including the transportation sector are described using the energy system model EPOLA – a dynamic linear optimization model. The resulting response of the Finnish forests (their carbon balance) to the increasing demand for wood biomass is modelled using the EFISCEN forest model.

The analysis demonstrates the importance of including market-mediated impacts in the analysis. The majority of adjustments toward the biofuel target takes place in the ETS sector, among the energy producers participating in the EU Emission Trading System, even though the transportation biofuel target is set within the non-ETS sector. The demand for wood in biorefineries raises the wood price thereby weakening its competitive position against fossil fuels. In consequence, wood is likely to be partly replaced by fossil fuels within the ETS sector, for example in district heating. In addition, biorefineries would increase the total use of electricity. Thus, fossil fuel carbon dioxide emissions in the ETS sector within the Finnish borders would increase.

Total cumulative emissions, including the non-ETS sector and the forest carbon balance, are slightly lower in the biodiesel scenarios than in the baselines. In transport and in the non-ETS sector in general, the decrease in emissions takes full effect immediately, whilst the decrease in carbon sink in the Finnish forests appears to be gradual. The impact on the carbon sink is fairly small because wood harvesting increases by less than the amount of wood used for biodiesel production. The increase in emissions from the Finnish ETS sector is not accounted for in the total emissions, because at the EU level, emissions in the ETS sector are fixed. Any increase in ETS emissions in Finland has to be compensated by the purchase of emission allowances, and the corresponding emission reduction takes

place elsewhere in the ETS area. The possible carbon leakage due to the increased use of forest or imported biomass elsewhere in the EU is excluded from this analysis.

Biodiesel proves not to be a cost-effective measure for attaining climate or renewables targets. This is due to the low efficiency of the biodiesel chain in displacing fossil diesel emissions. Just from the mitigation point of view, the direct burning of solid wood biomass in energy-efficient boilers should be favoured.

Keywords

greenhouse gas balance, forest carbon balance, EU renewable energy targets, indirect impacts, transportation biofuels, wood-based biodiesel, EU emissions trading system, market-mediated effects, Finnish energy system, dynamic linear optimization model, EFOM model, EFISCEN model

Biodieseliä puusta

Päästö- ja kustannusvaikutukset Suomessa

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Tiivistelmä

Uusiutuvan energian tavoitteet ovat lisäämässä bioenergian ja liikenteen biopolttoaineiden kysyntää koko EU-alueella. Suomen tärkein bioenergian lähde on metsäbiomassa, joka on myös lupaavin raaka-aine liikenteen biopolttoaineiden valmistukseen.

Kotimaiseen metsäbiomassaan perustuvaa biodieselstrategiaa arvioitiin integroidulla markkinavaikutuksia kuvaavalla mallijärjestelmällä. Tarkastelun kohteena olivat potentiaaliset päästövaikutukset, kun 10 % tai 20 % liikennepolttoaineista korvataan kotimaisella puuperäisellä biodieselillä samalla kun täytetään muut nykyisen ilmasto- ja energiapolitiikan tavoitteet. EPOLA-mallilla, joka on dynaaminen lineaarinen optimointimalli, laskettiin energijärjestelmän kustannukset minimoiva sopeutuminen politiikkatavoitteisiin, puuraaka-aineen kysynnän lisäys sekä energijärjestelmän päästövaikutukset. EFISCEN-mallilla laskettiin puun lisäkysynnän aiheuttama muutos metsien hiilitaseeseen.

Analyysi osoittaa, että on tärkeää ottaa huomioon energijärjestelmän markkinavaikutukset. Suurin osa energijärjestelmän sopeutumisesta biopolttoainetavoitteeseen tapahtuu päästökauppasektorilla, vaikka liikenteen biopolttoainetavoite koskee välittömästi ainoastaan ei-päästökauppasektoria. Biojalostamojen puun kysyntä nostaa raakapuun hintaa ja heikentää puupolttoaineiden kilpailuasemaa suhteessa fossiilisiin polttoaineisiin. Puu korvautuu osin fossiilisilla polttoaineilla päästökauppasektorilla kuten kaukolämmössä. Lisäksi biodieseliä valmistavat biojalostamot lisäävät sähkön kokonaiskulutusta. Näin hiilidioksidipäästöt lisääntyvät päästökauppasektorilla Suomen rajojen sisäpuolella.

Kokonaispäästöt, jotka sisältävät ei-päästökauppasektorin ja metsien hiilitaseen, ovat hieman alhaisemmat kuin perusurissa, joissa kotimaista biodieseliä ei tuoteta. Liikenteessä ja ei-päästökauppasektorilla kokonaisuudessaan päästöt alenevat välittömästi, kun biodieseliä ryhdytään valmistamaan. Metsien hiilinielu heikentyy vähitellen suhteessa perusuriin. Vaikutus hiilinieluun on melko pieni, koska hakkuut lisääntyvät vähemmän kuin biodieselin valmistuksen edellyttämä puuraaka-aineen kysyntä. Suomen päästökauppasektorin kasvaneita päästöjä ei lasketa mukaan kokonaispäästöihin, koska päästöille on EU-tasolla asetettu päästökatto. Lisääntyneet suomalaiset päästöt kompensoidaan päästöoikeuksien ostolla, ja vastaavat päästönvähennykset toteutuvat jossain muualla EU:n päästökauppa-alueella. Tässä tutkimuksessa ei ole arvioitu mahdollista hiilivuotoa muualla EU:ssa. Se aiheutuu metsien lisäkäytöstä tai biomassan tuonnista EU:n ulkopuolelta.

Biodieselin valmistus ei ole kustannustehokas tapa päästönvähennysten tai uusiutuvan energian tavoitteiden täyttämiseen. Tämä johtuu biodieselketjun heikosta tehokkuudesta fossiilisen dieselin päästöjen korvaajana. Jos tavoiteltaisiin pelkkiä päästönvähennyksiä, kannattaisi suosia kiinteän puupolttoaineen käyttöä energiatehokkaissa kattiloissa.

Avainsanat

greenhouse gas balance, forest carbon balance, EU renewable energy targets, indirect impacts, transportation biofuels, wood-based biodiesel, EU emissions trading system, market-mediated effects, Finnish energy system, dynamic linear optimization model, EFOM model, EFISCEN model

Preface

This biofuel study formed part of the research carried out by the consortium “Forest-based bioenergy and its climatic and economic viability – an integrated analysis” (FOBIT) 2008–2011, funded by the Sustainable Energy Programme of the Academy of Finland. The consortium partners were VTT Technical Research Centre of Finland, the Department of Forest Sciences at the University of Helsinki, and the Finnish Forest Research Institute (Metla), while the European Forest Institute (EFI) acted as a subcontractor. The contribution of the members of the consortium’s steering group – Salla Seppo (Academy of Finland), Timo Heikka (Stora Enso Oyj), Pekka Kauppi (University of Helsinki) and Ilkka Savolainen (VTT) – is warmly acknowledged.

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Appendix 1: The biorefinery model

1. Introduction

The use of biofuels in transportation is increasing and being promoted in many countries with the aims of reducing greenhouse gas (GHG) emissions, securing the energy supply, and improving energy self-sufficiency and employment. EU targets have been set for member states concerning the use of renewable energy sources in general, and for the use of transportation biofuels in particular (EC 2009).

Life cycle assessment (LCA) is a widely-used method for evaluating the GHG impacts of products. In LCA, emissions are calculated at every stage of processing and consuming a product, from resource extraction to the conversion process, storage, distribution and end-use. The estimated range of GHG balances for biofuels varies significantly between studies due to methodological differences and chain-specific issues (Soimakallio et al., 2009a and 2009b; Cherubini and Strømman, 2010; Hoefnagels et al., 2010). The setting of the spatial and dynamic system boundary together with the selection of the reference system and allocation methods are the most critical issues related to GHG balances of biofuels. In addition, the selection of the parameter set and dealing with natural uncertainties due to regional differences or lack of knowledge may also be highly significant factors.

The release of nitrous oxide emissions in the production of biofuels – resulting from the processing and use of fertilisers – is a prominent factor that could reduce the GHG benefits of biofuels (Crutzen et al., 2008). Another essential factor weakening the GHG benefits is direct land use change (dLUC) due to land clearing for biomass plantations. The conversion of carbon (C) rich lands, such as tropical rainforests and peatlands, to produce food-crop based biofuels causes a change in land use with a permanent loss of terrestrial C stocks. The ecosystem C pay-back time (Gibbs et al., 2008) – the time taken for biomass regrowth to compensate the initial C loss – could in the worst case be several centuries. On the other hand, biomass plantations in degraded lands, if available, could increase terrestrial C stocks. Bioenergy does not always result in dLUC. Bioenergy feedstock can also be produced in combination with food and fibre, avoiding land use displacement and improving the productive use of land.

Sustainably managed forests can be harvested without any change in land use. For instance, in Finland and Sweden, managed forests are a major source of biomass and its use could be increased significantly on a sustainable basis. Currently, forests in both countries form a significant C sink as the annual increment

of the growing stock substantially exceeds the drain. In addition, logging residues are an under-utilized biomass resource for biofuel production.

An important limitation of conventional LCA with limited system boundaries is that it excludes substantial, typically market-mediated indirect impacts. Among these impacts, those related to indirect land use change (iLUC) have been especially highlighted in the scientific literature (Searchinger et al., 2008; Melillo et al., 2009; Hertel et al., 2010). For example, demand for biofuels may affect the market price of food and feed, which in turn may lead to additional deforestation and land clearance for new croplands. The negative climate impact of iLUC could exceed the positive impact of substituting gasoline for liquid biofuels. These market-mediated effects are essentially global. Consequently, biofuel policies, for instance in the EU or US, could create incentives for deforestation in the tropics.

Besides LUC and the dynamics of terrestrial C stocks, there are other indirect impacts on the GHG benefits of biofuels. Energy and climate policies affect relative fuel prices, thus having an influence on consumption of fossil fuel and their substitutes. This has the potential to cause a rebound effect where the additional biofuel supply would not fully substitute for the fossil fuels (Stoft, 2010; Rajagopal et al., 2011). A general or partial equilibrium has been applied in analysing commodity prices, land availability and sectoral changes resulting from biofuel production (Hoefnagels et al., 2010; de Vries, 2009; Tyner et al., 2010).

Another viewpoint is to consider the climate impacts under energy and climate policy frameworks such as the Kyoto Protocol or climate and energy policy of the EU, where prescribed targets are set for the development of emissions. Besides the emission reduction targets there are overlapping policy measures for the national share of renewables and transportation biofuels. Characteristic of the EU framework is the emission trading system (ETS) under which large-scale energy producers have a fixed total amount of emission allowances within the EU, being tradable within the whole EU region. In addition, there is a fixed national target for emissions outside the ETS, i.e. the non-ETS sector. The emissions from transportation are all accounted for under the non-ETS sector. In addition, the national emissions from land use, land-use change and forestry (LULUCF) are accounted for separately outside the ETS and non-ETS sectors. It is noteworthy that accounting of LULUCF emissions with respect to the emission reduction target is incomplete, so that, for instance, the true C balance of forests differs from what is accounted for under Article 3.4 of the Kyoto Protocol. As a major part of the forest C sink is outside the accounting, the balance of forest C does not have any strong steering effect on climate policy at present.

When the emission reduction target is fixed, the issue of climate impacts is transformed largely into an issue of cost-effectiveness in fulfilling the target. Relevant literature from this viewpoint deals with cost-effectiveness of different energy and climate policy instruments and strategies. König (2011) investigates the cost-effective utilization of biomass under different policy packages in Germany. The cost-efficiency of different policy instruments to promote the use of bioenergy in Austria is assessed in Schmidt et al. (2011). Both studies utilize detailed energy system models based on cost-minimization. Kretschmer et al. (2009) utilize a

global model to study the market and welfare implications of a 10% transportation biofuel target. Their model is, however, simpler than in other studies and renewables can be used only in electricity generation. Additional costs related to overlapping regulation and emission market segmentation are evaluated in Böhringer et al. (2009). They found that emission market segmentation between ETS and non-ETS sectors cause substantial excess costs as compared to a uniform cap-and-trade system, while the costs of a target for renewables, in addition to EU-ETS, are evaluated to be modest.

