# ANALYSIS OF THE ECONOMIC IMPACT OF LARGE-SCALE DEPLOYMENT OF BIOMASS RESOURCES FOR ENERGY AND MATERIALS IN THE NETHERLANDS

## MACRO-ECONOMICS BIOBASED SYNTHESIS REPORT

Creative Energy
Energy Transition

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**Authors**
Ric Hoefnagels
Veronika Dornburg
André Faaij
Martin Banse, Agricultural Economics Research Institute (LEI)

**Copernicus Institute**
Utrecht University
Department of Science, Technology and Society

Heidelberglaan 2
3584 CS Utrecht
The Netherlands

Telephone: +31-30-2537600
Fax: +31-30-2537601
Website: http://www.chem.uu.nl/nws/www/nws.html

# PREFACE

The Bio-based Raw Materials Platform (PGG), part of the Energy Transition in The Netherlands, commissioned the Agricultural Economics Research Institute (LEI) and the Copernicus Institute of Utrecht University to conduct research on the macro-economic impact of large scale deployment of biomass for energy and materials in the Netherlands. Two model approaches were applied based on a consistent set of scenario assumptions: a bottom-up study including techno-economic projections of fossil and bio-based conversion technologies and a top-down study including macro-economic modelling of (global) trade of biomass and fossil resources. The results of the top-down and bottom-up modelling work are reported separately. The results of the synthesis of the modelling work are presented in this report.

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# 1 INTRODUCTION

The transition to a more sustainable energy system leading to a strongly reduced dependency on fossil fuels and significant greenhouse gas (GHG) emission reductions is an unsurpassed challenge. In the Netherlands, this challenge is addressed by the 'Energy Transition', in which stakeholder platforms have formulated strategies and pathways for different key themes to realise the required changes. One of these platforms deals with 'bio-based raw materials' (Platform Groene Grondstoffen, or PGG), tackling the large-scale and sustainable use of biomass for energy and material applications. As a longer term vision, the platform has targeted 30% replacement of fossil fuels by biomass resources (assuming a stabilised energy use), divided over: 17% of the heating demand, 25% of electricity demand, 25% of feedstock use for chemicals and 60% of transport fuels.

Such proposed changes will require large investments in infrastructure and conversion capacity. In addition, the technologies that may facilitate such large-scale use of biomass partly require further development (including biomass production and supplies), which will need financial support. Another major implication is that such a strategy means a considerable shift in the use and production of primary energy carriers. Imported (coal, oil, natural gas) or indigenous (natural gas) fossil fuels are to be replaced by imported biomass (e.g. as pre-treated material or biofuel) as well as indigenous biomass resources which are available (e.g. residues and waste streams) or can be produced (agriculture, algae). As a consequence, economic activity will shift to different sectors of the economy.

In addition to investments in infrastructure and technology development, a 'bio-based strategy' will also generate new economic activity. This is particularly true when biomass is produced within the Netherlands (compared to imports of fossil fuels). However, even imported biomass, which is further processed in the Netherlands, may generate a higher added value to the national economy when compared to imported oil and natural gas. The latter require limited further processing compared to biorefineries, for example. If this could be realised, this can have very significant (positive) impacts on the trade balance of the country, given the large annual expenditures on imported energy (see also the Roadmap on Sustainable Biomass Import prepared for the PGG, [Faaij, 2006]). In addition, fossil energy prices are likely to continue rising in the medium to longer term [IEA 2006b; IEA 2007], while there is substantial potential for reducing the production and supply costs of biomass cropping systems.

Provided the Netherlands can build and maintain a leading position in the relevant areas, other benefits include export opportunities of technology and knowledge and reduced GHG emissions (with an equivalent value that may be determined by the international carbon market). The latter is inherently considerable, given the projected role of biomass in replacing fossil fuels (30% of total fossil fuels replaced). Furthermore, developing biomass as a new key pillar of the (national) energy and material supply will increase diversity in the energy supply mix and could therefore contribute substantially to improved energy security. A more stable energy supply (particularly compared to international supplies of oil and natural gas) also has a positive impact on (macro-) economic development.

With respect to the use of biomaterials, new biochemicals in particular may also lead to considerable (energy) savings in the production chain, as highlighted by [Sanders et al., 2006] and [Bruggink, 2006] outlined for the PGG. Such indirect savings and potentially higher value chemicals will contribute positively to economic growth. Another opportunity for the Netherlands may lay in a strengthened role as a logistic hub for Europe in the bio-based arena, as such developments will also take place throughout the rest of Europe.

However, the real (net) impact of building a large bio-based industry in the Netherlands over the coming 3-4 decades will depend strongly on the cost developments of key biomass conversion technologies (such as biorefinery concepts, 2nd-generation biofuel production technology and advanced power generation) and the prices at which biomass resources can be made available. Those costs will then be evaluated against the (relative) future costs of fossil fuels (most notably oil and gas), which are also uncertain (although likely to follow an upward trend over the coming decades). Other economic factors, such as growth rate, sectoral change in the (national) economy, prices for $CO_2$ and agricultural policies (subsidies and prices) are also unknown variables. Determining the economic value of a bio-based strategy for the Netherlands must therefore be implemented while keeping these uncertainties in mind. With improved understanding of the mechanisms and uncertainties, more targeted policies and implementation strategies can be devised, which is fundamentally important for both the market and the government. Such information allows for optimising the (economic) benefits and minimising the risks (costs) of implementation and development of a bio-based infrastructure and relevant sectors. This justifies a full-blown analysis of these matters. Remarkably, to date, such analyses are very rare.

## Objective and scope

The main objective of this study is defined as:
*To provide quantitative insight into the macro-economic impacts of the large-scale deployment of biomass-based resources and related infrastructure and production capacity for the supply of energy and materials.*

More specifically, the sub-objectives are:
- Quantitative descriptions of scenarios for biomass use in the Netherlands in 2010 to 2030, under different premises of technological development and biomass trade. These descriptions include biomass resource availability, production and costs, main conversion options for energy and materials and are relative to a baseline scenario.
- A description of the impact of biomass use in the scenarios with regard to biomass use for energy and materials, fossil primary energy saving, total costs

for bio-based production and net costs and GHG emission reduction for fossil-based substitution by biomass. These impacts are calculated using bottom-up information on technologies for biomass production and use, taking into account future technological learning.

- A quantification of the macro-economic impact of large-scale biomass deployment in the Netherlands. GDP, employment, trade balances with the most detailed possible breakdown (including current methods and data) of macro-economic impacts with respect to GDP impact, sectoral effects (e.g. agriculture, chemical industry, energy sector, etc.), employment effects and trade balance of bio-based scenarios.
- Insights into the uncertainty of key parameters and the impact of these variables on the final results. The selected variables include fossil fuel and $CO_2$ prices. The variables 'technology change' and 'international cooperation' are taken into account in the scenario projections.

  A thorough and clear interpretation of results that can be used to formulate sound policy strategies, which allows for optimising the (economic) benefits and minimising the risks (costs) of implementation and development of a bio-based economy.

This study focuses on bio-based production of electricity, liquid fuels for road transport and bio-based chemicals. Bio-based production of heat is only taken into account for industrial CHP plants in the energy and greenhouse gas balances. Stand-alone production of heat from biomass in industries and households is not taken into account, as the LEITAP model is not capable of modelling this commodity directly.

A limited selection of biomass conversion technologies is represented in this study. For chemicals, the bio-based production is aggregated and represented by three conversion options to represent C1 chemicals, C2 chemicals and specialised chemicals. Direct production of functionalised chemicals from biorefineries are not included in this study, due to limitations to represent these multiple output options in the LEITAP top-down model, as well as limited data available on the (economic) performance of these technologies.

The bottom-up scenarios are based on a set of pre-defined technology portfolios for biomass conversion. No optimisation modelling tools are used for this study. The results do not support information on economic, energetic or environmental optimal combinations of technologies or feedstocks. It should be noted that a full optimisation study would also require the addition and comparison of competing energy and GHG mitigation technologies, such as wind or photovoltaics (PV), but also electric or fuel cell vehicles. This is beyond the scope of this study.

### Outline

The structure of this report is as follows. Section 2 describes the methodology of this study, section 2.3 summarises the results of the bottom-up scenarios and projections. The results of the top-down projections using the CGE model LEITAP are summarised in section 4. Section 5 deals with the discussion of the results via an assessment of the bottom-up and top-down results and section 6 lists the conclusions of this study.

# 2 METHOD

In order to quantify the impact of biomass for bioenergy and bio-based materials in the Netherlands, this study combines a bottom-up model with a top-down model. Detailed bottom-up technology projections of biomass conversion options in combination with an advanced multi-sector and multi-region macroeconomic computable general equilibrium (CGE) model, support understanding of both the impact on the macro-economy as the required technological development, fossil energy avoided and greenhouse gas emissions avoided.

To address for change in bio-based production sectors, the CGE model LEITAP is extended for bioenergy in the sectors electricity generation, petrol and bulk and specialised chemicals. The bottom-up model comprises scenarios of a bio-based economy for the electricity, transport fuels and chemicals sectors in the Netherlands projected to 2030. Figure 1 summarises the approach and interaction between the bottom-up model and the top-down model. A description of the individual modelling approaches is given in section 2.1 and 2.2 and in more detail in the individual bottom-up and top-down reports. This synthesis report presents the combined results of the study in which projections of final energy demand and biomass shares of the LEITAP model are used as input parameters for the bottom-up model.

