Air polluting emissions from biofuel and biomass supply chains

Final report BOLK II

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Final report BOLK II

-Confidential-

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Summary

European[1] and Dutch climate and energy policies[2] are currently focussing on reduction of greenhouse gas emissions. The effects of new climate policies on emissions of classical air pollutants in the Netherlands in 2020 are not well known. The Dutch BOLK programme[3] assesses these effects. After a first phase (BOLK I), which was used to identify the main areas of research, the BOLK programme is currently in its second phase (BOLK II) and focuses on several specific research topics related to this question.

The topic within this study is to analyse the emissions of classical air pollutants that will occur in the Netherlands and abroad in 2020 caused by the supply chains of biofuels, biogas and biomass. The end-use emissions by the application of biofuels, biogas and biomass (production of electricity from biomass), are not part of this project but are addressed within other projects within BOLK.

This study analyses the air quality emissions for supply chains given in Table 6 - 1.

Table 6 - 1 Overview of selected chains and their reference.

Bioenergy chains	**Fossil reference**	**BOLK I**	**New in BOLK II**
Biodiesel from rapeseed	Diesel	√	
Biodiesel from palm oil	Diesel	√	
FT diesel from wood pellets	Diesel		√
Ethanol from sugar beet	Gasoline	√	
Ethanol from sugar cane	Gasoline	√	
Ethanol from straw	Gasoline		√
Ethanol from wood pellets	Gasoline		√
Biogas as transport fuel	Diesel		√
Palm oil for heat and power	Natural gas	√	
Wood pellets for electricity	Coal	√	
Biogas for electricity	Natural gas		√

For each chain, the emissions are calculated and expressed per GJ. These emissions are combined with a geographical distribution of activities along the chain, to estimate the emission within regions.

The innovative biofuel supply chains in general perform better on air polluting emissions than the fossil reference supply chains but also compared to the current biofuel supply chains. The supply chains of FT diesel, lignocellulose ethanol from wood and biogas have lower emissions on all air polluting substances than the fossil references and the current ethanol and biodiesel chains. The current biodiesel and ethanol supply chains perform better then the fossil references diesel and gasoline on

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[1] 'Renewable Energy Directive' 'Fuel Quality Directive' as set by the European Commission in 2009

[2] Policy trajectory 'Schoon & Zuinig'

[3] The BOLK program stands for 'Beleidsgericht Onderzoeksprogramma Lucht en Klimaat' – Dutch Policy Research Programme on Air and Climate led by the Netherlands Environmental Assessment Agency (PBL) and financed by the Dutch ministry of Housing, Spatial planning and Environment.

SO_x and $PM_{2.5}$, but worse on NH_3 and PM_{10}. This is mainly caused by emissions in the agricultural part of the current biofuel supply chains (which is often absent with innovative and fossil chains).

Regarding electricity production, the supply chains of biogas and wood pellets have lower air polluting emissions than the coal, natural gas and palm oil supply chains. The palm oil and coal chains have highest air polluting emissions in their supply chain.

When using scenarios of the application of bioenergy in the Netherlands, the total effect on air quality (over the whole supply chain) depends to a large part on which biofuels are used. In general it can be stated that emissions like NH_3 and PM_{10} are higher when bioenergy is used compared to fossil energy for both stationary as biofuel applications. Regarding SO_x and $PM_{2.5}$, the emissions were generally lower or similar.

For NO_x and NMVOC, emissions resulting from bioenergy supply chains were mostly higher for the stationary applications and biofuel scenarios including large contributions of current ethanol chains. For the other biofuel scenarios emissions of NO_x and NMVOC were mostly lower.

Air polluting emissions affect the local surroundings, unlike greenhouse gas emissions that impact the global climate. Compared to the fossil supply chains, a larger part of the bioenergy chains is located in the Netherlands. This has possible positive effects on aspects like employment, security of supply and greenhouse gas emissions savings, but is less positive regarding local air polluting emissions. Connecting the geographical location of the emissions with the size of the emissions showed large parts of the emissions occurring outside the Netherlands, especially for the fossil chains. The overall impact of the use of bioenergy on air polluting emissions resulting from the supply chain in the Netherlands compared to the fossil supply chains is thus negative.