The objective of this study is to analyse the rationale of the transportation biofuel targets from the perspective of climate change mitigation and economic efficiency. The study assumes that these biofuel targets will be met using solely domestic forest biomass as feedstock without biofuel imports. The starting point for its analysis is the prevailing GHG accounting framework of the Kyoto Protocol, in which the GHG balance of forests is only partially accounted for. The study evaluates the overall impact of climate policy on the true domestic GHG balance in Finland by also considering the GHG balance in forests, not currently accounted for in the climate policy framework. The climatic and economic impacts of transportation biofuel targets are analysed under current EU climate policy, and the different positions of the ETS and non-ETS sectors are highlighted when assessing the actual climate impacts of transportation biofuels. The study's approach, furthermore, is market-oriented. It focuses on the indirect impacts and energy system adjustments brought about through the changing relative competitiveness of different energy sources by using a cost-minimizing, detailed energy system model. Interaction between the ETS and non-ETS sectors is demonstrated. Transportation biofuels are assumed to be produced in second-generation, forest-based biorefineries which will be likely realised by 2020.

2. Methods and scenarios

2.1 EPOLA energy system model

The Energy Policy Analysis (EPOLA) model is a version of an Energy Flow Optimisation Model (EFOM) (Van der Voort et al., 1985) for Finland augmented with descriptions of forest industry processes. The model has been developed for energy policy assessment and comparison. It is an intertemporal linear programming model in which the user defines the useful energy demands. The model has been used in several energy scenario analysis projects (Tuominen et al. 2010; Honkatukia, 2008). Typical energy policy measures include incentives, disincentives or legislation, in the form of taxes, investment grants, feed-in tariffs and so on.

The general structure of the EPOLA model is presented in Figure 1. The model covers the whole energy system from fuel supply and conversion, to the demand sectors of energy. A wide range of existing and potential technologies are described. The emissions can be reduced in the model by replacing more fossil fuel intensive technologies with less intensive or carbon free ones in existing plants, or by investing in less carbon intensive technologies as well as in energy saving technologies.

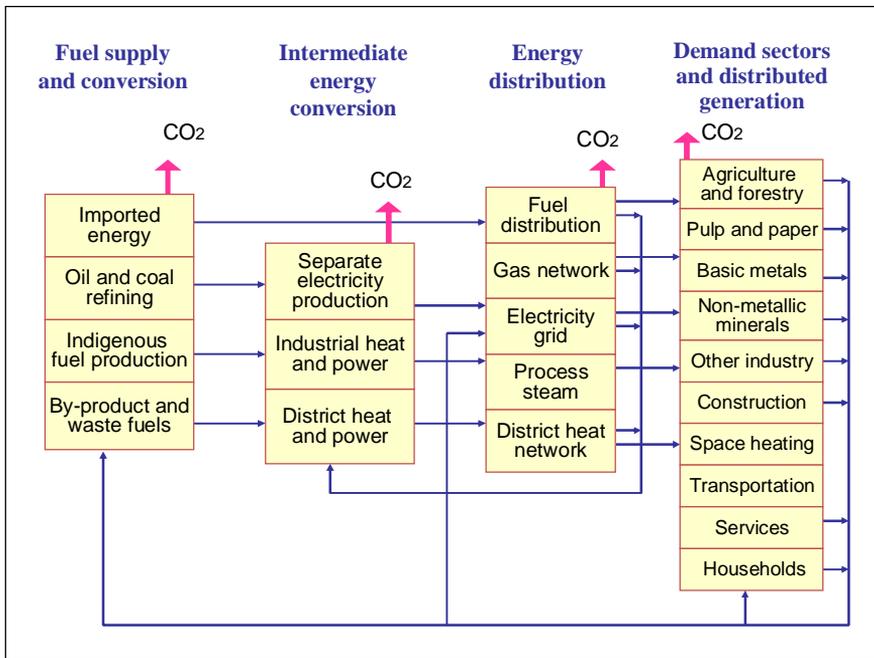


Figure 1. General structure of the EPOLA energy system model.

Energy production covers the following classes: hydro, nuclear, conventional condensing power, combined heat and electricity (urban and industrial), wind, import and export. All these classes are disaggregated by fuel, technology and plant size forming a technology database of tens of different production-technology classes. The geographical dimension is important for those processing units that are dependent on items that are expensive to transport. Examples include wood, solid fuels, natural gas and district heat. To take into account the impact of the transportation issue on the opportunities and costs of the use of the above mentioned commodities the model is localized into five separate geographical areas. Localization means that these resources have a local price in each of the areas, if available at all.

Energy consumption means the use of electricity, heat or fuel. Industry (disaggregated by sector), space heating and services form the main energy consumption classes. The energy intensive part of industry is described using alternative process models in order to be able to estimate the effects of choosing particular processing options. Wood pulping forms an example of this. The basic alternatives are mechanical and chemical pulping. Mechanical pulping uses only half of the amount of wood compared to that of chemical pulping but at the expense of increased energy use: specific use of electricity increases at least four-fold compared to that of chemical pulping. The price ratio between these two resources dictates which of these pulping processes is preferred over the other, although the

pulps are not perfect substitutes. The impacts of this flexibility cannot be revealed without a model describing technologies at a sufficiently detailed level. Energy consumption is defined as the amount of energy end-use. This amount can be cut down by making an energy saving investment. These investments are carried out if they are the most economic way of meeting energy demand.

The energy system is divided into two parts depending on their relationship to the European Emissions trading scheme (ETS); the ETS sector covers those parts of the energy system that participate in emission allowance trading and the non-ETS sector covers the rest. Figure 2 illustrates in more detail the linkages between the different parts of the energy system model and its external drivers. The economic rationale for adapting to externally set bounds differs in these sectors and the model structure reflects this division.

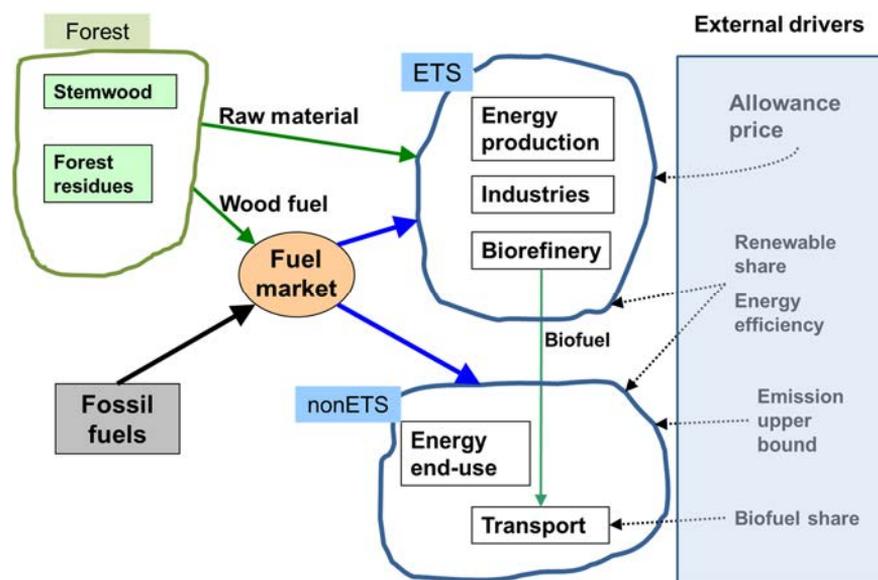


Figure 2. Linkages and material and information flows in the energy system model EPOLA. Figure 1 offers a different view of the same model. Fuel market is emphasized here to clarify the twofold role of wood: it is either raw material or fuel.

The non-ETS sector can be disaggregated into five main areas of energy use: transportation, space heating, small-scale industry (from the energy use point of view) and other energy use (mainly agriculture and construction). Transportation comprises at present over 50% of the energy-based GHG emissions in the non-ETS sector in Finland. This sector can adapt to the externally set bounds of GHG emissions by changing fuel mix or by applying energy saving investments. The ETS sector consists of the majority of energy production and use: separate electricity generation; combined heat and power (CHP) production both in industry and

in cities; and other industries using energy in large amounts. This sector has to have an emission allowance for every ton of CO₂-equivalents it emits. This can be achieved through buying or selling emission allowances, through fuel-mix changes or by investing in energy saving. Typically all these measures are applied using a context-dependent set of measures.

The production of biofuels is an energy intensive undertaking producing a large amount of heat as a by-product. The economics of production improve substantially if there is an opportunity to use that heat as a substitute for heat produced by other means. This is one of the reasons why biorefineries are planned to be integrated into existing pulp mills. Appendix 1 shows the details of the biorefinery process applied in the analysis.

2.2 EFISCEN forest resource model

2.2.1 EFISCEN description

The European Forest Information Scenario Model (EFISCEN) (Sallnäs, 1990; Schelhaas et al., 2007) is a large-scale scenario model that assesses the supply of wood and projects forest resource development and carbon stocks and fluxes at the regional to the European scale (Eggers et al., 2008; Ľupek et al., 2010). EFISCEN has been validated for Finland by Nabuurs et al. (2000) and a detailed model description is given by Schelhaas et al. (2007).

In EFISCEN, the state of the forest is described as an area distribution over age and volume classes arranged in matrices, based on data on forest area, growing stock and increment by age class and forest type collected from national forest inventories (NFI). This study uses data from the Finnish NFI 10 (Table 1). During simulations, the forest area moves between matrix cells, describing different natural processes (e.g. growth and mortality) and human actions (e.g. forest management). Growth dynamics are simulated by shifting area proportions between matrix cells. In each 5-year time step, the area in each matrix cell moves up one age-class to simulate ageing. Part of the area of a cell also moves to a higher volume-class, thereby simulating volume increment. Growth dynamics are estimated by the model's growth functions whose coefficients are based on inventory data.

Table 1. Structure of the forest inventory data.

Year of inventory	2004–2008
Area covered (1000 ha)	18480.24 (Forest available for wood supply)
Number of regions	13 (Ahvenanmaa excluded)
Owner classes	Private and non-private
Site classes	Mineral soils and peatlands
Tree species	Scots pine, Norway spruce, deciduous

Management scenarios are specified at two levels in the model. First, a basic management regime defines the period during which thinnings can take place and sets a minimum age for final fellings. These regimes can be regarded as constraints on the total harvesting level. Thinnings are implemented by moving the area to a lower volume class and final fellings by moving the area outside the matrix to a bare-forest-land class, from where it can re-enter the matrix. The applied management regimes are based on a country level compilation of management guidelines (Yrjölä, 2002). Secondly, the demand for wood is specified for thinnings and for final felling separately and EFISCEN may fell the demanded wood volume if available. If wood demand is high, management is intensive and rotation lengths are close to the lower limit defined in the management regimes. If wood demand is low, rotation lengths are longer, because less fellings are needed to meet demand. Wood demand was based on projections made by the EPOLA model.

In addition to wood demand, it is possible to extract logging residues (stem tops and branches) and stumps. In this study the age of final fellings varied between 76 to 90 years for pine and spruce and 61 to 81 years for deciduous species in Southern Finland. In Northern Finland, the same values were 91–140 for pine, 91–130 for spruce and 61–70 for deciduous species. The thinning age ranged between 10 to 75 years in pine and spruce forests and between 5 and 60 years in deciduous forests in Southern Finland. In Northern Finland the thinning range was from 10 to 90 years for pine and spruce and between 5 and 60 for deciduous forests. The minimum age of thinnings was set quite low to represent the energy wood extraction from pre-commercial thinnings.

EFISCEN projects stemwood volume, increment, age classes and wood removals for 5-year time steps. To calculate the carbon stocks, stemwood volume is converted to carbon in stems, branches, leaves, coarse and fine roots using basic wood density (IPCC, 2003), carbon content (50%), and species- and age-dependent biomass distributions based on published biomass expansion factors (Vilén et al., 2005). The amount of carbon in the soil is calculated by a dynamic soil carbon module YASSO (Liski et al., 2005), which is dynamically linked to EFISCEN. YASSO simulates litter fractionation and decomposition based on carbon input from biomass, consisting of logging residues, the litter production of trees and climate data. This study uses the average climate data from the period 1971–2000.