Figure 1 Model system for macro-economic modelling using bottom-up input data for bioenergy and bio-based chemicals

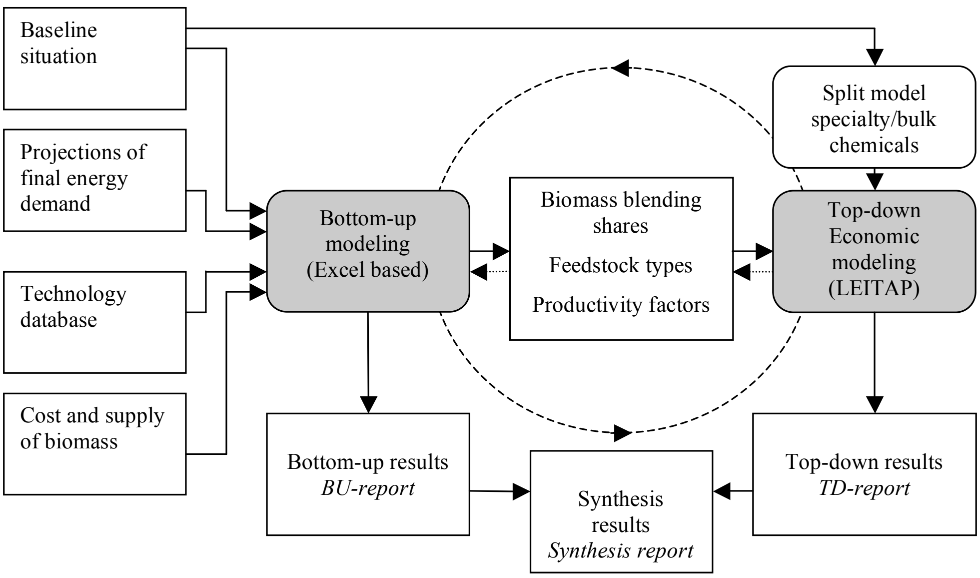



Figure is partly based on Schäfer et al. [2005]

The model interaction in this study is essentially in one direction, i.e. the results of the bottom-up model are translated into bio-based blending shares for the electricity, transport fuels and chemical sectors and applied to the LEITAP model as mandatory bio-based blending shares in these sectors. Further model adjustments were based on comparisons using the final results of the bottom-up model and the top-down model, e.g. technology substitution. Final projections of the LEITAP model are used as input for the bottom-up model in order to generate the synthesis results. This report summarises both the bottom-up results based on the WLO projections and the results based on the LEITAP projections as explained in section 2.3.

A bilateral and iterative exchange between the models, represented by the dotted lines in Figure 1, would improve consistency between the bottom-up and top-down models. However, these calibration steps are not conducted for this study due to time constraints. The discussion section deals with the differences between the outcomes of the bottom-up and top-down models and discusses possible further steps to improve the linkage between the models.

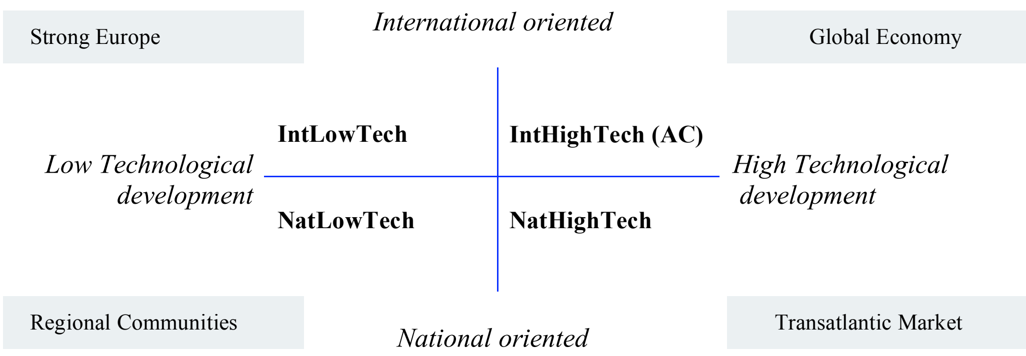
## 2.1 Bottom-up scenarios

To make future projections of biomass for bioenergy and bio-based materials through to 2030 for the Netherlands, this study includes four scenarios. Emphasis in these scenarios is on technological development of (biomass) conversion technologies and on international cooperation including international trade of biomass (Figure 2). The two national scenarios include limited sources of biomass available from EU27+[1] countries. The two international scenarios include global biomass sources available for the Netherlands, such as palm oil, sugar cane and eucalyptus. Other than international cooperation, the two national and international scenarios include one scenario with low technological development and one with high technological development. For the low-tech scenarios (NatLowTech and IntLowTech) we assume biomass conversion technologies to be used until 2030 that are already commercially available, while for the high-tech scenario (NatHighTech and IntHighTech) we assume that advanced ($2^{nd}$-generation) technologies substitute current technologies from 2010 onwards. The IntHighTech scenario includes one projection with bio-based synthesis gas in the chemical industry and one scenario with both bio-based synthesis gas and substitution of bulk and specialised petrochemicals (IntHighTech AC)[2]. Projections of socio-economic change and final energy demands were derived from the WLO-scenarios (Welfare and Environment) [Janssen et al., 2006].

1 EU27 + Norway, Switzerland and Ukraine.

2 The IntHighTech AC scenario is aimed to be more consistent with the goal of the PGG to substitute 25% of fossil-based raw materials in the chemical industry with biomass. This scenario includes both bulk C1 and C2 chemicals as well as specialised chemicals. Blending targets are derived from Rabou et al. [2006]. It should be noted however that, as opposed to Rabou et al., this study does not include bio-based options with direct extraction and production of functionalised chemicals (biorefinery concept).

**Figure 2** Four scenarios for bioenergy in the Netherlands, 2010 – 2030
The WLO scenarios are displayed in the grey-shaded areas.




A selection of biomass conversion technologies is projected to be deployed in the scenarios in order to substitute fossil energy and fossil-based chemicals. The biomass conversion technologies in the scenarios differ on biomass feedstock types (availability of non-EU biomass in the international scenarios), technological development and availability. In all scenarios, wet organic waste and solid organic waste are assumed to be used for electricity generation by anaerobic digestion and incineration respectively.

The LowTech scenarios include technologies that are already used on a commercial scale. For electricity generation, biomass is assumed to be co-fired in PC plants, biopetrol and biodiesel are assumed to be produced from fermentation of sugar and starch crops and transesterification of oil and fat residues and vegetable oils respectively. In the NatLowTech scenario, biodiesel and biopetrol are assumed to be made from EU rapeseed and EU starch respectively. In the IntLowTech scenario, imported sugar-cane-derived ethanol is assumed to be used for transport fuels and for ethylene production via ethanol dehydration. Imported palm oil and jatropha oil are the major feedstock for biodiesel production in this scenario.

In the HighTech scenarios, advanced conversion options are assumed to be commercially available from 2010 onwards. Included are ethanol production from lignocellulosic biomass and synthesis gas production from biomass gasification. Synthesis gas is used for electricity generation (co-combustion in gas turbine combined cycle plants), biodiesel production via Fischer-Tropsch synthesis and for substitution of fossil-based synthesis gas in the chemical industry. The latter option is only assumed to be available in the IntHighTech scenario. In the NatHighTech scenario, bio-based caprolactam, a precursor for the production of nylon-6 is assumed to substitute fossil-based caprolactam from 2020 onwards. Please note that, although 100% of caprolactam was assumed to be replaced by biomass, the total share of bio-based production in the chemical industry will remain limited due to the production share of caprolactam in the chemical industry. In reality, a variety of chemicals will be substituted by biomass instead of substitution of one single product completely, as assumed in the scenarios. Different from the IntHighTech scenario, the IntHighTech AC scenario includes all three chemical representative routes in order to substitute 25% of fossil raw materials in the chemical industry, as targeted by the PGG.

The bottom-up model is a simple Excel spreadsheet model with exogenous inputs of final energy demand from existing scenarios, a detailed technology dataset for bioenergy and bio-based materials and scenario-dependent assumption on the use of biomass by these different technologies. Scenarios include cost estimates and supply potentials for fossil-based and bio-based energy carriers.

### 2.1.1 Input data

The *baseline situation* includes a detailed assessment of current biomass use for bioenergy. It was not feasible to quantify the current use of biomass for bio-based chemicals as these statistics are not reported. The baseline situation also includes information on the structure of the electricity sector (vintage). This data is used to model the replacement rate of retired capacities in the electricity generation sector.

Projections of *final energy demand* for electricity, transport fuels and chemicals are used to estimate the demand for primary fossil energy carriers and the substitution potential of biomass. The bottom-up projections include final energy demand projections from the WLO scenarios [Janssen, Okker et al., 2006]. The final energy demands in the LEITAP projections are modelled endogenously.

The *technology database* includes the technology characterisation and aggregation per sector and commodity. A selection of representative technologies was made for the current situation and for the various scenarios until 2030 (see part I for a more detailed description). This implies that technologies were also considered that are not yet commercialised. Data on cost and performance of these technologies was collected from bottom-up engineering studies. Future projections of cost were made using economies of scale, technological learning and innovation factors. The Excel model includes a detailed database of these technologies, but in order to assess the results for the data calibration process with the production functions in the top-down model, the technologies in this study are aggregated to single commodity options.

For the bottom-up estimations of *cost and supply of biomass* in the scenarios, existing studies were used that estimate the cost and supply relations for biomass energy crops produced in the EU27+ region [Wit et al., 2007] and the global supply potential [Hoogwijk et al., 2005]. Furthermore, domestic supply of primary, secondary and tertiary residues are taken into account. The projected supply of residues are based on PGG publications [Rabou et al., 2006; Kip et al., 2007] and [Koppejan et al., 2005]. For evaluation, the results are compared with the cost and supply of biomass that result from the top-down model outcomes.

### 2.1.2 Bottom-up biomass blending shares and model interaction

The amount of fossil energy that can be substituted by biomass depends mainly on cost and supply of biomass and the techno-economic performance of biomass conversion technologies. The blending targets, i.e. the fossil energy fractions of fossil resources that can be replaced by biomass, are different per scenario and are based on policy objectives and the performance on technologies in the different scenarios.