The main conclusion of this study is that the use of bioenergy in the Netherlands has a negative effect on *Dutch* air polluting emissions resulting from bioenergy supply chains. The main reason for this is not that air polluting emissions for bioenergy supply chains are overall higher than for their fossil reference, but that a larger part of the supply chain occurs within the Netherlands.

Influencing air polluting emissions in the supply chain is difficult for the part of the supply chains that occurs outside the Netherlands. Especially the agricultural production and transport emissions are main causes of air polluting emissions, and for several chains larger parts of these emissions occur outside the Netherlands. Current focus on sustainability might have an impact on air polluting emissions due to reductions in the use of fertilizers, transport or process energy. Replacing fossil sources with biomass sources for energy provision during the conversion process is positive from the greenhouse gas emission perspective, but does not directly have a positive effect on air polluting emissions.

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1 Introduction

The project 'Local emissions biofuel scenarios' under the BOLK II programme is a direct follow-up of the 'Quick scan of local emissions from biofuel scenarios', as performed under the programme BOLK I. The main topic is to analyse air polluting emissions resulting from bioenergy supply chain in the Netherlands.

1.1 Objective and approach of the project

This project is a straightforward follow-up to the Quick scan[4] that has been performed in the BOLK Inventory Phase. It will both analyze a broader range of bioenergy supply chains and it will analyze these supply chains in more detail and reckoning with the (technological) changes outside the direct influence of these chains.

The objective of the project is to answer the following question:

"What are the effects of European and Dutch policies[5] on emissions of classical air pollutants in the Netherlands in 2020, resulting from the production, import and supply of bioenergy in the Netherlands?"

To answer this question we perform the following tasks:

- Selection of chains to be analysed;
- Calculating with the use of SimaPro software, SO_2, NO_x, NH_3, NMVOS, PM_{10} and $PM_{2.5}$[6] emissions for a number of bioenergy supply chains and attributing these emissions to geographical locations (the Netherlands, Europe and world);
- Actualisation of the most relevant emission factors in SimaPro (with an impact over 5% on the overall emissions) for all chains. Actualisation focuses on technological and policy developments towards 2020;
- Detailed analysis of fossil reference chains (diesel, gasoline, natural gas and coal) with strong focus on effects in the Netherlands;
- Analysis of the relevant emissions of the non-manure part of co-digestion chains;
- Conclusions regarding the most relevant or remarkable emissions and recommendations for policy makers for possibilities where to address these.

The results of the modelling are not only given in emissions per amount of energy carrier compared to their fossil reference, but the resulting emissions are also combined with the extent to which each chain is applied in 2020. Then, the overall impacts of the use of bioenergy can be estimated. The extent, to which each chain is applied in 2020, is determined in the BOLK II subprojects by CE/TNO (direct emissions

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[4] Koper, M, Hamelinck C. and R. Chifari, 2008: Quick scan local emissions biofuel scenarios. Ecofys final report June 2008, Utrecht, the Netherlands.

[5] Policy trajectory 'Schoon & Zuinig'

[6] In this study PM10 are all particle matter emissions smaller then 10 micrometer, excluding the PM2.5 emissions. These are separated in PM2.5 emissions

of transport fuels) and ECN/TNO (direct emissions of stationary biomass for energy applications). For detailed description on either of these projects, we refer to the final reports of these projects[7].

The project approach is indicated in Illustration 1 - 1. The first step is the selection of chains to be included in the analysis. Several chains were already analysed in the quick scan in BOLK I and these are updated on relevant parts (phase 3). The additional chains are modelled (phase 2) and updated (phase 4) in an iterative manner. Together with modelling the new chains, a short description of the chain will be given to indicate the assumptions made. The co-digestion chain is set up similar to the co-digestion description in the Dutch 'Option document[8]'. After all modelling and updating is finalized conclusions on individual chains are drawn, integration with the other parts of the BOLK II programme is done and recommendations are made.