2.3 Integrative analysis framework

The analysis in this study utilizes an integrative framework covering direct and indirect impacts of the transportation biofuel targets on GHG balance. In this study's model system (Figure 3), the energy system model EPOLA evaluates the GHG emission impacts in the energy system while the forest resource model EFISCEN provides the estimates for changes in the GHG balance in forests. The total GHG balance within the national borders is obtained by adding together the emissions from the two models. The models are linked by wood demands that are obtained as

results from the EPOLA model and given as inputs into the EFISCEN model. Thus so-called soft-linking is applied instead of solving the models simultaneously.

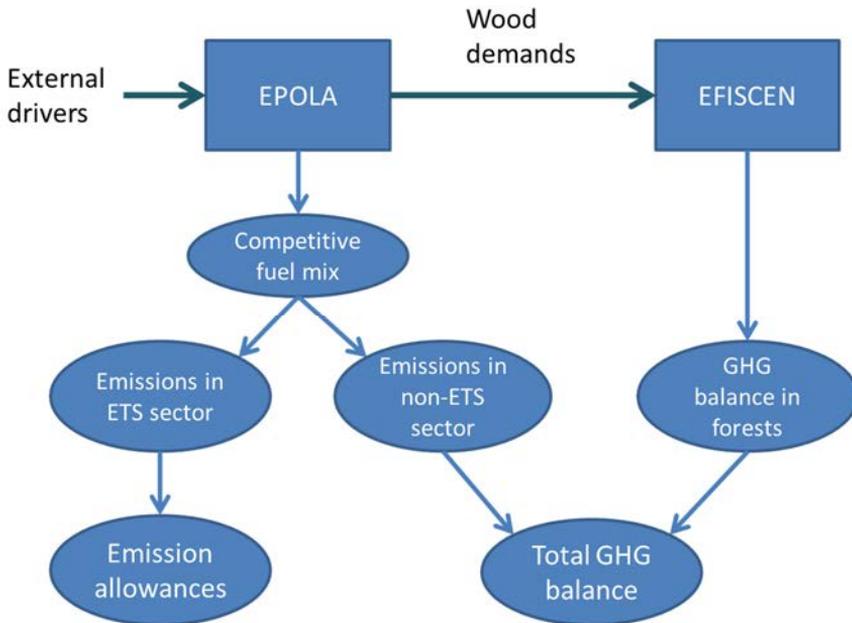


Figure 3. Main structure of the modelling framework.

First, an EPOLA calculation is carried out. The outcome of this is affected by several external drivers. The whole energy system is affected by a minimum constraint for renewables and requirements for energy efficiency. The ETS and non-ETS sectors behave differently due to the inherently different positions as far as emissions are concerned: the non-ETS sector is forced (a) not to emit more than a specified amount of CO₂ per annum, and (b) to use a specified share of biofuel in the transportation fuel mix. The ETS sector can balance its mitigation efforts by using the price of the allowance as a reference without any fixed values for emissions. Its adaptation is purely economic, contrasting with the basically regulatory approach for the non-ETS sector. However, if it is cost-effective for the agents in the non-ETS sector they can choose measures such as to optimize fuel-mix or to emit less CO₂ than required.

External drivers affect relative prices in the energy system, which in turn alter the competitive position of fossil fuels and renewables as well as the profitability of energy saving investments and the supply of wood. The ETS and non-ETS-sectors are linked with each other by fuel markets. Thus for example an impact on the non-ETS-sector is reflected in the ETS sector and an adjustment takes place in the whole energy system, instead of only in the sector that was impacted. A new optimal fuel mix and related emissions are obtained as the main results of EPOLA.

The EPOLA results for demands for stemwood and energy wood are given to EFISCEN as inputs. EFISCEN calculates the final fellings and thinnings needed to satisfy the given demand and updates the forest resources accordingly. Thus, a price mechanism is not included in EFISCEN. EFISCEN also estimates the balance of C in trees and the soil, including the YASSO soil C model.

2.4 Set of biofuel scenarios

Preliminary calculations showed that the emission allowance price and the wood supply are the main drivers that affect the competitiveness of wood in the fuel market. This in turn has an impact on future emissions trends. This led us to define not only one base case but a set of base cases by systematically varying the values of the main drivers. The base case set can be described as a two-dimensional system consisting of: 1) the emission allowance price and 2) the wood supply situation. Both of these scenario variables are given three different values and thus producing nine base cases. These base cases have no target for the domestic production of transport biofuels.

Each of these base cases forms a point of reference for the subsequent biofuel share cases of 10% and 20%. Thus this study consists of 27 different cases in all. In addition to the biofuel target the other two EU obligations for the year 2020 and onwards, the 38% renewables in energy end-use and the energy efficiency improvement defined as an upper bound for energy end-use, are met in each scenario.

The alternative carbon prices range from 30, 50 to 80 €/tonCO₂. The price of emission allowances is given different values because it significantly affects the energy system through the relative prices of renewables and fossil fuels. For wood supply, three alternative supply curves are used: *Low*, *Intermediate* and *High*. Figure 4 shows the wood supply curves and allowance price curves used in the analysis.

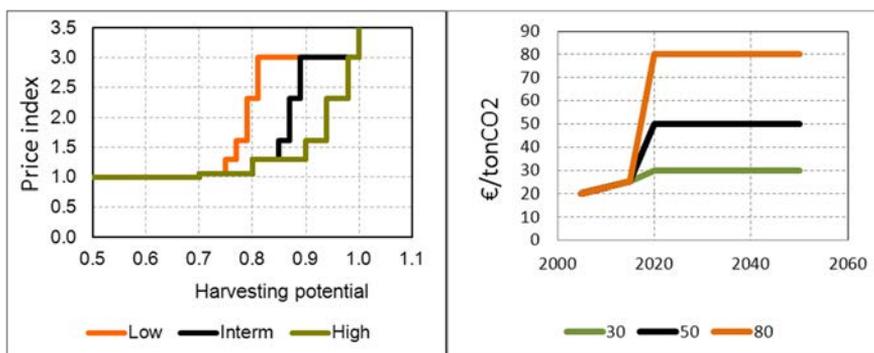


Figure 4. Alternative wood supply curves and emission allowance price scenarios (€/tonCO₂).

These supply curves describe more or less abundant supply. The above defined wood supply curves are used separately for each of the four wood supply areas of Finland. Wood harvested consists of stemwood and wood residues. For each cubic metre of stemwood harvested there is a certain share of residue available. This will be utilized if its harvesting turns out to be economic.

2.5 The Finnish energy system

2.5.1 Structure of the system

The Finnish energy system is used here as a reference for finding out the impacts of introducing biofuels into transport. The following briefly describes some of the main features of the system and highlights the opportunities for increasing the use of renewables.

- The large relative proportion of combined heat and power (CHP) production is a special feature of the Finnish energy system. These plants generate one third of the electricity generated in Finland.
- CHP technology is applied both in industry and in urban areas. The pulp and paper industry has large local heat loads and CHP technology is an economically viable option for producing both the heat and electricity for the mill. In urban areas, district heating networks aggregate individual space and water heating loads, making it possible to apply CHP technology and meet a part of the community's electricity demand as well.
- CHP plants in urban areas form the largest single option for increasing the use of wood fuels instead of fossil fuels. The opportunities to increase wood use in the pulp and paper industry are, however, limited due to the already existing high proportion of wood fuels. In other industrial energy plants the potential is proportionally higher.
- District heating covers half of the total space heating load. The other half also offers potential for increasing the use of renewable energy sources either in the form of wood fuel or heat pumps. These energy forms could replace oil in detached houses.
- Transport's share of the final energy use is about 18%. In principle all the fossil fuels could be replaced by bio-based fuels.
- The share of renewables (hydro power, wind power and wood fuels) in 2005 was 27% of the total energy end-use.

The subject matter of this study is, however, transport biofuels and their impacts on achieving the national emission and energy efficiency targets. To study this, the division of the energy system into the ETS and non-ETS sectors is relevant because the control regimes differ in these two sectors.

The present share of transport based emissions in the non-ETS sector is substantial, as shown in Figure 5.

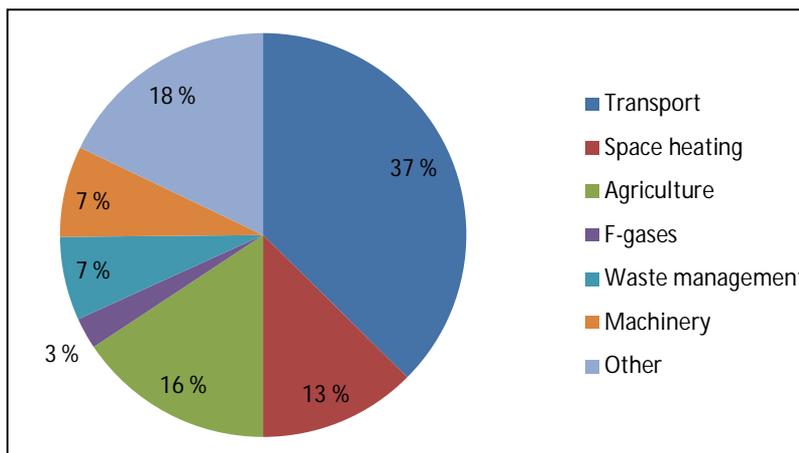


Figure 5. Non-ETS emissions in 2005. Machinery refers to internal combustion engine powered apparatus used in agriculture, construction, forestry etc. (Ekholm, 2010).

Transport forms the largest single source of emissions in the non-ETS sector. But only a part of the emissions in Figure 5 are energy based – the type of emissions considered by this study. For example, F-gases, waste management and agriculture refer to non-energy based emission sources. However, the emission reduction potential of these classes is taken into account when defining the target for energy-based emission reduction.

2.5.2 Future trends in energy end-use

The development of energy demand in the base cases forms an essential foundation for the analysis. We use the official climate and energy strategy (Long-term climate and energy strategy, 2008) for Finland and its updated version (2009) in defining future energy consumption as shown in Table 2 and Table 3 in a concise form.

Table 2. Scenario for energy consumption (Long term-climate and energy strategy, 2008).

TWh		2008	2020	2030
Electricity				
Industry and construction		44	44	48
Households		11	11	11
Electric heating		9	10	10
Services		15	18	19
Transport		1	1	4
Other incl. losses		7	7	8
Total		90	91	100
Space heating				
District heating		27	32	33
In-situ heating		28	33	30
Electricity		10	10	9
Fuels		18	23	21
Total		55	65	63
Transportation				
Road transport		46	53	54
Other		4	5	9
Total		50	58	63

Electricity consumption is assumed first to grow slowly and then stabilize if no additional measures are taken. The space heating trend points downward from the beginning of the time span. Transport shows a slight increase in the beginning and it is assumed to stabilize to the level reached in 2030.

The production scenario for forest industries is of special interest here as it defines the base level for wood harvesting. The analysis makes use of the scenario published by the Finnish Forest Research Institute, as shown in Table 3.

2. Methods and scenarios

Table 3. Production scenario for the Finnish forest industry (Hetemäki and Hänninen, 2009).

	2008	2020	2030
Papers and boards, 1000 ton			
Magazine paper	5 894	3 761	3 761
Fine paper	2 940	1 899	1 899
Other paper	1 394	900	900
Paperboard	2 897	2 867	2 867
Wood products, 1000 m3			
Sawn goods	9 881	10 000	10 000
Plywood	1 265	1 500	1 500
Other boards	360	400	400

The mechanical forest industry is estimated to maintain the present production level but paper and paperboard production figures follow the assumed decrease in demand for these products. This study expects wood imports to fade away by 2020.

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The aim of the study is to reveal the changes in the whole energy system caused by the introduction of biofuels into transportation. Although transportation belongs to the non-ETS sector and the biofuel obligation directly affects emissions in the non-ETS sector, the impacts of it migrate to the ETS sector through fuel and energy markets. The production of wood-based biofuels increases wood demand affecting the competitiveness of wood in the fuel market, leading to changes in fuel market shares. These changes have implications on emissions. These changes are studied here as impacts of the biofuel share obligation.

3.1 Base cases

In briefly describing how EU obligations affect the energy system in the base cases without targets for liquid biofuels in transportation, this study uses zero biofuel scenario base cases. The impacts of meeting the transportation biofuel targets are then studied against these base cases. A separate base case is formed for each allowance price level and wood supply case. This makes nine base cases in all.