**Table 1** Blending shares of biomass per scenario and sector (energy basis)

| | NatLowTech | | IntLowTech | | NatHighTech | | IntHighTech | | IntHighTech AC | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Electricity (% energy output)** | | | | | | | | | | |
| 2010 | 4% | | 4% | | 5% | | 5% | | 5% | |
| 2020 | 6% | | 5% | | 9% | | 24% | | 20% | |
| 2030 | 7% | | 6% | | 9% | | 29% | | 21% | |
| **Transport fuels (% energy output)** | | | | | | | | | | |
| 2010 | 5.75% | | 5.75% | | 5.75% | | 5.75% | | 5.75% | |
| 2020 | 10% | | 10% | | 10% | | 25% | | 25% | |
| 2030 | 10% | | 20% | | 20% | | 60% | | 60% | |
| **bio-based chemicals (% energy for raw materials in the chemical industry)** | | | | | | | | | | |
| | **Bulk[a]** | **Specialty[a]** | **Bulk[b]** | **Specialty** | **Bulk** | **Specialty[c]** | **Bulk[d]** | **Specialty[d]** | **Bulk[e]** | **Specialty[f]** |
| 2010 | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A |
| 2020 | N/A | N/A | 4% | N/A | N/A | 4% | 9% | 9% | 13% | 13% |
| 2030 | N/A | N/A | 7% | N/A | N/A | 7% | 19% | 19% | 25% | 25% |

a) No bio-based chemicals in the NatLowTech scenario
b) Bio-based production of bulk C2 chemicals, based on 10% and 20% replacement of fossil based ethylene by bio-based ethylene in 2020 and 2030 respectively.
c) Bio-based production of specialty chemicals, based on 50% and 100% replacement of fossil based caprolactam by bio-based caprolactam in 2020 and 2030 respectively.
d) Bio-based production of synthesis gas, replaces fossil based synthesis gas used for bulk and specialty chemicals. Note that the division between synthesis gas use for bulk and specialty chemicals is similar to the total use of fossil energy for chemicals (80% and 20%).
e) Bulk C1 and C2 chemicals, based on bio-based ethylene (25% substitution of petroleum products in 2030) and bio-based synthesis gas (30% substitution of natural gas in 2030).
f) Bio-based production of specialty chemicals, based on caprolactam (25% substitution of petroleum products in 2030) and synthesis gas (30% substitution of natural gas in 2030).

For electricity generation, the share of biomass was estimated by taking into account the structure of the Dutch electricity sector. In the LowTech scenarios, retired PC plants and new required capacities are met by new PC plants with a higher biomass co-firing share (20%). In the HighTech scenario, retired PC and NGCC plants and new required capacities are met by NGCC plants with NGCC plants with co-gasification of biomass. Blending shares of biomass for transport fuels in the IntLowTech and NatHighTech scenario were based on the EU 2003 directive on biofuels. The blending share of biomass in the NatLowTech scenario was assumed to be more conservative as of limited biomass sources and low production efficiencies. The shares in the IntHighTech scenario were based on the PGG targets for biomass in the transport sector including global biomass resources and high production efficiencies. In this study shares for biomass in the chemical industry were assumed to substitute one fossil-based chemical product per scenario. The IntLowTech scenario includes bio-based ethylene, the NatHighTech scenario includes bio-based caprolactam and the IntHighTech scenario includes bio-based synthesis gas. Please note that, although 100% of caprolactam was assumed to be replaced by biomass, the total share of bio-based production in the chemical industry will remain limited due to the production share of caprolactam in the chemical industry. In reality, a variety of chemicals will be substituted by biomass instead of substitution of one single product completely, as assumed in the scenarios. The IntHighTech AC includes all three chemical representative routes in order to substitute 25% of fossil raw materials in the chemical industry as targeted by the PGG.

## 2.2 Modelling approach under the Macro-economic Model LEITAP

### 2.2.1 The GTAP-E model

The methodological improvements of standard economic model such as the standard GTAP model are crucial for an economic modelling of biomass demand in the bio-based industries. The starting point for the analysis here was the standard version of the general equilibrium model GTAP which has been extended for energy and biomass markets necessary to model biomass demand.[3] An important aspect for this study is related to the question, how the shift in technologies in the bio-based industries is implemented for the different scenarios described in part I of the study. The main difference between the scenarios are the degree of openness of the economy, i.e. National versus International scenarios, and  the shift from Low to High technologies.

The implementation of biofuels builds on a modified version of the GTAP multi-sector multi-region CGE model [Hertel, 1997]. This multi-region model allows the capture of inter-country effects, since the enhanced biofuel use influences demand and supply, and therefore prices on world markets and hence will affect trade flows, production, and GDP. The multi-sector dimension enables to study the link between energy, transport, and agricultural markets. The model is extended through the introduction of energy substitution into production by allowing energy and capital to be either substitutes or complements (GTAP-E; Burniaux and Truong, 2002). Compared to the standard presentation of production technology, the GTAP-E model aggregates all energy-related inputs for the petrol sector – such as crude oil, gas, electricity, coal, and petrol products – in the nested structure under the value added side. At the highest level the energy-related inputs and the capital inputs are modelled as an aggregated 'capital-energy' composite (Figure 3, left panel).[4]

To introduce the demand for biofuels, the nested constant elasticity of substitution (CES) function of the GTAP-E model has been adjusted and extended to model the substitution between different categories of oil (oil from biofuel crops and crude oil), ethanol, and petroleum products in the value added nest of the petroleum sector. The model presents the fuel production at the level of non-coal inputs

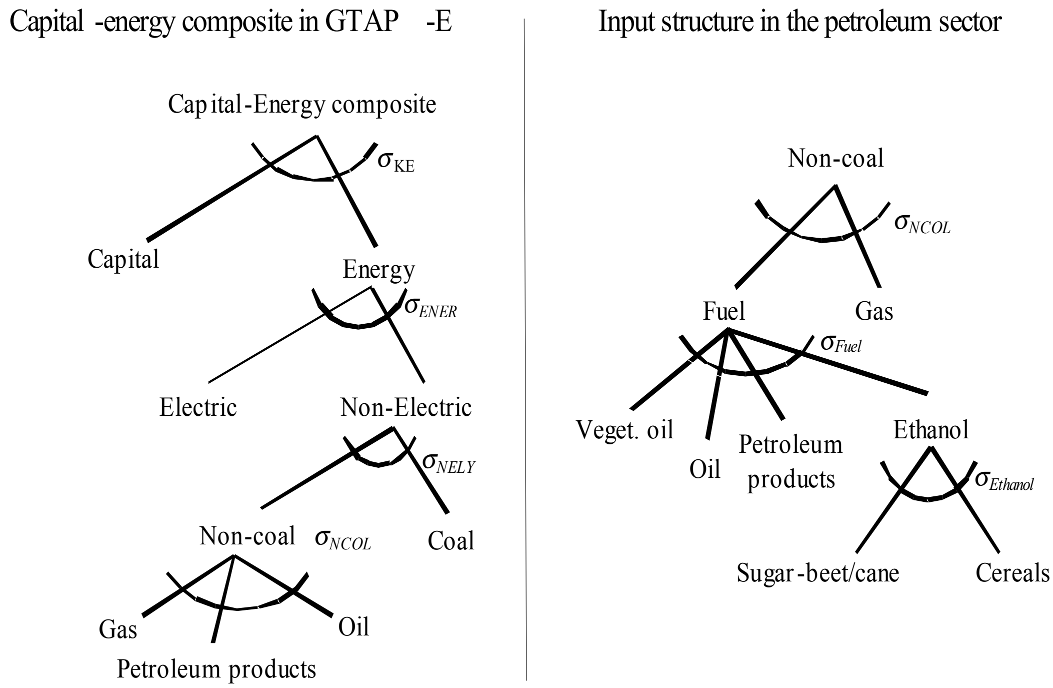
3 For further information and an application of the extended LEITAP model see also Banse et al. [2008].

4 The underlying technologies for the other bio-based sectors are outlined and discussed in part II of the study.

differently compared to the approach applied under the GTAP-E model (Figure 3, right panel). The non-coal aggregate is modelled in the following way: 1) the non-coal aggregate consists of two sub-aggregates, fuel and gas; 2) fuel combines vegetable oil, oil, petroleum products, and ethanol; and 3) ethanol is made out of sugar beet/sugar cane and cereals.[5]

This approach models an energy sector where industry's demand of intermediates strongly depends on the cross-price relation of fossil energy and biofuel-based energy. Therefore, the output prices of the petrol industry will be, among other things, a function of fossil energy and bio-energy prices.

Figure 3 **Nesting structure in energy modeling for liquid petrol.**




The nested CES structure implies that necessary variables in the demand for biofuels are the relative price developments of crude oil versus the development of agricultural prices. Also important is the initial share of biofuels in the production of fuel. A higher share implies a lower elasticity and a larger impact on the oil markets. Finally, the values of the various substitution elasticities ($\sigma_{Fuel}$ and $\sigma_{Ethanol}$) are crucial. These represent the degree of substitutability between crude oil and biofuel crops. The values of the elasticity of substitution are taken from Birur et al., (2007), who – based on a historical simulation of the period 2001 to 2006 – obtained a value of the elasticity of substitution of 3.0 for the US, 2.75 for the EU, and 1.0 for Brazil. This technological tree determines the possibility in a given sector to

5 Ethanol is not modelled as a product for final demand but only as an aggregated composite input in the petrol industry.

substitute for different production factors (labour, capital, land and natural resources) and energy inputs. Apart from the aforementioned elasticities of substitution between these individual inputs or aggregates of inputs, the initial cost shares play an important role in the demand for energy inputs or production factors. If a sector has only a small initial cost share, even strong shifts in relative price will not cause drastic shifts in the composition of intermediate inputs. As an example, if the initial share of bio-based inputs in a sector is relatively small it will also remain small, even under strong shifts between fossil and bio-based input prices.[6]

In addition, prices for outputs of the petroleum industry will depend on any subsidies/tax exemptions affecting the price ratio between fossil energy and bioenergy. Finally, and most important for current bioenergy policies, the level of demand for bio-based output will be determined by any enforcement of national targets through, for example, mandatory inclusion rates or the provision of input subsidies to the bio-based industries.

In this study biomass policies are modelled as mandatory blending obligations fixing the share of bio-based inputs in transport fuel, natural gas, electricity and chemicals. It should be mentioned that this mandatory blending is budget neutral from a government point of view. To achieve this in a CGE model two policies were implemented. First, the share of biomass inputs in the bio-based industries are specified and made exogenous such that it can be set at a certain target. An input specific subsidy on biomass is specified endogenously to achieve the necessary biomass share. The input subsidy is needed to change the relative price ratio between biomass and fossil energy inputs. If the bioenergy share is lower than the target, a specific subsidy on biomass inputs is introduced to make them more competitive. Second, to implement this incentive instrument as a 'budget-neutral' instrument, it is counter-financed by an end-user tax on consumption of output from bio-based sectors. The end-user taxes on bio-based products are made endogenous to generate the necessary budget to finance the subsidy on biomass inputs necessary to fulfil the mandatory blending. Due to the end-user tax, consumers pay for the mandatory blending as end-user prices of blended petrol, electricity, gas or chemicals increase. The higher price results from the use of more expensive biomass inputs relative to fossil energy inputs in the production of bio-based products.

### 2.2.2 Assumptions for different scenarios

One of the main goals of this study is to show the consequences of different degrees of biomass use in the Dutch economy, under alternative technology assumptions and different degree of openness. The macro-economic model has to be adjusted to represent these differences between the scenarios.

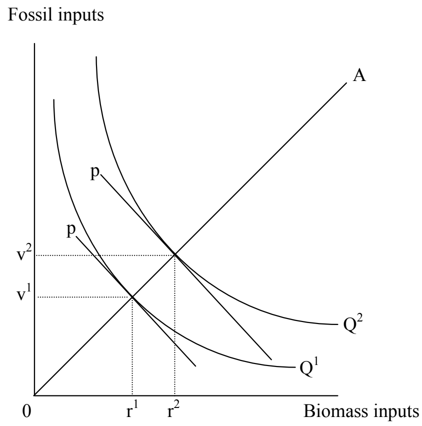
6 This feature of the macro-economic model applied for this study will be discussed further below. The initial data base and the adjustments we applied to it are outlined in part II of the report.

In terms of **openness**, we vary the trade elasticities (Armington elasticities) which determine the degree that domestic producers/consumers react to changes in the ratio of domestic and international prices. Under the 'National' scenarios we apply lower values while under the 'International' scenarios the level are doubled compared with those applied for the 'National' scenarios. The higher trade elasticities under the 'International' scenario will lead to a stronger increase in imports if domestic demand expands.

**Alternative technologies** (LowTech vs. HighTech): The main difference between the HighTech and the LowTech scenarios is the different degree of the substitutability between biomass and fossil inputs in the bio-based industries. We assume that under the LowTech scenario production of the bio-based industries is mainly based on current ($1^{st}$-generation biomass) technologies, while under HighTech scenarios the use of $1^{st}$-generation biomass is mainly substituted by $2^{nd}$-generation biomass. Therefore, we assume that under the LowTech scenarios mainly 1st-generation biofuels than can be substituted with fossil fuels based on a technology with relatively low efficiency of biomass conversion which is a consequence of low elasticities of substitution between biomass and fossil inputs, and the assumption of 'neutral' technical progress. However, especially under the LowTech scenarios, the efficiency of biomass conversion is assumed to be low, which leads to a relative low elasticity between fossil and biomass energy inputs and consequently also to low cost shares of biomass inputs in the bio-based industries.

Apart from the assumption of the higher degree of substitutability of biomass with fossil inputs under the HighTech scenario we also assume that the conversion efficiency is higher compared with the LowTech scenarios. This is implemented in the macro-economic model by different assumptions on the rate of input augmenting technical progress. Under the LowTech scenario we assume that the technical progress is 'neutral' without affecting the composition of intermediate demand in different sectors. A graphical presentation is given in the following Figure 4. In the initial situation a bio-based industry produces the output $Q^1$ (illustrated by the isoquant $Q^1$) with a mix of fossil and biomass inputs of $v^1$ and $r^1$, respectively. The quantity of demanded inputs is determined by the price ratio of fossil and biomass input, p.

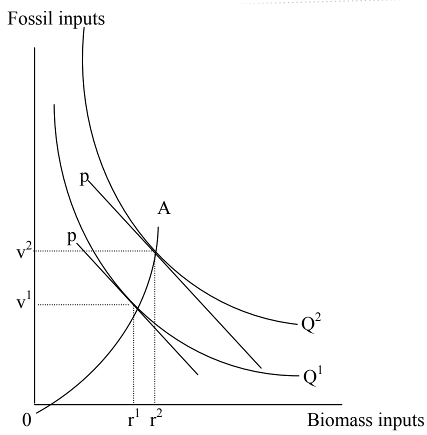
**Figure 4** Technical Progress in the Bio-based Industry under LowTech Scenarios




Under the assumption that p remains constant, technological progress will shift the isoqant $Q^1$ to $Q^2$ with a new a mix of fossil and biomass inputs at $v^2$ and $r^2$. The assumption of neutral technological progress is described by a linear 'expansion path' of this industry as the straight line 0A. Therefore, under these assumptions, technical progress in bio-based production will not affect the mix of biomass and fossil inputs.

Under the HighTech scenarios this assumption is dropped, and technical progress is input -saving for biomass inputs in the bio-based sectors. Starting from the same initial situation of production level $Q^1$ with $v^1$ and $r^1$ as the input quantities demanded, technological growth is now input-saving for biomass inputs, i.e. a higher conversion rate for biomass inputs in the bio-based economy. Under $Q^2$ the optimal input combination is $v^2$ and $r^2$, but the ratio between both types of inputs altered. The expansion path A of this industry is now a non-linear path 0A.

**Figure 5** Technical Progress in the Bio-based Industry under HighTech Scenarios




To identify the effect of an enhanced use of biomass inputs we also run all four scenarios without a mandatory blending obligation for biomass use in the bio-based industries, i.e. petrochemicals, electricity and chemicals. It should be mentioned that even without a mandatory blending the use of biomass inputs changes due to changes in relative prices (biomass crops vs. fossil fuel). Especially in the HighTech scenarios it can be assumed that the required subsidies for the biomass use will strongly decline due to the high technological progress we assume for these scenarios.

## 2.3 Integration of the LEITAP projections into the bottom-up model

The results of the bottom-up study, as in the bottom-up reports, includes projections of energy demand and growth in the chemical industry sectors based on the WLO scenarios as displayed in Figure 1. For this report, the projection results of the top-down LEITAP are translated into physical input parameters for the bottom-up model. This section describes how the data is translated from monetary outputs of the LEITAP model to physical input parameters. The results of the synthesis of both models are presented in section 3.

### 2.3.1 Transport fuels

Figure 6 Biofuels in the bottom-up scenarios (left bars) and the top-down scenarios (right bars)

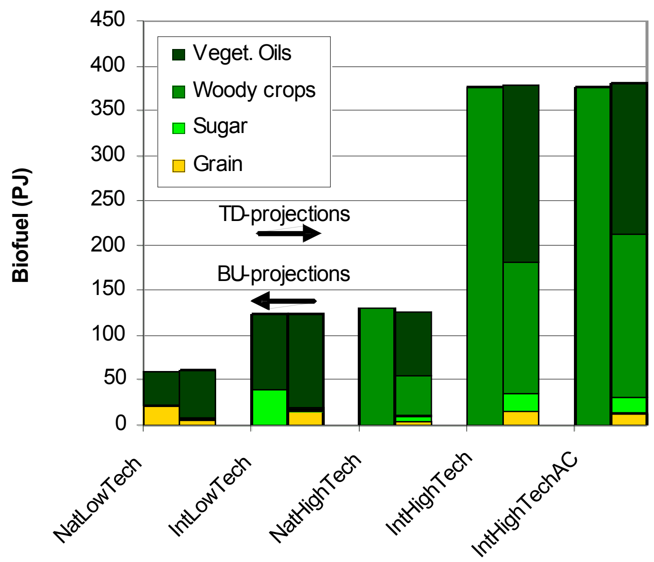
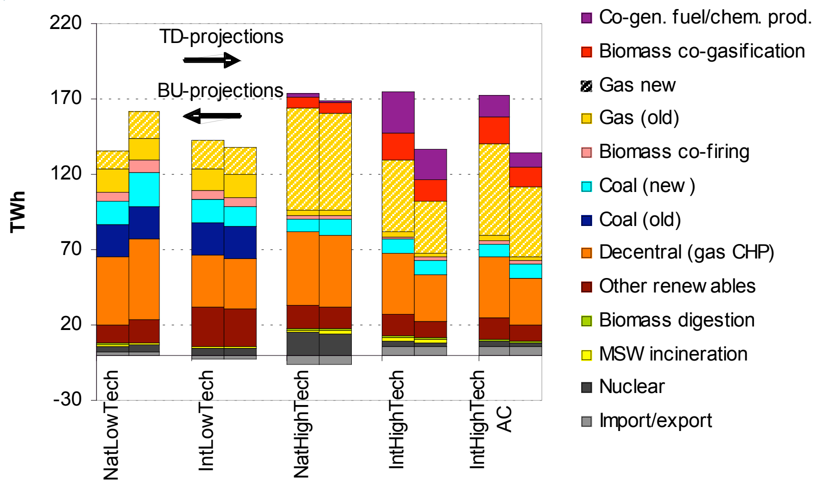



Figure 6 displays the projections of biofuel per feedstock type. The bars on the right summarise the results of the LEITAP projections, the bars on the left summarise the results of the bottom-up projections based on the WLO scenarios. There are two important differences between these projections. The results of the HighTech scenarios of the bottom-up study, only include transport fuels from lignocellulosic feedstock whereas the LEITAP projections still include a large share of oil crops and some sugar and starch crops. Furthermore, the total production of biofuels in the LowTech scenarios and the NatHighTech scenarios is 14-35% higher in the LEITAP projections as a result of the higher demand for transport fuels relative to the WLO projections used for the bottom-up results. For this report, both the final demand as the shares of crop types of the LEITAP results are integrated in the bottom-up model. All sugar crops are assumed to be sugar cane, while the ratio for ethanol and FT-diesel from woody biomass is assumed to be similar to the initial bottom-up projections.