3.1.1 Energy system development

Figure 6 illustrates how the energy system, fulfilling the other EU obligations except the biofuel share, develops over time. The EU obligations are as follows: an emission reduction of 16% in the non-ETS sector; an EU-wide emissions upper bound for the ETS sector represented here by an exogenously given price of emission allowances; a 38% share for renewables and the energy efficiency target defined as an upper bound of 310 TWh for energy end-use.

3. Results

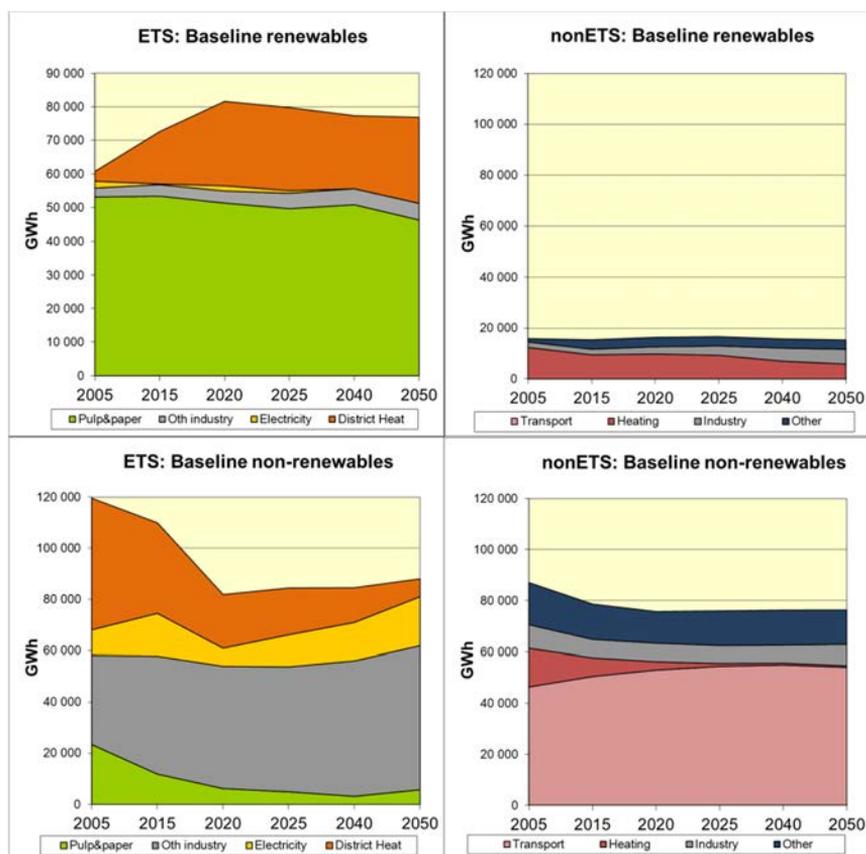


Figure 6. The development of primary energy use divided into renewables and non-renewables in ETS and non-ETS sectors with price of emission allowance of 50 €/tonCO₂ and intermediate wood supply. N.B: In the electricity sector, nuclear fuel is not included.

Wood has a major role in achieving the 38% target for renewables in energy end-use. At present the pulp and paper industry has a dominant role in wood fuel use. This role will weaken a little in the future according to Figure 6. The district heating sector will make a major shift in its fuel mix: wood fuel will replace fossil fuels as shown in the top and lower left panels of Figure 6. The other renewables consist of hydro and wind power. Expansion opportunities for hydro are next to nil but for wind power they are favourable: it is expected to expand rapidly during the coming decade to attain 6 TWh by 2020, a target set in the Finnish climate and energy strategy (Long-term climate and energy strategy, 2008). In the non-ETS sector, the absolute amount and share of renewables is notably lower than those of the ETS sector, as shown in Figure 6. The share of renewables increases mainly by substituting heat pumps for light fuel oil in detached house space heating. This

change will take place regardless of the biofuel obligation. Another option for increasing its share is to substitute wood fuel for fossil fuels in non-energy intensive industries, in agriculture and construction. The non-renewable energy forms (Figure 6: lower panels, nuclear fuel not included) in the ETS industry and energy production, i.e. district heat and electricity, have almost equal shares but their future trends are diverging: in energy production, wood fuel gains more market share but the same development cannot be seen in industry and the growth of industrial fuel use leads to a growth in fossil energy use. On the non-ETS side, transportation is the main user of fossil fuels. Reduced oil use for space heating is the largest change in this sector in all the base cases.

3.1.2 Emissions

Emissions in the base cases – in which no biofuels are produced but the other energy and climate policy obligations for Finland are fulfilled, are shown in Figure 7. Three separate panels show the impacts of wood supply and allowance price on emissions in the ETS and non-ETS sectors of the energy system.

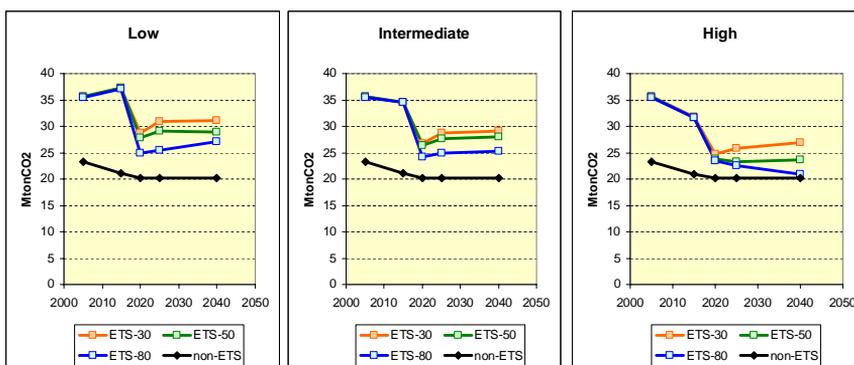


Figure 7. Impacts of wood supply (corresponding to the Low, Intermediate and High wood supply curves in Figure 4) and the price of emission allowances on emissions in ETS and non-ETS sectors in the base cases.

Although road transport dominates the energy-based non-ETS emissions the reduction obligation, a 16% reduction in emissions in 2020 compared to the 2005 value can be achieved without any measures taken in road transport. There are two main adjustment mechanisms for doing this. In the first, solid wood fuels substitute for fossil fuels in heating both in industry and other sub-sectors, while in the second, a small amount of imported bio-based liquid product substitute for light fuel oil in internal combustion engine powered equipment used in agriculture, construction, forestry etc. The reduction needed could have been achieved by applying only the first of the above mechanisms to the extreme but a more balanced approach was applied by using both mechanisms. It means that in all cases

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analyzed there is the same small amount of imported bio-oil to be used in the other sub-sectors of the non-ETS sector except in road transport.

The non-ETS sector does not react at all to the variations in wood supply or allowance price. In all base cases it reduces emissions by 16% in 2020 compared to 2005 figures; being the minimum obligation. The ETS sector is, on the other hand, sensitive to the allowance price level and wood supply situation. The higher the price of the emission allowance the lower the emissions in the ETS sector. Also, the more abundant the wood supply, the lower the emissions.

Figure 7 reveals that there is at first a transition period in the energy system during which it adapts to the new obligations. From 2025 onwards, the situation stays more or less stable because there are no additional driving forces, external or internal, which would push the system away from the apparent equilibrium. Thus, in what follows, the study concentrates on comparing values for the year 2025 as a representative for the whole 2020's. This is the first decade during which biofuel obligations are fully effective. Also, it is close enough to the present that the major technologies assumed to be in widespread use are those already known today. Thus the analysis rests on safe ground. For example, the widespread use of CCS technologies will not yet be possible during that decade and cars powered by internal combustion engines will still dominate road traffic.

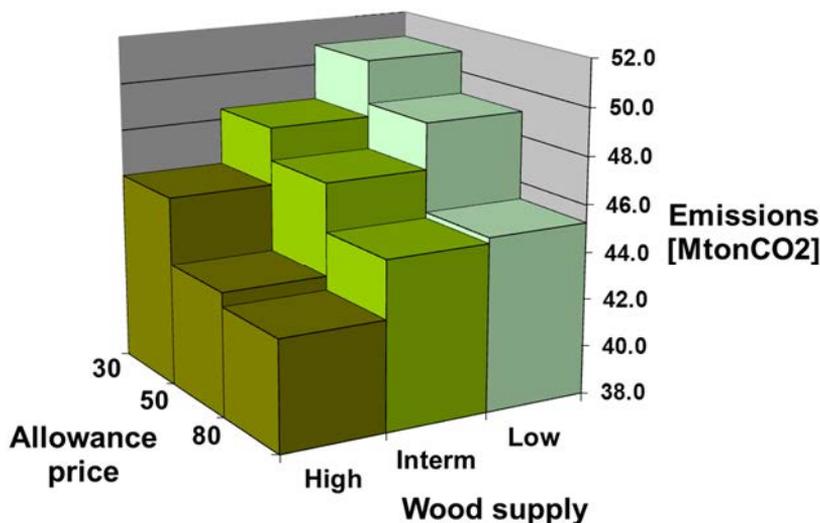


Figure 8. The base-case surface of total emissions of the energy system in 2025. Allowance price and wood supply define the system state without biofuels.

The base-case surface for total energy system emissions is shown in Figure 8. It summarizes the dependency of emissions on the price of allowances and on wood supply when transportation biofuels are excluded. The level of total emissions depends consistently on the emission allowance price level and on wood supply.

The following section compares how harvesting and emissions will change due to the introduction of transportation biofuels.

3.2 Impacts of biofuel targets

3.2.1 Harvesting and wood allocation

We assume that biorefineries will be built into existing pulp and paper mills. These sites already have all the facilities needed to procure and handle large amounts of wood, whilst the mills themselves can use the excess heat produced by the biorefinery process. These are crucial aspects of the economics of a biorefinery.

The required amount of biofuel is produced in biorefineries that use wood as their only solid, raw material. A fixed biofuel share leads to fixed biorefinery wood demand. In all scenarios in this study, the forest industry has the same fixed production plan with a fixed stemwood input. Thus the only flexible (price dependent), part of the total wood demand is wood used as solid fuel. The price of wood determines its competitive position in the fuel market and the main drivers affecting this are price of emission allowances and wood supply. Figure 9 shows how these drivers affect wood harvesting in Finland¹.

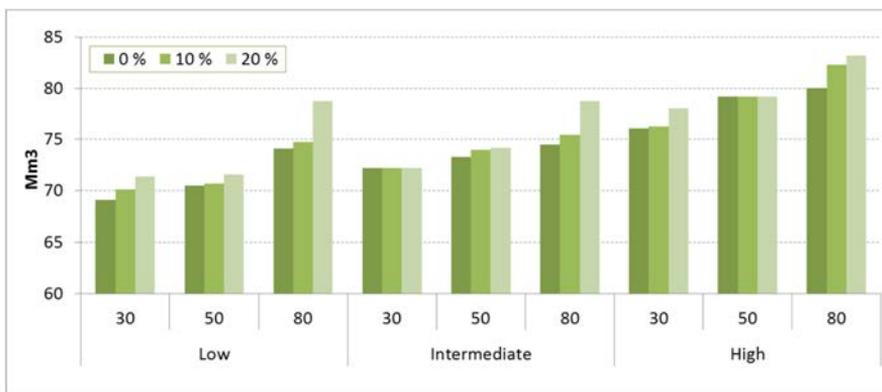


Figure 9. Total wood use (stemwood + residues) in the scenarios with biofuel share of 0, 10 or 20% for different prices of emission allowance (30/50/80) and wood supplies (Low/Intermediate/High).

¹ A rough estimate of the order of magnitude of wood needed for fulfilling the biofuel obligation can be calculated as follows: 10% of road transport fuels at 2020 correspond to about 450 kt of fuel or 5.4 TWh of fuel energy. A biorefinery transforms wood into liquid fuel with 60% efficiency. The amount of wood needed amounts to $5.4/0.6 = 9$ TWh (4.5 Mm³ of solid wood, dry matter 45%). This corresponds to almost 10% of typical domestic stemwood harvesting in Finland.

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Figure 9 reveals that allowance price and wood supply both affect the level of wood harvested in all biofuel cases. However, the increase varies in size and it is evident that increased harvesting levels do not, at least in all cases, meet the biorefinery input demand. Where, then, does the wood for biofuel production come from?

Figure 10 gives an answer to the question by comparing the changes in wood use in 2025 and 2005. This comparison reveals how the EU directive package affects wood fuel uses with or without biofuel production.