### 2.3.2 Electricity

Figure 7 presents the results of the bottom-up and LEITAP projections for electricity generation. Note that the results of the LEITAP projections are translated into physical units to make the results comparable. The replacement of retired existing capacities is assumed to be similar to the bottom-up scenarios (section 3.2 of the bottom-up report). The final demand is based on projections of the LEITAP model and, apart from the NatLowTech scenario, is lower than the WLO projections, which are used for the bottom-up results. Also co-production of electricity is slightly lower in the top-down projections as these scenarios include more 1st-generation technologies for biofuel production without co-generation of electricity (Figure 6).

**Figure 7** Electricity generation in the bottom-up scenarios (left bars) and the top-down scenarios (right bars)

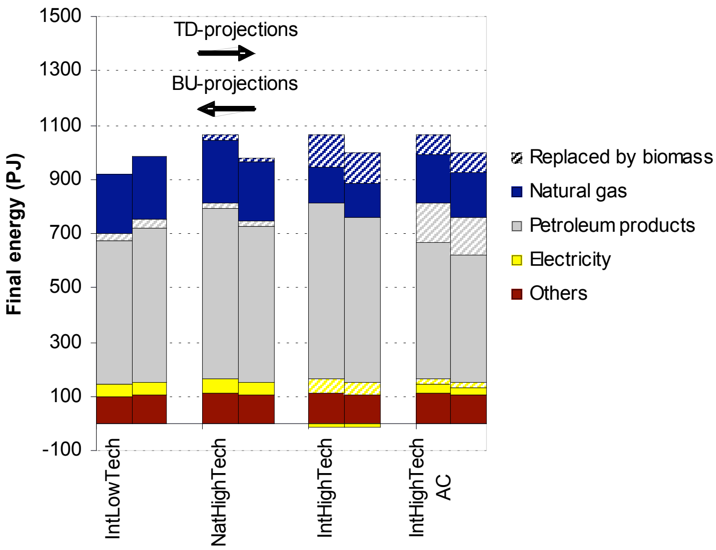



### 2.3.3 Chemicals

For chemicals, the projected growth of the chemical industries is used to estimate the demand for energy and biomass in the scenarios. Figure 8 shows the size of the chemical industries as projected using the WLO scenarios (left bars) and the LEITAP projections (right bars). The variation between the scenarios is much larger for the WLO-based bottom-up scenarios than the LEITAP projections. This is mainly the result of efficiency improvements in the high-tech scenarios and different socio-economic assumptions[7].

7 GDP and population growth are equal for all LEITAP scenario projections. In the WLO scenarios, these parameters vary significantly over the four WLO scenarios.

Figure 8 Final energy demand of the chemical industry sectors in the bottom-up (left bars) and top-down (right bars) scenarios




The projections of the LEITAP model for biofuels, electricity generation and chemicals (Figure 6 through Figure 9) are integrated into the bottom-up model to generate the results of section 3. The initial results, based on the WLO projections, are also included for comparison.

In general, the projections for energy demand in the LEITAP results are higher for the NatLowTech scenario and lower for the other scenarios. This is particularly true for electricity demand and energy demand in the chemical industries of the IntHighTech scenarios. The total demand for bioenergy and the total amount of fossil energy and GHGs avoided is therefore in the IntHighTech scenarios as covered in section 3.

# 3 RESULTS OF THE BOTTOM-UP PROJECTIONS (PART I)

This section presents the results of the bottom-up model which are based on both the WLO scenarios and on the output of the LEITAP model for 2030. The bottom-up report includes a detailed discussion of the results with the WLO projections for 2010 and 2020.

The bio-based production of electricity, transport fuels and chemicals ranges from 74 PJ in the NatLowTech scenario to 680 PJ in the IntHighTech scenario (Figure 9). Although production of bio-based chemicals is higher in the IntHighTech AC scenario, the total bio-based production is lower in this scenario as a result of the lower share of bio-based synthesis gas and related co-production of electricity. The total avoided primary energy is therefore also 10% lower in the IntHighTech AC scenario than in the IntHighTech scenario (Figure 14). The results of the LEITAP projections (Figure 10) are higher for the NatLowTech scenarios because of the higher demand for electricity (Figure 7) and related co-firing of biomass in this scenario. The total production of bio-based electricity is lower in the IntHighTech scenarios of the LEITAP projections because for these scenarios it is assumed that 1st-generation technologies are still used for the production of biofuels (Figure 6).

**Figure 9** Bioenergy and bio-based chemicals in the scenarios in 2030, WLO projections

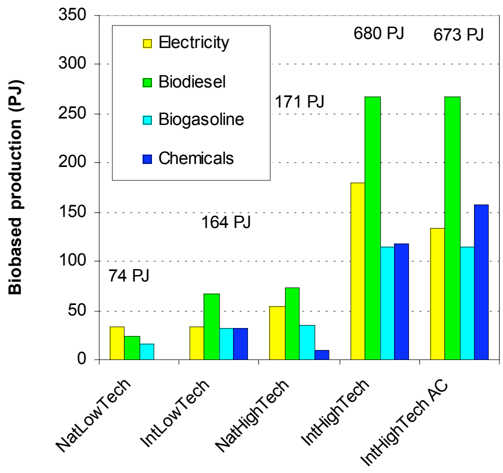



**Figure 10** Bioenergy and bio-based chemicals in the scenarios in 2030, LEITAP projections

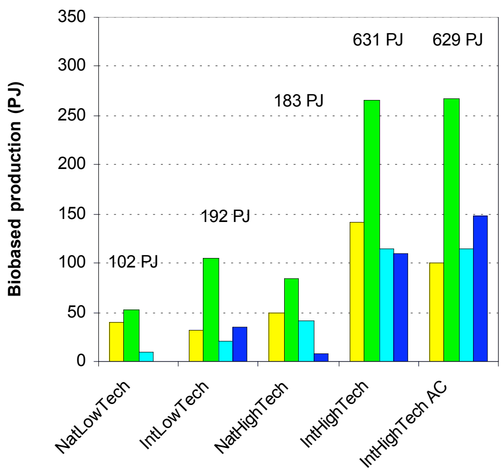


Figure 11 Required biomass from residues and energy crops per sector in 2030, WLO projections

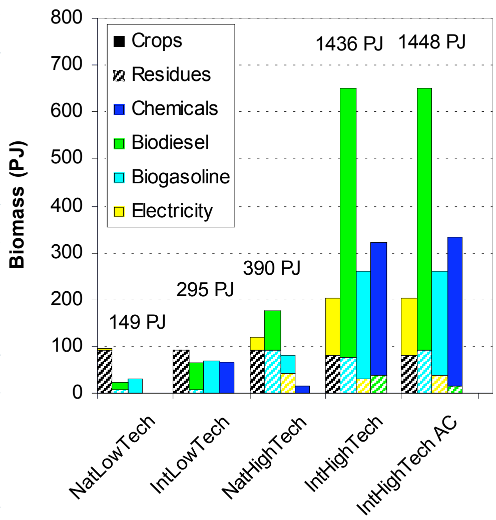
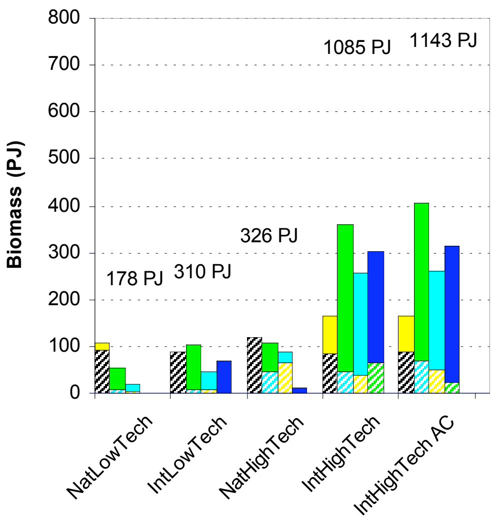



Figure 12 Required biomass from residues and energy crops per sector in 2030, LEITAP projections




The required biomass for bioenergy and bio-based materials in the NatLowTech scenario can almost entirely be met by domestic residues. For the production of biofuels, energy crops are required as 1st-generation technologies in this scenario limit the use of residues for biofuels to fat and oil residues. In the IntLowTech scenario, a 10% higher blending share for biofuels and the production of bio-based chemicals (bulk C2) increases the required biomass to almost 300 PJ. Although blending shares for biofuels are similar in the IntLowTech and the NatHighTech scenario, the lower conversion efficiency of FT-diesel in the IntHighTech scenario relative to biodiesel from vegetable oil in the IntLowTech scenario explains the higher demand for biomass in the NatHighTech scenario. The difference between the two IntHighTech scenarios is limited. For the IntHighTech AC scenario, more biomass is required to produce bio-based chemicals (Figure 11). The result of the projections based on the LEITAP-scenarios (Figure 12) indicates that less biomass is required for the HighTech scenarios. Biodiesel from vegetable oil requires less biomass in terms of energy than biofuel from lignocellulosic biomass. Part of the higher demand for lignocellulosic biomass is compensated by co-production of electricity which is higher in the results of the WLO-based bottom-up projections.

The greenhouse gas (GHG) emission reduction due to substituting fossil energy with biomass ranges from 8 Mton $CO_2$ eq. in 2030 for the NatLowTech scenario to 56 Mton $CO_2$ eq. in the IntLowTech scenario. The total avoided GHG emissions in the IntLowTech scenario and NatHighTech scenario were almost identical (Figure 15). Although advanced biodiesel production (FT synthesis) improved the mitigation potential of transport fuels, there was little difference in the GHG mitigation performance of ethanol from sugar cane and lignocellulosic biomass[8]. Despite the use of more efficient electricity generation technologies (co-gasification), the

8 It should be noted though that the effect of indirect land use change was not taken into account.

difference in GHG emissions avoided for the IntLowTech and NatHighTech scenario was limited because biomass replaced mainly carbon-intensive coal in the low-tech scenarios, while for the high-tech scenarios, relatively clean gas technologies were assumed to be replaced by biomass. The projections, based on the LEITAP results show a difference of ~10 Mton for $CO_2$ mitigation in 2030 (Figure 14) as a result of the lower demand for electricity, but mainly due to the moderate environmental performance of biodiesel from vegetable oil still used on a large scale in these scenarios.

**Figure 13** Avoided non-renewable primary energy by biomass in the scenarios in 2030, WLO projections

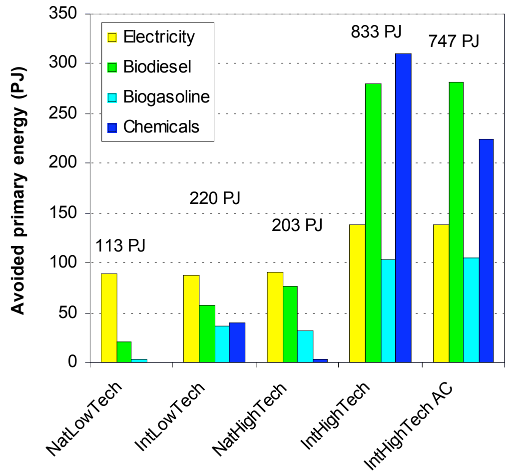



**Figure 14** Avoided non-renewable primary energy by biomass in the scenarios in 2030, LEITAP projections

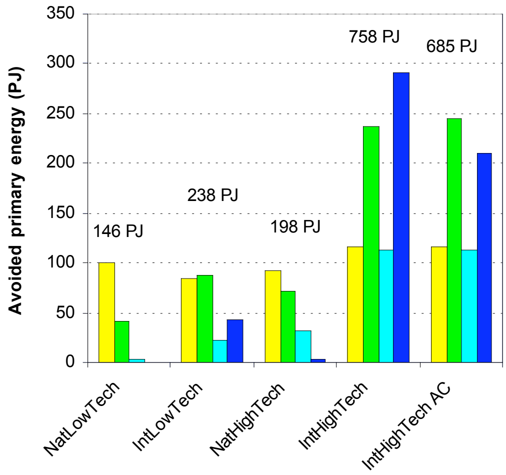



**Figure 15** GHG emissions avoided per scenario in 2030, WLO-projections

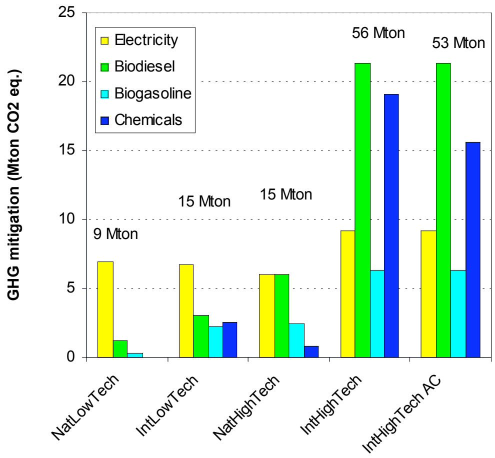
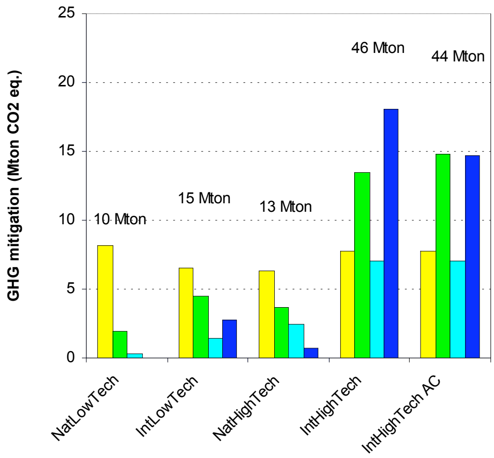



**Figure 16** GHG emissions avoided per scenario in 2030, LEITAP-projections




The total expenditures for bioenergy and bio-based chemicals range from 1,073 M€ in the NatLowTech scenario to 9,655 M€ in the IntHighTech AC scenario in 2030. Costs for biofuel production from vegetable oil and sugar/starch crops are dominated by feedstock cost as, especially for biodiesel from vegetable oil, few conversion processes are required to produce biodiesel. The additional costs for substitution of fossil fuels with biomass depend on the difference between the fossil reference[9] technologies and the biomass substitutes and ranged from 300 M€ in the NatLowTech scenario to 2,731 M€ in the IntHighTech scenario (Figure 17). Figure 19 shows the additional cost projections based on the LEITAP scenarios. These are over 1000 M€ lower than in the bottom-up projections based on the WLO projections as a result of 1st-generation biofuels that are still used on a large scale in these projections. The additional costs for bio-based production are lower in the IntHighTech AC scenario than in the IntHighTech scenario because production costs of both bio-based specialty chemicals (such as bulk C2 chemicals) are closer to, or even lower than, the fossil-based variant than bio-based synthesis gas. It should be noted that the additional costs are sensitive to fossil fuel prices. If fossil fuel prices (crude oil, coal and natural gas) increase by 50%, biomass is already competitive in the international scenarios, and limited additional costs are made for the production of electricity and FT-diesel (Figure 18). It should be noted, however, that the bottom-up model is limited in reflecting higher fossil fuel prices. The model does not include cost escalations for higher fossil energy prices that also result, for example, in increased costs of energy crop production and capital costs of bioenergy technologies that are also linked to fossil fuel prices. The projections in Figure 18 might therefore be too optimistic.

**Figure 17** **Additional cost for bio-based substitution in the scenarios in 2030.**
**Oil price = 50 US$/bbl, coal = 2€/GJ,**

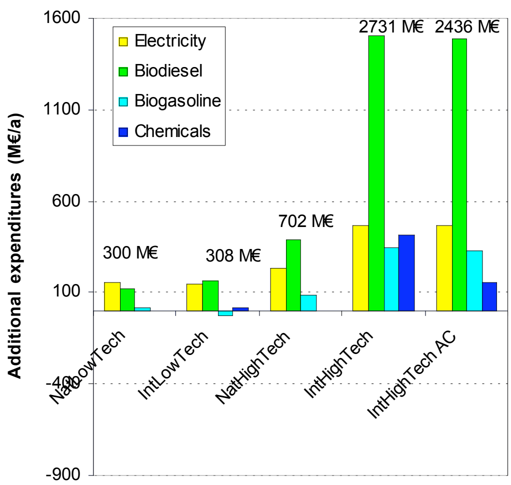
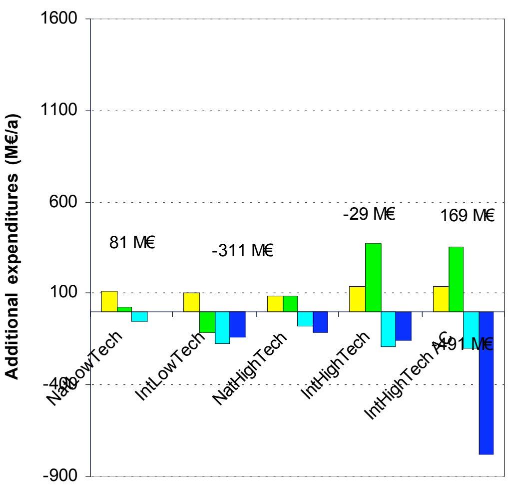



**Figure 18** **Additional cost for bio-based substitution in the scenarios in 2030.**
**Oil price = 75 US$/bbl, coal = 3€/GJ,**




GHG mitigation costs differ per scenario as a result of different biomass conversion technologies used and their techno-economic performance. Mitigation costs, with fossil fuel prices as in Figure 17, are estimated to be 19 €/tonne $CO_2$ eq. in 2006 and increase to 35 €/tonne $CO_2$ eq. in the NatLowTech scenario in 2030. This increase is mainly the result of the poor mitigation performance of biodiesel from rapeseed and

9 Oil price = 50 US$2006/bbl, Natural gas price = 6 €/GJ and coal price = 2 €/GJ.

starch crops. Lower feedstock prices and better GHG mitigation performances of biodiesel from palm oil and jatropha oil and ethanol from sugar cane result in mitigation cost of 21 €/tonne $CO_2$ eq. in the IntLowTech scenario in 2030. The mitigation costs are highest in the high-tech scenarios, with 46 €/tonne $CO_2$ eq. for the NatHighTech and IntHighTech AC scenarios and 49 €/tonne $CO_2$ e for the IntHighTech scenario. The main reasons for the higher mitigation costs in the high-tech scenarios are better environmental performances of the reference technologies for electricity generation[10] and the use of advanced and capital intensive conversion technologies.

The results based on the LEITAP projections (Figure 19 and Figure 20) already indicate that, if optimised for costs, biodiesel production from palm oil or jatropha and imported ethanol from sugar cane from Brazil is cheaper than the production of FT-diesel and ethanol from lignocellulosic biomass. The mitigation costs of the LEITAP projections for 2030, based on an oil price of 50 US$/bbl, are estimated to be 50-52 €/tonne $CO_2$ eq. in the NatLowTech and NatHighTech scenarios, 27 €/tonne $CO_2$ eq. for the IntLowTech scenario and 36 – 38 €/tonne $CO_2$ eq. for the IntHighTech scenarios. It should be noted, however, that the costs of vegetable oils, in particular, are sensitive to fluctuations in supply and demand which could increase costs again.