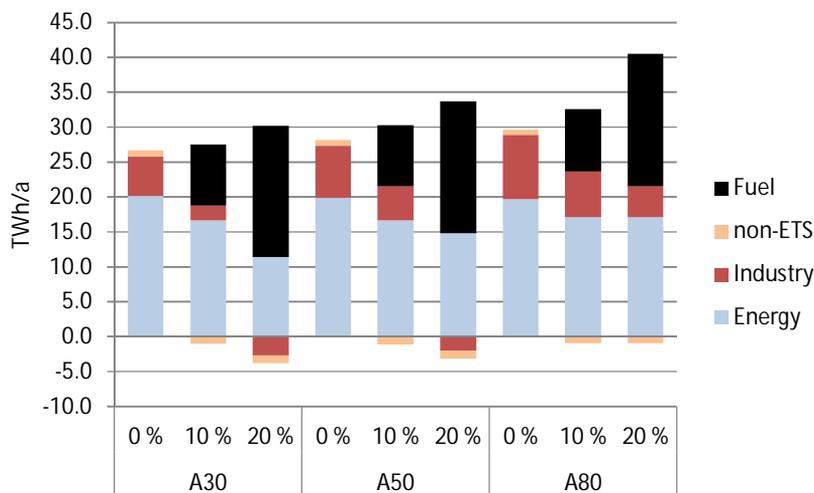


Figure 10. Increase in wood-based energy use from 2005 to 2025 by sector. Wood supply is at an intermediate level and the allowance price increases from 30 €/ton CO₂ to 80 €/ton CO₂ (A30/A50/A80). Fuel refers to the biorefinery wood input.

The majority of the increase in wood fuel use to fulfil the 38% obligation with zero biofuel shares takes place in combined heat and power production (Energy). The introduction of biofuels increases the total amount of wood used for energy for all allowance price levels. The higher the allowance price, the more harvesting levels increase because the competitiveness of wood in fuel markets improves in line with the allowance price. But these increases in wood fuel use (differences in column heights) are significantly smaller than the biorefinery inputs (the black parts of the column). This means that all the other sectors than biorefineries using wood as an energy source decrease their wood use due to the biofuel production. In the non-ETS sector the sum of all its subsector changes compensate each other such that total wood use stays practically constant. The two largest changes that take place are the following: wood use for detached house heating declines and the industrial use of wood fuel increases.

In Figure 10, all the cases were compared to 2005 wood use. If comparisons are made against the corresponding 2025 base case (zero biofuel share, the same allowance price and wood supply scenario) the results are as shown in

Figure 11 and Figure 12. Figure 10 describes the total change of wood use from 2005 to certain scenario values at 2025. This change is composed of two separate elements: first from 2005 to 2025 using the zero biofuel case and then in the same period from the zero biofuel case to the 10% or 20% biofuel cases. Figure 11 and Figure 12 describe this latter part with varying allowance prices and wood supplies.

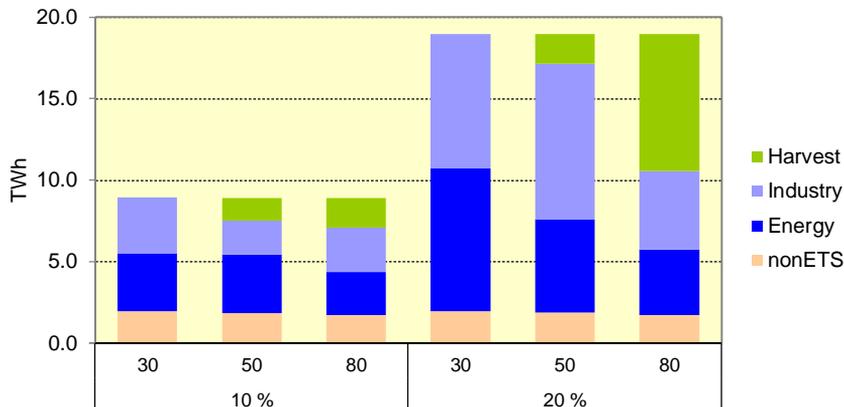


Figure 11. Wood procurement by biorefineries in the case of biofuel targets 10 or 20% with different prices of emission allowances (30, 50 and 80€/ton CO₂) and intermediate wood supply. (Harvest = wood from additional harvesting; Industry = wood from reduced energy wood use in industry; Energy = wood from reduced wood use within large-scale energy production; NonETS = wood from reduced wood-use in the other parts of the non-ETS sector).

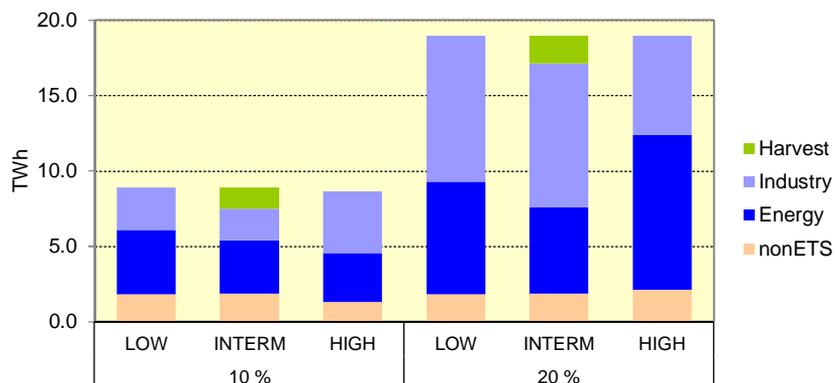


Figure 12. Wood procurement by biorefineries in the case of biofuel targets 10 or 20% with different wood supply assumptions (Low, Intermediate, High) and price of emission allowance of 50 €/ton CO₂. (Harvest = wood from additional harvesting; Industry = wood from reduced energy wood use in industry; Energy = wood from reduced wood use within large-scale energy production; NonETS = wood from reduced wood-use in the other parts of the non-ETS sector).

Figure 11 and Figure 12 show that fulfilling the biofuel obligation leads to adjustments in fuel use in every sector of the energy system. The impacts of biofuel production are reflected in the ETS sector via wood and fossil fuel markets. Fossil fuels or energy-saving investments, or both, substitute for wood fuel compared to the 0% biofuel case in sectors that contribute to the biorefinery raw material base. In the non-ETS sector there appears to be a certain amount of adaptation potential and this is taken up already in the 10% case. Non-ETS adaptation seems to be robust even if biofuel production doubles.

In industry, the largest transition in wood use takes place in pulp and paper production where wood fuel goes to the biorefinery instead of to direct burning in the industrial steam plants. However, only part of the decreased fuel use need be replaced by other fuels because the by-products of the biorefinery process, steam and a small amount of non-liquefied synthesis gas, are fed back to the pulp and paper mill partly meeting its fuel and energy needs. The net effect of this wood reallocation is thus smaller in industry than in other sectors.

The most striking change in biorefinery wood procurement is the furthest right hand bar in Figure 12, where energy production forms the largest source of wood for biofuel production. In the case of abundant (high) wood supply and 0% biofuel share even the wood-based condensing generation of electricity appears economically viable. Increasing the biofuel share from 0% to 20% reallocates wood from electricity generation to biofuel production.

3.2.2 Domestic emissions in the energy system

The impact of the transportation biofuel targets on emissions in ETS and non-ETS sectors is shown in Figure 13, using an allowance price of 50 €/ton and varying wood supply cases. The ETS and non-ETS sectors behave differently due to their inherently different positions as far as emissions are concerned: the non-ETS sector is forced (a) not to emit more than a specified amount of CO₂ per annum, and (b) to use a specific share of biofuel in its transportation fuel mix. The ETS-sector can balance its mitigation efforts using the price of allowances as a reference without any fixed values for emissions. Its adaptation is purely economic. Only a part of the non-ETS sector responds to the price signals while the rest is controlled by the regulatory approach.

The non-ETS sector is able to achieve the emission reduction target with 0% biofuel share. This is used as a point of reference for the 10% and 20% cases, Figure 13.

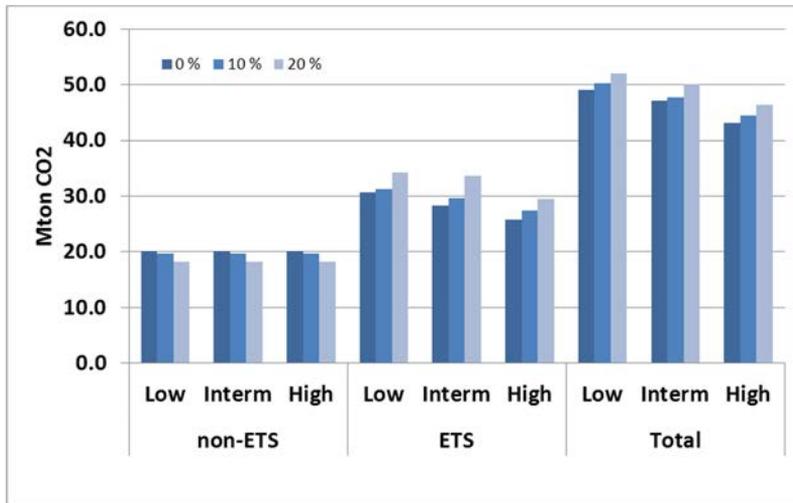


Figure 13. The emissions for the biofuel shares 0, 10 and 20% in non-ETS and ETS sectors and in total with different assumptions for wood supply.

The non-ETS emissions decrease with the introduction of biofuels but not with its full potential. It means that a part of the emission reduction due to biofuel use is compensated by other non-ETS sub-sectors using more fossil fuels. Figure 14 shows the non-ETS sector in more detail.

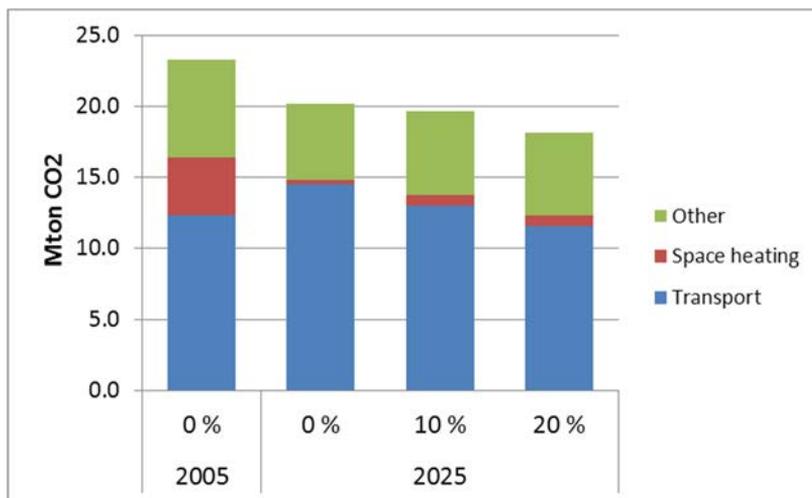


Figure 14. Emissions in the sub-sectors of the non-ETS sector for biofuel shares of 0, 10 and 20% when the price of emission allowance is 50 €/ton and wood supply is 'intermediate'.

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The emissions in road transport in 2025 are estimated to decrease from 14.1 Mton CO₂ to 11.6 Mton CO₂ due to biofuels. Space heating and industrial energy use (part of the other class in Figure 14) have some flexibility in their fuel use and it is reflected in the emission figures. In space heating outside the district heating networks we assume a major shift away from light fuel oil to heat pumps and/or pellet based heating. This change will take place because there is a substantial share of old oil-based heating systems in the latter part of their life cycle and these systems will be renovated during the coming decade. It is assumed that only a fraction will continue to use oil as the main fuel for heating.

An increasing biofuel share increases emissions in the ETS sector so much that total emissions in the energy system also increase. This outcome is a result of two main phenomena. First, the production of biofuels increases electricity demand (volume effect) and the more biofuel production there is, the higher the emissions become. A 10% biofuel share corresponds to approximately 450 kt of biofuel, the production of which uses about 1 TWh of electricity and a 20% share doubles this figure. Second, the specific emissions of fuel use in energy production increases due to changes in a competitive fuel-mix (fuel-mix effect). Fossil fuels substitute for wood due to the increased demand for (and price of) wood caused by biofuel production.