10 Biomass co-gasified in NGCC plants replaces natural gas with relatively low GHG emissions, while biomass replaces carbon-intensive coal in the low-tech scenarios.

# 4 RESULTS OF THE TOP-DOWN PROJECTIONS (PART II)

The macro-economic analyses results cover impacts of the different bio-based scenarios on the Dutch trade balance, GDP, sectoral effects (in particular agriculture, energy and chemical), employment, all compared to the baseline development where only a low share of biomass use (mainly for energy) is included. To summarise, the following conclusions can be drawn from the results of the quantitative analysis:

- All bio-based scenarios have a positive effect on the trade balance of the Netherlands. In 2030 the net (positive) impact compared to the baseline developments simulated by LEITAP are about 2000 (LowTech scenario) to 4000 (HighTech scenario) million € per year.
- Imports of biomass (and biofuels, especially ethanol; depending on the scenario) are substantial, varying between over 2600 million € (NatLowTech) up to 7400 (IntHighTechAC) million € annually. South America,[11] in particular, is a likely major supplier.
- The production of biomass used in the Dutch bio-based economy varies in value between some 180 Million € (IntLowTech) and almost 720 million € (IntHighTechAC). This is substantial, but also reflects the relatively modest role of national biomass resource production compared to imports.
- In terms of employment generated, the share of employers working in the bio-based 'part' of the bio-based sectors (fuel, electricity and fine chemicals), the total employment in these three sectors remains relatively stable over the projected period, but the increasing share in employment in the 'bio-based part' indicates a growing importance of the bio-based economy for those sectors. The results show that, with a shift towards a bio-based economy, agricultural employment will continue to decline. However, a growing demand for biomass will slightly dampen this structural change in agriculture.
- The macro-economic modelling results confirm the large shares of 1st-generation biofuels for the LowTech scenarios as defined by the bottom-up approach. The use of lignocellulosic biomass (both for fuels and for biomaterials) covers over half the total demand for the HighTech scenarios in 2030.
  - This result, different from the bottom-up scenarios, where this share is even higher, is explained by the incorporation of continuous functions in the modelling framework that basically take into account the lifetime of investments and reasonable rates of change in production capacity over time.

11 An important difference between the top-down model and the bottom-up model is that there is no absolute restriction for the NatLowTech and NatHighTech scenarios to use only biomass from EU27+ sources. The lower trade (Armington) elasticities in the national scenarios decrease imports of biomass. Nevertheless, there will still be trade with non-EU countries. Furthermore, imported biomass is also used for other purposes than energy or chemicals (e.g. food or feed).

  - With the base scenario assumptions, the share of lignocellulosic based biomass applications would increase further after 2030 and overall costs would go down. Furthermore, this share is sensitive to the rate of technological progress (learning) of new technologies. A more conservative progress would lead to lower shares and vice versa.
- Required support levels to ensure the realisation of the projected shares of biofuel shares in the different scenario's differ strongly between the scenarios (following data are all versus a reference oil price of 75 U$/bbl (in 2006 US$):
  - The NatLowTech scenario requires (for a modest share of 10%) a subsidy of about half a billion per year (and around 0.40 €/litres of biofuel).
  - IntLowTech this is reduced to 350 million € annually and 0.12 €/litres of biofuel for a 20% share (especially due to cheaper imports such as ethanol). Costs increase again for the NatHighTech scenario (due to higher feedstock costs).
  - IntHighTech achieves the 60% share of biofuels in 2030 with some 300 million € per year subsidies (and a low 0.034 €/litres biofuel subsidy). This subsidy is only required for the 1st-generation biofuel part and to some extent for 2nd-generation biodiesel; in this scenario competitive production costs are achieved for 2nd-generation ethanol production, given the technology assumptions and base oil price of 75U$/bbl.
  - In addition to the IntHighTech scenario, the IntHighTechAC scenario includes bio-based production of natural gas and petroleum products and in both the specialty and bulk chemical industries. Under the (extreme) high blending shares assumed under IntHighTechAC imports of biomass is projected to increase to more than 5 billion € with most of imports from South American countries. Additional income and employment under the IntHighTechAC scenario is mainly created in the petrol sector; while around ¼ is generated in the in electricity and chemical sectors.
  - These results are highly sensitive to the oil price; with lower oil prices, required support increases and vice versa. In addition, the scenarios assume a fixed (and high) diesel demand in the transport sector. When this could be replaced by 2nd-generation bioethanol or cheaper synfuels than Fischer-Tropsch diesel (such as methanol or DME), costs would go down and be competitive at the 75 U$/barrel reference oil price. This implies, however, also more adjustments investments in the transport sector (e.g. engine adjustments, fuel distribution).
- Shares of additional income across the bio-based industries in 2030 for the IntHighTech Scenario) due to biomass expansion amount 19% for electricity production using biomass, 78.5% for production of biofuels and, 2.5% due to the production of the assumed biomass derived chemicals.

# 5 DISCUSSION

This section covers the discussion of the results of the top-down and bottom-up projections and the used methodology to link these models. Part I and part II of this study discuss the individual results. The emphasis of this discussion section is on a comparison of the bottom-up and top-down results (5.1) and the methodology of linking the bottom-up with the top-down model and potential improvements that can be made to improve consistency between the models (5.2).

## 5.1 Results

The results, presented in detail in part I and part II of this study, include a set of bottom-up and top-down projections of biomass for bioenergy and bio-based materials, the (macro) economic impact, the required resources and the avoided fossil energy and greenhouse gas emissions. The results of the bottom-up and top-down projections are compared for biomass use, i.e. the total biomass required to generate bioenergy and bio-based chemicals, the produced bioenergy and bio-based materials and bio-based materials and the additional costs/benefits. Although the bottom-up and the top-down projections are generated for similar biomass blending targets, the difference in modelling approaches results in different outputs.

The top-down results are expressed as total expenditures or sales for inputs and outputs per sector (in M$ weighted indices). The mix of goods produced in sectors is aggregated to a total value. These can be disaggregated for the baseline year for which statistical data on physical quantities (e.g. kton, PJ) and technology portfolios are available. For top-down projections however, difficulties arise in disaggregating as both quantitative as qualitative changes are implicit to the total economic growth or decline in each sector. The translation of the bottom-up projections in monetary units back to physical quantities that are used for the bottom-up model is therefore partly based on the baseline situation for which both physical and economic data is available. The bottom-up results that are based on the LEITAP projections therefore still include data from the WLO scenarios (e.g. diesel/petrol ratio, electricity generation technologies) as these could not be derived from LEITAP. A further disaggregation of sector/commodities in the top-down model would improve the exchangeability of data between the bottom-up and top-down models.

### 5.1.1 Biomass use in the models

Both the top-down and the bottom-up model include a range of similar biomass energy crops for bioenergy and bio-based materials. The main difference between the models is that the bottom-up model also includes a detailed set of residues from domestic sources. The bottom-up projections show that a significant share, ranging from 15% in the IntHighTech scenarios to almost 70% in the NatLowTech scenario, can be met by domestic residues as displayed in Figure 11. The integration of biomass options from (domestic) residues would decrease the demand for dedicated crop production resulting in lower bio-based production costs and required imports

of biomass for bioenergy and bio-based materials.
The biomass required for the production of transport fuels as projected with the top-down model for 2030 ranges from 100 PJ in the NatLowTech scenario to around 360 and 455 PJ for the IntHighTech and the IntHighTech AC scenario respectively (Figure 13 in report II). It should be noted, however, that part of the bio-based ethanol in the IntHighTech AC scenario substitutes naphtha for ethylene production rather than petrol for road transport. For the bottom-up projections, we projected the demand for transport fuel to be 910 PJ in the IntHighTech scenarios in 2030. The difference in demand can be explained by the use of 1st-generation conversion options in the top-down model, whereas all transport fuels are produced from lignocellulosic biomass, with lower conversion efficiencies, in the bottom-up projections (42% in the bottom-up scenarios) relative to biodiesel from vegetable oil (~100%). For the HighTech bottom-up scenarios, it was assumed that 2nd-generation biomass conversion technologies would substitute 1st-generation technologies from 2010 onwards to achieve a 100% market share in 2030. Figure 12 shows that if the bottom-up model uses similar shares of 1st and 2nd-generation biofuel production technologies, the demand for biomass for transport fuels is 620 PJ in the IntHighTech and 670 PJ in the IntHighTech AC scenario.

As discussed above and in part II of this study, the applied macro-economic model does not allow a sudden shift from one technology to another, and the shift to advanced technologies might require a longer transition period (as assumed for the bottom-up scenarios). Comparing the outcome of the top-down, macro-economic model with the estimate of the bottom-up approach one could expect a larger share of 2nd-generation biomass, especially for the HighTech scenarios in the bottom-up scenarios as only a limited delay in transition is assumed. Under the IntHighTech scenario 1st-generation biomass (oilseeds) still contributes for a significant part to total biomass use in the petroleum industry in the top-down model. This outcome is explained by the underlying technology assumption of the LEITAP model. Due to the fact that technology changes follow a path of substituting an existing technology (based on 1st-generation biomass) with a new and modern one (based on 2nd-generation biomass) the model seems to react a bit 'sticky'. Thus, LEITAP does not allow for drastic changes in the composition of the feedstock in the biomass sector.[12] Thus, even in the IntHighTech scenario, 1st-generation biomass crops such as oilseeds continue to contribute to biofuel production at a significant level. Based on the economic model applied for this study the achieved results indicate that an economy fully based on 2nd-generation biomass inputs would require a longer timeframe for adjustment.