The significance of the impact of the volume effect on emissions can be seen in Figure 15.

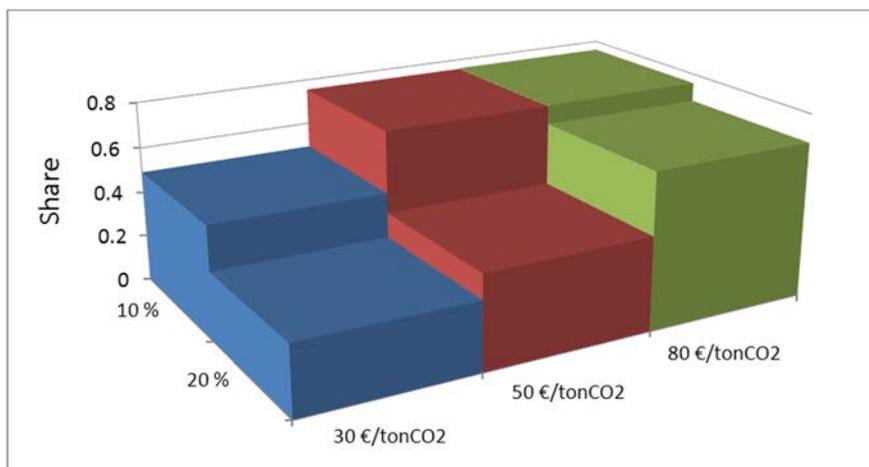


Figure 15. The proportional contribution of increased use of electricity, due to biorefineries, on emissions, in the case of 10 and 20% biofuel shares for different prices of emission allowances and intermediate wood supply. The shares of the volume and fuel-mix effects add up to one.

There is a clear dependence of the volume effect on both the biofuel share and allowance price. The higher the allowance price the lower the fuel-mix effect, i.e.

the volume effect dominates. The opposite is true for the 30 €/ton CO₂ case. With a high allowance price the competitiveness of wood fuel is good and an increasing biofuel share leads to increased harvesting levels. Thus the fuel-mix changes are small. But at the other end of the price range, even a small increase in wood demand leads to a high enough price increase to make wood lose market share to fossil competitors and so the electricity volume effect remains small.

In the ETS sector, the emission increase has to be compensated by buying emission allowances abroad. In the EU itself, emissions allowances in the ETS sector are fixed. Thus the increased demand for emission allowances would push up the price of emission allowances, as well as increase the trade of emission allowances between countries and sectors. However, these impacts cannot be assessed in the single country model in which the price of emission allowances is fixed.

3.2.3 Cost efficiency of biofuels in emission abatement and increasing renewables

The cost-effectiveness of transportation fuels is evaluated by using two approaches. The first approach is based on the comparison of the average costs of emission abatement in the non-ETS sector with and without biofuels. Transportation biofuels belong to the non-ETS sector and thus its fuel use affects directly the emission reductions in the non-ETS sector. The second approach evaluates the additional costs of the biofuel target using levelized annual costs.

Both cost calculations are based on the total system costs that are obtained by minimizing the costs of the development of the whole energy system over the time span of interest. These costs include all the system-wide cost components: investment costs, fuel costs, maintenance costs, taxes, emission allowance costs, cost of investing in energy efficiency etc. The production and investment decisions in the model are based on the net present value criterion. The base year is 2005 to which all the costs are discounted. In all cases, wood supply is at an intermediate level and the emission allowance price is fixed at 50 €/tonCO₂.

In the first approach, a *new reference case* is defined in which all other EU obligations are taken into account except the emissions upper bound for the non-ETS sector. This test reveals that the non-ETS target is not achieved as a by-product of fulfilling the other EU obligations. Its fulfilment needs additional measures and thus the first variation to the reference case is defined by forcing the system under the non-ETS emissions target using a 0% biofuel share. In the second and third variations the system is forced to adopt a 10% or 20% biofuel share in road transport. In these latter cases emissions remain under the target level.

The impacts of biofuel targets on average emission abatement costs are represented in Figure 16. The zero case represents the costs of achieving the non-ETS target applying some other than additional transportation measures. The biofuel cases of 10% and 20% show how the costs change when a share of wood-based transport biofuel is fixed as one of the means to achieve the emission target. The

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average emission abatement cost is calculated by dividing the additional costs of meeting the emissions target by the change of emissions in these cases.

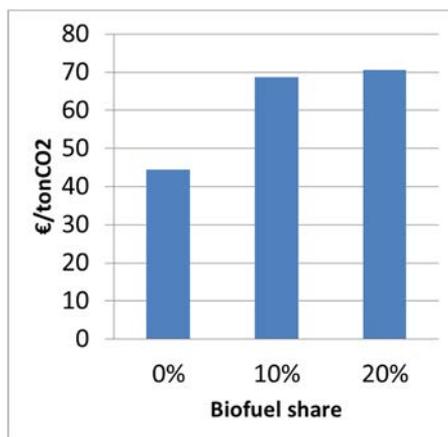


Figure 16. Average CO₂ abatement cost in the non-ETS sector over the whole time period.

The system is rather close (1 milj.ton CO₂) to the non-ETS emission target already achieved in the cost-effectiveness reference case due to the other obligations set on the system. However, some additional measures are still needed. The average cost rises due to the fixed biofuel share, but not dramatically. The difference between 0% and 10% means 50% increase in specific CO₂ reduction costs. The cost difference between 10% and 20% cases is negligible because the share of the cumulative values of costs and emission reduction does not change. From the cost-effectiveness point of view biofuels do not seem as promising a means of achieving the emission targets.

In the second approach, the calculation of costs is based on scenarios that differ only with respect to inclusion of a biofuel target (0% vs. 10/20%). Other policy measures examined (upper bound for non-ETS emissions; price of emission allowances; target for renewable and target for efficiency) are included in all scenarios.

The levelized cost is based on the idea of transforming the net present value of the original costs to a cost stream with equal annual payments over the time span of interest. These annual values are easier to understand and compare to some other costs than the net present values of the corresponding cases.

Comparing the costs of the 0% case with 10% and 20% cases produces cost differences the levelized annual values of which are 134 M€ and 343 M€ respectively. Doubling the biofuel share doubles the investments but the purchases of additional emission allowances explain the most of the non-linear character of the cost development.

Another suitable figure for motor fuel comparison is the price (cost) per litre. For the 10% case the additional cost for each litre of biodiesel can be calculated as

$134 \text{ M€} / 450 \text{ kton/a} \times 0.845 \text{ ton/m}^3 = 0.25 \text{ €/ltr}$. For the 20% case the corresponding figure is 0.32 €/ltr . These are the additional costs at the refinery gate. As a comparison the pump price for diesel oil without taxes was 0.75 €/ltr in May 2011². This price includes costs of crude, refining, transportation and all other cost items except taxes.

3.3 Forest carbon balance

The EFISCEN model was parameterized for the three biofuel scenarios of the share of domestically produced biofuels (0%, 10%, 20%). The results presented here concern only the emission allowance of 50 €/ton CO_2 . Wood demand for the scenarios was derived from the energy system model EPOLA (Figure 17). In EFISCEN, 1/3 of the wood demand was allocated to thinnings and 2/3 to final fellings, and harvests were allocated by tree species and region based on availability.

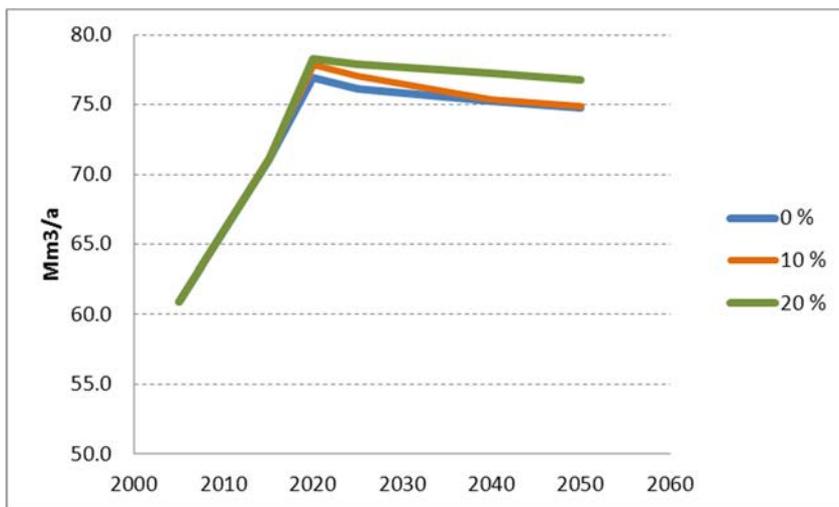


Figure 17. Total wood supply for the three bioenergy scenarios.

Based on data from Finnish Statistical Yearbook of Forestry 2010, the energy wood demand (Figure 18) derived from EPOLA was allocated into thinnings (all tree species), logging residues (all tree species) and stumps (spruce and pine) by assuming that 50% of the energy wood is logging residues, 13% stumps and the rest is thinnings energy wood. Thinnings energy wood is furthermore divided into stem (50%) and whole tree (50%). Logging residues and stumps are extracted

² www.oil.fi, visited 1.7.2011.

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only from mineral sites. However, if the extraction rate at the mineral site exceeds 70%, the overage is taken from peatlands.

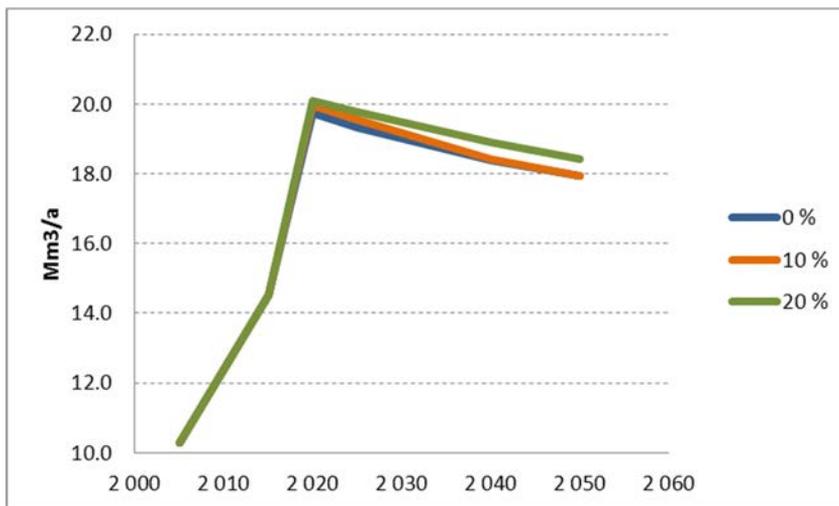


Figure 18. Total (industrial and non-industrial) energy wood supply for the three bioenergy scenarios.

Almost all of the increase in wood demand over the time periods was due to increases in energy wood demand. The overall impact of bioenergy use was very large compared to the additional impacts of biofuel shares (see the small differences in Figure 18).

The large increase in bioenergy use did, however, have a relatively small impact on the total carbon stock of Finland's forests (Figure 19). This was because most of the bioenergy was logging residue or small-sized wood from thinnings. The forest carbon stock will significantly increase in the next 40 years, but the size of the sink is smaller when more biomass is extracted from the forest.

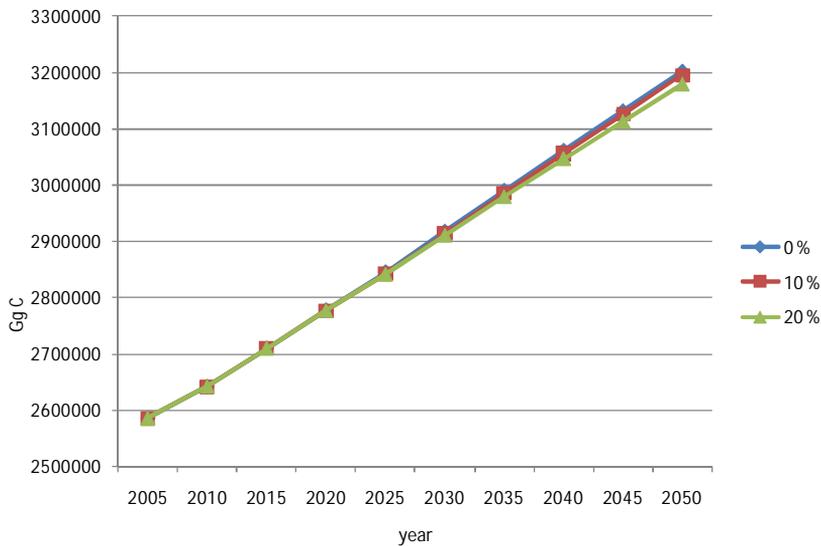


Figure 19. Development of C stocks in Finland's forests (trees and soil) in different biofuel scenarios.

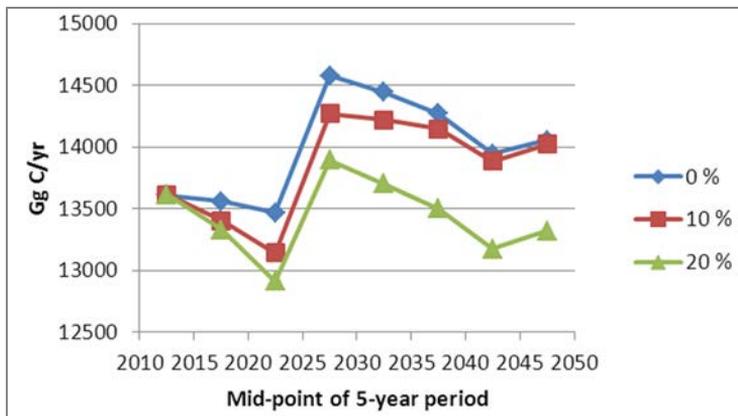


Figure 20. Forest carbon stock change in different biofuel scenarios.

The total carbon sink of Finland's forests was projected to be around 12 to 15 TgC/a, depending on the time period and the biofuel requirement (Figure 20). The time period 2005–2010 was not available for soil carbon due to model dynamics and the necessary lag with respect to biomass harvest. The time paths depend on the development of harvesting levels in the scenarios and the soil carbon levels, which lag behind harvests due to decomposition. The increasing harvests up to 2025 first slowed biomass growth but later the enhanced logging residue amounts increased the soil carbon stocks. The differences in the forest carbon sink due to biofuel needs

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were largest in the 10% share in the period 2020–2025 (328 Gg C, or 1.20 Mton CO₂) and in the 20% share in the period 2040–2045 (773 Gg C, or 2.83 Mton CO₂).

3.4 Total impact on emissions

The biofuel obligation is one of the means for the non-ETS sector to achieve its emission target. Biofuel production takes place in the ETS part of the system but is used in the non-ETS part. The production of biofuels increases the emissions of the ETS part but it balances its position with the EU-wide mechanism developed for that purpose: the emissions trading system (ETS). This mechanism guarantees that the EU-level emissions of all the ETS sectors combined do not increase due to changes in the overall system although it may change the allocation of allowances across the EU-countries.

To understand the impacts the introduction of wood-based transport biofuels has on emissions and costs, the analysis has to cover the whole chain that begins in the forest, goes through all the processing steps of its production and up to the end-use of the product. The analysis should cover also the “side impacts” the chain has through the interaction of the various system components. It is important to look at the whole system: forest and both the ETS and non-ETS fuel and emission flows.

The production of biofuels increases harvesting and decreases the forest carbon sink. This is an emission from the climate point of view – although not fully accounted for in the national climate obligations – and it is shown as a cumulative figure in the Forest sink lines in Table 4. The use of biofuels overrides a corresponding amount of fossil fuels decreasing emissions. This is shown as negative cumulative figures in the non-ETS rows of Table 4. The production of biofuels increases emissions in the ETS part of the system and this can be seen as positive cumulative figures on the ETS rows.

Table 4. Cumulative emission differences between the 0% and 10% vs. 20% biofuel share cases [Mton CO₂]. *Sum-ES* refers to the energy system emissions, *Climate* stands for emissions of the *Forest* and *non-ETS* sectors together and *Finland* sums up all the emission differences within Finnish borders.

		2020	2025	2030	2035	2040	2045	2050
10 % case								
Forest C-balance	1	0,4	1,2	2,7	4,8	7,4	10,3	13,1
nonETS	2	-3,2	-6,4	-8,9	-11,5	-14,0	-16,0	-18,0
ETS	3	9,6	16,7	23,7	30,7	37,7	44,0	50,3
Sum-ES	2+3	6,3	10,3	14,8	19,2	23,7	28,0	32,3
Climate	1+2	-2,8	-5,1	-6,2	-6,6	-6,6	-5,7	-4,9
Finland	1+2+3	6,7	11,5	17,5	24,0	31,1	38,3	45,4
20% case								
Forest C-balance	1	1,3	5,5	12,5	22,0	33,8	46,9	59,8
nonETS	2	-6,8	-17,1	-26,9	-36,8	-46,7	-56,0	-65,3
ETS	3	18,9	44,7	68,2	91,7	115,2	135,6	155,9
Sum-ES	2+3	12,1	27,6	41,2	54,9	68,6	79,6	90,6
Climate	1+2	-5,5	-11,6	-14,5	-14,8	-12,8	-9,1	-5,5
Finland	1+2+3	13,4	33,1	53,7	76,9	102,4	126,5	150,4

All the figures represent cumulative differences between the 0% case and the 10% / 20% cases. Increased ETS emissions indicate increased demand for emission allowances in the Finnish ETS sector. But these amounts do not cause climate impact because the EU-wide ETS emissions remain level in all instances. They only represent the increased pressure on allowance price and the re-allocation of these allowances.

Instead, the decreased carbon sink of forests and the changed emissions of the non-ETS sector have an impact on global atmospheric emissions. Figure 21 plots the cumulative climate impact figures for both of the biofuel cases as a function of time:

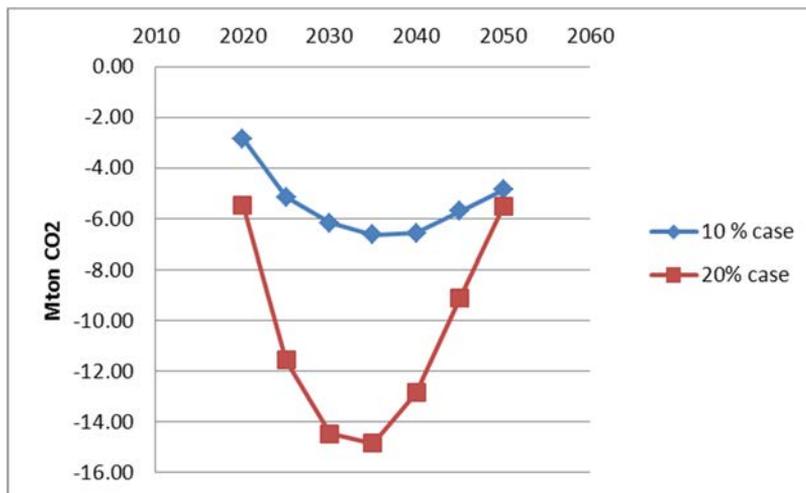


Figure 21. Cumulative emissions due to transportation biofuels including forest carbon sink and non-ETS emissions over time (Climate rows in Table 4). Emissions decrease rapidly in the beginning but the impact of reduced forest carbon stock almost cancels out the transportation emission reduction in the latter part of the study period.

The emissions decrease in the beginning because the effect of biofuel use dominates. The use of each ton of biofuel has the same impact on emissions every year but the market based fuel mix changes in the non-ETS part of the energy system reduce it somewhat. The annual forest sink changes are rather small because the majority of the raw material for a biorefinery would have been used in other processes without a biofuel obligation. The impact of only slightly increased harvesting on the forest carbon sink due to biofuel production accumulates slowly. Later in the study period the forest part of the system impact exceeds that of the biofuel use and so the cumulative emissions start to diminish. But Figure 21 shows that the total emissions are smaller with biofuel production and use than without it. The ETS sector is not included in the graph in Figure 21 because its emission increases will be compensated by buying emissions allowances in the ETS market area. This means that the corresponding amount of emission reductions take

3. Results

place somewhere in the ETS area (assuming here that there is no carbon leakage due to biomass imports outside the EU area or due to biomass production within the EU).

Figure 22 shows the cumulative emission components of Table 4 as average annual values per biofuel ton over the study period for both the biofuel cases. After the transition period the demand for allowances, ETS-M, stabilizes so that the demand for them less than doubles when the biofuel share doubles. The 10% share for biofuel corresponds to 450 kt of fuel corresponding to 1.5 Mton CO₂ or 5% of the ETS emissions. For the 20% case the figures are 900 kton and 4.5 Mton CO₂ or 15% of ETS emissions.

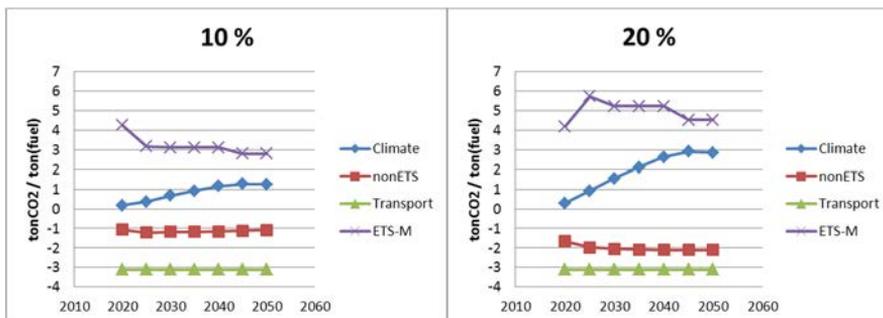


Figure 22. Average annual impacts of biofuel target on emissions in forests, non-ETS-sector and transportation. ETS-M describes the increased allowance purchases in the ETS sector.

The differences in forest sink effect reflect the differences in harvesting levels. The fact that impacts on transport emissions and non-ETS emissions are not the same is due to the fuel mix changes in non-ETS energy production. The difference of the 20% case is half of that of the 10% case meaning that in the last 10% of the 20% case the changes in transport emissions are fully reflected in the non-ETS emission changes.

4. Conclusions

The objective of this study was to demonstrate the economic and emissions impacts of launching forest-based second-generation biodiesel production in Finland under the current climate and energy policy framework of the EU. The analysis contributes to earlier literature by including the indirect market-mediated impacts on the energy system, as well as the impacts on the GHG balance of forests.

In this study, the production of wood-based biofuels increased the use of electricity and wood. The 10% biofuel target represents 450 kt of fuel. To produce this amount of biofuel requires 4.5 Mm³ of wood and 1 TWh of electricity. Harvesting of logging residues and other energy wood increased only slightly, as most wood available at a competitive price was already utilized in the base cases to meet the target for renewables. The biofuel target therefore largely reallocated wood from energy production and industry into biorefineries. Increasing electricity generation meant higher emissions. The additional demand for wood by biorefineries pushed the price of wood up and deteriorated its competitive position as a fuel in energy production. This led to new fuel mixes in all sectors of the economy with more fossil fuels and emissions. The significance of the volume and fuel mix effects varies in such a way that the lower the price of allowances the stronger the fuel mix effect on emissions.

Our analysis demonstrates the importance of including market-mediated impacts on the analysis of transportation biofuels. The results show that while the transportation biofuel target is set for the non-ETS sector the majority of adjustments take place in the ETS sector. This outcome reflects the known fact that the ETS sector is in general more efficient in carrying out the emission reductions than the non-ETS sector.

The EFISCEN forest model simulations showed that the additional wood demand due to biodiesel production would weaken the terrestrial C sink in Finland for the next 40 years when examined with respect to the baseline with no biodiesel. Finnish forests would still remain as a net C sink, but neglecting the sink change in the accounting framework can be considered a principal C leakage mechanism. However, because of the adjustments in the ETS sector the decrease in forest sink is much less than in case the demand would be fulfilled just by additional harvest.

4. Conclusions

This study formulated the total system-wide emissions by combining the changes in the forest C sink and the emissions of the non-ETS sector. It was evaluated under current policy mechanisms as being close to neutral when ETS emissions were excluded. In the near future, emission reductions from transportation dominated the total impact. However, the impact of reduced carbon stock in the forests accumulates slowly and in the end almost cancelled out the benefits obtained from the transportation sector.