12 Other modelling approaches such as a linear-programming model would allow for these immediate shifts in the mix of 1st and 2nd-generation biomass. However, these modelling approaches would neglect other important features such as the endogenous development of relative prices between different inputs.

Due to the remaining use of 1st-generation biomass crops, even under the HighTech scenario some subsidies are still necessary to meet the blending target.
The ‘persistent’ contribution of 1st-generation biomass also has consequences for the calculation of social costs of an enforced utilisation of biomass crops in the bio-based industries (see Table 1 in part II).
It should be noted though that also bottom-up optimisation models, e.g. Biotrans (Londo et al. 2008), show 1st-generation crops still to have a major share[13] for road transport fuels in Europe in 2030. The bottom-up assumptions on technology substitution in the High-tech scenarios might therefore be too drastic.

### 5.1.2 Costs of bio-based substitution

The additional costs of substituting fossil energy carriers with biomass are expressed in the top-down mode by subsidies required. These are projected for transport fuels to be 578 M€ in the NatLowTech scenario, 346 M€ in the IntLowTech scenario, 828 M€ in the NatHighTech scenario and 293 M€ in the IntHighTech scenario. These results show the sensitivity of the model to international trade barriers, but also to technological development. If we compare these projections with the additional costs of the bottom-up projections (Figure 17 through Figure 20), required subsidies are mainly for FT-diesel. This can be explained by the high demand for diesel whereas costs for FT-diesel production are also higher than conventional diesel at crude oil prices of 50-75 US$/bbl. Furthermore, the top-down model does not include additional capital and O&M cost required for 2nd-generation technologies. The subsidy levels, as projected with the top-down model are therefore expected to be too optimistic for the HighTech scenarios that include advanced and capital intensive conversion technologies.

## 5.2 Methodology

This study is built on a new and innovative approach that links the results of a bottom-up approach with the outcome of a macro-economic, general equilibrium model to analyse the impact of an enhanced use of biomass inputs in the bio-based sectors of the Dutch economy. This approach combines the details of a technology-based analysis with the complexity of a model which enables to trace the impact of changes in relative prices for the overall economy.

The results – presented in part I and II of this study – shows the need for this kind of integrated assessment of a move towards a more bio-based oriented economy which is built on various uncertainties, e.g. availability of large-scale technologies or the development of crude oil prices. The approach of linking bottom-up engineering models and macro-economic top-down models is not new, and numerous efforts are being made in order to combine the strength of these modelling approaches. For example, the bottom-up linear optimisation model MARKAL (MArket ALlocation) is coupled to (among others) the CGE model MACRO

13 Depending on scenario conditions.

[Messner et al., 2000], TIMES and GEMINI-E3 [Loulou, 2005] and EPPA [Schäfer and Jacoby, 2005]. Introducing bottom-up engineering data in a top-down model is also reported by McFarland et al. [2004] and Faber et al. [2007]. However, developing scenarios with a top-down model and imposing these detailed scenarios in an extended CGE model for multi-sector and large-scale deployment of biomass is innovative.

The models were linked by imposing blending shares of biomass in the sectors electricity, road transport fuels and chemicals. The final LEITAP model results were integrated into the top-down model to enhance the consistency between the models. However limited calibration steps were conducted in order to achieve full consistency between the models. We planned more iterative feedbacks between the two different models, which would also help to calibrate the productivity growth path and the different level of substitution elasticities of the macro-economic model in a better way, but this proved to be infeasible due to time limitations. This could be an area of further research in a follow-up study.

The level of aggregation in the top-down model also limits the possibilities for introducing advanced bio-based conversion options, especially for the chemical industries. For this research, the chemical sector was divided into bulk and specialty chemicals by assuming shares of 80% bulk and 20% specialties as limited data was available, mainly for the structure of the specialty chemical industries. The available bio-based chemicals in this study are limited to three representative options for natural gas replacement (synthesis gas), replacement of base chemicals from petroleum products (ethylene) and direct replacement of functionalised chemicals (caprolactam). Although more advanced biorefinery options could be available in 2030, a full assessment of the macro-economic impact of these technologies and advanced energy crops (e.g. GMO) are beyond the scope of the current model capabilities and this study. Further research with a disaggregation of the chemical industries and petrol sectors [e.g. Choumert, Paltsev et al., 2006] in the LEITAP model supported with detailed bottom-up, physical and economic data on the structure of these sectors could improve the understanding of the macro-economic impact of biomass for the chemical industry sectors.

Full consistency between the top-down and the bottom-up model could be improved by introducing an iteration process with data calibration. Full linkage of the results could provide more understanding of the technological progress and technology substitution and the related cost that are implicit to the top-down projections. Furthermore, the impact on the environment, e.g. biodiversity and spatial land-use effects could be linked to the physical outputs not covered in this study. Therefore, further research is required, which extends the approach of combined assessment of technological and economic with environmental effects.

# 6 CONCLUSIONS

Overall, the results of the work show that pursuing a significant role for bio-based options and value chains in the Netherlands can have major positive impacts on reducing GHG emissions, replacing fossil fuels, as well as economic activity in the agricultural and energy sectors. However, the magnitude of such benefits depend strongly on the development pathway and the strategies followed.

The baseline scenario in this study (NatLowTech) results, in 2030, only in 74 PJ bioenergy and replacing 113 PJ fossil energy. GHG mitigation amounts 9 Mton, with an overall support required of over 300 M€ per year (versus an oil price of 50 U$/barrel). In contrast, the IntHighTech scenario results in the supply of 680 PJ bio-energy (and materials), avoidance of 833 PJ fossil energy (around one-quarter of total national energy use) and 56 Mton of avoided GHG emissions. The latter is more than a quarter of current CO2 emissions from the Netherlands, making a bio-based strategy the largest mitigation option currently considered. Required financial support versus an oil price of 50 U$/barrel amounts to 2730 M€. IntLowTech and NatHighTech give fairly comparable results (both avoid 15 Mton of GHG emissions and the primary energy avoided amounts to over 200 PJ). NatHighTech requires higher support levels, some 700 M€ vs 310 M€ vs. 50 U$ barrel), especially due to the more expensive biomass feedstocks utilised. The IntHighTech AC scenario, including a higher blending share of chemicals (25% vs 19% for the IntHighTech scenario) requires more biomass than the IntHighTech scenario, but mitigates less GHG emissions and primary fossil energy. However, it also requires lower support levels (2430 M€) than the IntHighTech scenario, as bio-based substitutes for petroleum products are more competitive than bio-based substitutes for natural gas.

However, in macro-economic terms the differences between the scenarios are less pronounced for impacts on trade balance (overall positive, more so for the HighTech scenario's) and employment (all positive). Clearly, the support levels needed to realise the different shares of biomass use for electricity, fuels and materials differ strongly between the scenarios, with the (per unit of energy or GHG mitigation achieved) highest economic efficiency for the IntHighTech scenario, followed by the NatHighTech scenario. This stresses the importance of technology development to reduce costs and increase efficiency, and the sensitivity of the results for this factor of the HighTech scenarios. In addition, the sensitivity towards the oil price (fossil energy prices in general) is high: if oil prices move to well over 75 U$ barrel, the IntHighTech scenario becomes fully competitive. This is (to some extent) also true for the IntLowTech scenario (especially compared to imports of sugar-cane-based ethanol and vegetable oils). However, if this is assumed to be is a worldwide trend, price mechanisms would also increase biofuel costs following increasing demand.

Another factor that would make a key difference is the pricing of $CO_2$. Results obtained suggest that mitigation costs lay between 40-50 €/ton $CO_2$ eq avoided in 2030 for all high-tech scenarios (versus an oil price of 50 U$/barrel). This can be considered attractive under the condition that far-reaching targets (20% reduction in 2020 and moving to 50-80% reduction in 2050) are seriously pursued, both in the Netherlands and in Europe as a whole.

Realising high ambitions for a bio-based economy in the Netherlands whilst minimising the required financial support and maximising the macro-economic benefits would require: accelerating technology development with the emphasis on 2$^{nd}$-generation biofuels (feedstock and technology), biochemical options and efficient power generation.
An open market approach, allowing for large-scale imports; this is the only way to achieve high shares of biomass use in the biofuels and bio-electricity sectors.
'Smart' temporisation of implementation over time, following technology development speeds (thus avoiding high levels of financial support for expensive bioenergy options). Stabilising policies that maintain a stable investment climate and that dampen the impacts of inevitable fluctuations in oil and $CO_2$ prices over the coming years. Following such a strategy and subsequently achieving the more ambitious scenarios sketched in this study will result in a situation that public investments needed in the shorter term are compensated by the macro-economic benefits that can be achieved.

Projections of the macro-economic impact of bioenergy and bio-based materials are important for exploring different futures and effects of certain limitations and opportunities. However, a full understanding of the role of biomass as a $CO_2$ and fossil-fuel mitigation option can only be explored for a full set of competing mitigation options such as wind, PV or other type of vehicles, including fuel cells or plug-in hybrids. It should be noted, however, that this would also demand a further disaggregation of the sector/commodities in the CGE model, in combination with the use of a bottom-up dedicated energy optimisation model, such as Markal, using an integral approach.

In relation to biomass and bioenergy conversion technologies, this study was particularly limited when modelling bio-based chemicals. The difference between the IntHighTech and IntHightech AC scenario indicates that the LEITAP model is sensitive to fossil-based substitution of different products. At the same time, the CGE model is limited in representing technologies that produce multiple products such as biorefineries. Other studies indicate that the production of chemicals in biorefineries (via extraction) substantially increases the added value of energy crops and mitigation potential. It would therefore be interesting to explore the potential of this concept in a macro-economic model by increasing the added value for domestic energy crops by using biorefinery concepts, if sufficient data is available.

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# APPENDICES

- Appendix I: Bottom-up scenarios
- Appendix II: Macro-economic scenarios