In this study, the emissions increase in the ETS sector had to be compensated by the purchase of emission allowances from abroad under the current emissions trading system. This implies that corresponding additional emissions reductions were realized outside Finnish borders. Additional emissions from the ETS sector in Finland did not cause GHG impacts at the EU level except possibly increased forest harvest, not fully accounted for under the present climate obligations. Another carbon leakage mechanism could be reduction in fossil GHG emissions based on the use of biomass imported from outside the EU and assumed to be carbon neutral.

Under the present climate policy framework, with fixed emission reduction targets, the issue of climate impacts is largely transformed into an issue of cost-effectiveness to meet the set targets. This study's results indicate that the target for forest-based transportation biofuels imply an additional cost on the energy system even though biofuels will have been produced with modern, second-generation technology.

We used two indicators to characterize the cost-effectiveness of fulfilling the biofuel target. First, we calculated the specific costs of CO₂ emission reduction in the non-ETS sector. Without biofuels the cost was found to be 45 €/ton CO₂ and 70 €/ton CO₂ with biofuels (in 2005).

Levelized annual cost was used as the second cost-effectiveness index. It was estimated to be 134 M€ for the 10% case and 343 M€ for the 20% cases. These costs correspond to the additional cost component of 0.25 €/ltr and 0.32 €/ltr for the 10% and 20% cases respectively. The costs were mainly due to the investments in biodiesel plants as well as buying additional emission allowances. At the EU level, there would be upward pressure on the price of emission allowances that would imply additional costs. We estimated that the 10% biofuel target would increase the demand for emission allowances by 5% and the 20% target by 15%. In the single country model used in our study, the impact on allowance price and related costs for emitters cannot be evaluated.

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Appendix 1: The biorefinery model

This study adopted the following input-output description for the two alternative types of FT (Fischer-Tropsch) biorefinery based on wood gasification shown in Figure A-1 (McKeough and Kurkela, 2008).

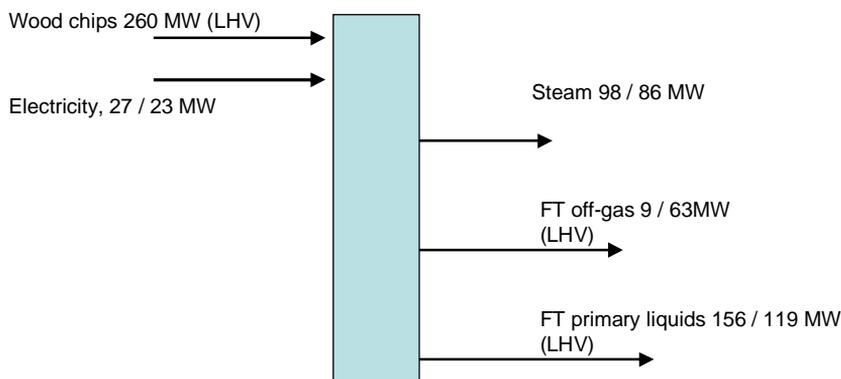


Figure A-1. Alternative energy and material flows of the biorefineries in this study (LHV = lower heating value).

The processes differ mainly in output flows. The first numbers refer to a concept in which the non-liquefied gas is redirected into the FT process. The second numbers are based on the once-through principle where the amount of liquids is lower but the gas volume is respectively larger. This configuration is simpler and cheaper to build.

From the numbers given, one can calculate the efficiency of the process in transforming wood energy into liquid biofuel: $156/260 = 0.6$ and $119/260 = 0.46$. In addition to wood the process needs electricity as an input and it produces three energy commodities: steam, non-liquefied gas and the main output, liquid fuel. Steam and purified gas can be used in a pulp mill as substitutes for corresponding fuels and energy forms.

In the model runs where the costs are minimised, the once-through process was never chosen. The liquids produced still need gentle refining in a refinery and this process requires some additional energy inputs.

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Title	Wood-based biodiesel in Finland Market-mediated impacts on emissions and costs
Author(s)	Juha Forsström, Kim Pingoud, Johanna Pohjola, Terhi Vilén, Lauri Valsta & Hans Verkerk
Abstract	<p>Renewable energy targets create an increasing demand for bioenergy and transportation biofuels across the EU region. In Finland, forest biomass is the main bioenergy source and appears to be the most promising source for transportation biofuel production.</p> <p>In this study, a biodiesel strategy based on domestic forest biomass is analysed using an integrated modelling framework. A market-oriented framework is applied to estimate the potential greenhouse gas impacts of achieving a national transport biofuel target (10% vs. 20% of total consumption) under the current climate and energy policy obligations. The cost-minimising adaptation of the energy system to policy targets, the demand for wood biomass and emissions from the energy system including the transportation sector are described using the energy system model EPOLA – a dynamic linear optimization model. The resulting response of the Finnish forests (their carbon balance) to the increasing demand for wood biomass is modelled using the EFISCEN forest model.</p> <p>The analysis demonstrates the importance of including market-mediated impacts in the analysis. The majority of adjustments toward the biofuel target takes place in the ETS sector, among the energy producers participating in the EU Emission Trading System, even though the transportation biofuel target is set within the non-ETS sector. The demand for wood in biorefineries raises the wood price thereby weakening its competitive position against fossil fuels. In consequence, wood is likely to be partly replaced by fossil fuels within the ETS sector, for example in district heating. In addition, biorefineries would increase the total use of electricity. Thus, fossil fuel carbon dioxide emissions in the ETS sector within the Finnish borders would increase.</p> <p>Total cumulative emissions, including the non-ETS sector and the forest carbon balance, are slightly lower in the biodiesel scenarios than in the baselines. In transport and in the non-ETS sector in general, the decrease in emissions takes full effect immediately, whilst the decrease in carbon sink in the Finnish forests appears to be gradual. The impact on the carbon sink is fairly small because wood harvesting increases by less than the amount of wood used for biodiesel production. The increase in emissions from the Finnish ETS sector is not accounted for in the total emissions, because at the EU level, emissions in the ETS sector are fixed. Any increase in ETS emissions in Finland has to be compensated by the purchase of emission allowances, and the corresponding emission reduction takes place elsewhere in the ETS area. The possible carbon leakage due to the increased use of forest or imported biomass elsewhere in the EU is excluded from this analysis.</p> <p>Biodiesel proves not to be a cost-effective measure for attaining climate or renewables targets. This is due to the low efficiency of the biodiesel chain in displacing fossil diesel emissions. Just from the mitigation point of view, the direct burning of solid wood biomass in energy-efficient boilers should be favoured.</p>
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Nimeke	Biodieseliä puusta Päästö- ja kustannusvaikutukset Suomessa
Tekijä(t)	Juha Forsström, Kim Pingoud, Johanna Pohjola, Terhi Vilén, Lauri Valsta & Hans Verkerk
Tiivistelmä	<p>Uusiutuvan energian tavoitteet ovat lisäämässä bioenergian ja liikenteen biopolttoainien kysyntää koko EU-alueella. Suomen tärkein bioenergian lähde on metsäbiomassa, joka on myös lupaavin raaka-aine liikenteen biopolttoainien valmistukseen.</p> <p>Kotimaiseen metsäbiomassaan perustuva biodieselstrategiaa arvioitiin integroidulla markkinavaikutuksia kuvaavalla mallijärjestelmällä. Tarkastelun kohteena olivat potentiaaliset päästövaikutukset, kun 10 % tai 20 % liikennepolttoainesta korvataan kotimaisella puuperäisellä biodiesellillä samalla kun täytetään muut nykyisen ilmasto- ja energiapolitiikan tavoitteet. EPOLA-mallilla, joka on dynaaminen lineaarinen optimointimalli, laskettiin energijärjestelmän kustannukset minimoiva sopeutuminen politiikkatavoitteisiin, puuraaka-aineen kysynnän lisäys sekä energijärjestelmän päästövaikutukset. EFISCEN-mallilla laskettiin puun lisäkysynnän aiheuttama muutos metsien hiilitaseeseen.</p> <p>Analyyssi osoittaa, että on tärkeää ottaa huomioon energijärjestelmän markkinavaikutukset. Suurin osa energijärjestelmän sopeutumisesta biopolttoainetavoitteeseen tapahtuu päästökauppasektorilla, vaikka liikenteen biopolttoainetavoite koskee välittömästi ainoastaan ei-päästökauppasektoria. Biojalostamojen puun kysyntä nostaa raakapuun hintaa ja heikentää puupolttoainien kilpailuasemaa suhteessa fossiilisiin polttoaineisiin. Puu korvautuukin osin fossiililla polttoaineilla päästökauppasektorilla kuten kaukolämmössä. Lisäksi biodieseliä valmistavat biojalostamot lisäävät sähkön kokonaiskulutusta. Näin hiilidioksidipäästöt lisääntyvät päästökauppasektorilla Suomen rajojen sisäpuolella.</p> <p>Kokonaispäästöt, jotka sisältävät ei-päästökauppasektorin ja metsien hiilitaseen, ovat hieman alhaisemmat kuin perusurissa, joissa kotimaista biodieseliä ei tuoteta. Liikenteessä ja ei-päästökauppasektorilla kokonaisuudessaan päästöt alenevat välittömästi, kun biodieseliä ryhdytään valmistamaan. Metsien hiilinielu heikentyy vähitellen suhteessa perusuriin. Vaikutus hiilinieluun on melko pieni, koska hakkuut lisääntyvät vähemmän kuin biodieselin valmistuksen edellyttämä puuraaka-aineen kysyntä. Suomen päästökauppasektorin kasvaneita päästöjä ei lasketa mukaan kokonaispäästöihin, koska päästöille on EU-tasolla asetettu päästökatto. Lisääntyneet suomalaiset päästöt kompensoidaan päästöoikeuksien ostolla, ja vastaavat päästönvähennykset toteutuvat jossain muualla EU:n päästökauppalueella. Tässä tutkimuksessa ei ole arvioitu mahdollista hiilivuotoa muualla EU:ssa. Se aiheutuu metsien lisäkäytöstä tai biomassan tuonnista EU:n ulkopuolelta.</p> <p>Biodieselin valmistus ei ole kustannustehokas tapa päästönvähennysten tai uusiutuvan energian tavoitteiden täyttämiseen. Tämä johtuu biodieselketjun heikosta tehokkuudesta fossiilisen dieselin päästöjen korvaajana. Jos tavoiteltaisiin pelkkiä päästönvähennyksiä, kannattaisi suosia kiinteän puupolttoaineen käyttöä energia- tehokkaissa kattiloissa.</p>
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Julkaisu aika	Tammikuu 2012
Kieli	Englanti, suomenkielinen tiivistelmä
Sivumäärä	47 s. + liitt. 1 s.
Avainsanat	greenhouse gas balance, forest carbon balance, EU renewable energy targets, indirect impacts, transportation biofuels, wood-based biodiesel, EU emissions trading system, market-mediated effects, Finnish energy system, dynamic linear optimization model, EFOM model, EFISCEN model
Julkaisija	VTT PL 1000, 02044 VTT, Puh. 020 722 111

Wood-based biodiesel in Finland. Market-mediated impacts on emissions and costs

Renewable energy targets create an increasing demand for bioenergy and transportation biofuels across the EU region. In Finland, forest biomass is the main bioenergy source and appears to be the most promising source for transportation biofuel production. In this study, a biodiesel strategy based on domestic forest biomass is analysed using an integrated modelling framework.

The analysis demonstrates the importance of including market-mediated impacts in the analysis. The majority of adjustments toward the biofuel target takes place in the ETS sector, among the energy producers participating in the EU Emission Trading System, even though the transportation biofuel target is set within the non-ETS sector. The demand for wood in biorefineries raises the wood price thereby weakening its competitive position against fossil fuels. In consequence, wood is likely to be partly replaced by fossil fuels within the ETS sector, for example in district heating. In addition, biorefineries would increase the total use of electricity. Thus, fossil fuel carbon dioxide emissions in the ETS sector within the Finnish borders would increase.

Total cumulative emissions, including the non-ETS sector and the forest carbon balance, are slightly lower in the biodiesel scenarios than in the baselines. The impact on the carbon sink is fairly small because wood harvesting increases by less than the amount of wood used for biodiesel production. The increase in emissions from the Finnish ETS sector is not accounted for in the total emissions, because at the EU level, emissions in the ETS sector are fixed. The possible carbon leakage due to the increased use of forest or imported biomass elsewhere in the EU is excluded from this analysis.

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