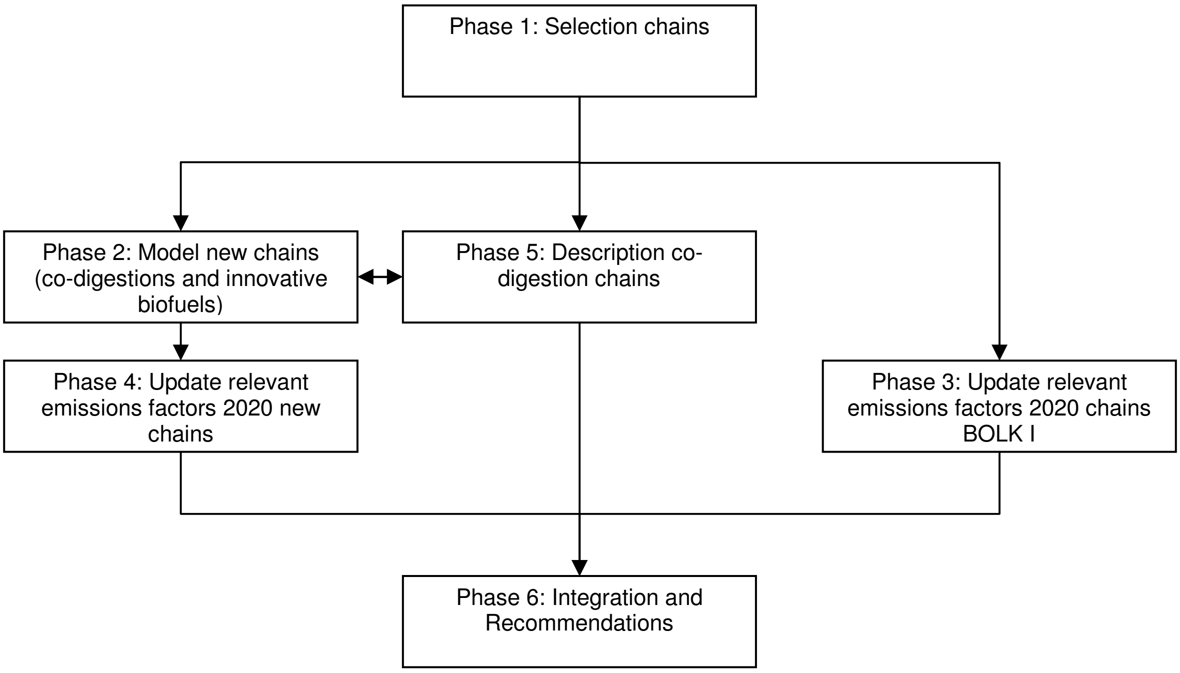

Illustration 1 - 1 Schematic overview of project approach

1.2 Set up of the report

As indicated by the client at the end of BOLK I, there is no current need for a broad scale actualisation and calculation of emissions over the whole spectrum of biofuel and bioenergy chains. Therefore, this project is limited to a number of relevant chains and only to the emission factors with a significant impact on the final results.

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[7] BOLK II study 'Impact biofuels on emissions of air pollutants' by CE/TNO 2009 and 'Emissions of stationary applications' by ECN/TNO 2009

[8] These are descriptions of relevant options, which could be used to obtain 2020 targets on for example reduction of greenhouse gas savings. These options are documented by ECN and further information can be found on http://www.ecn.nl/units/ps/themes/netherlands-climate-policy/options/

Therefore, in Chapter 2, a selection is made of chains that will be analysed and described in this project. Following the chain selection, the relevant emission factors are determined and updated (where possible) in Chapter 3. Chapter 4 presents the main results regarding the chain analysis as done in SimaPro[9] and gives the total impact regarding air polluting emissions of the Dutch policy in 2020. Chapter 5 allocates the emissions to different regions by means of a geographical split, which gives insight in the part of the emissions that will take place within the Netherlands. Conclusions and recommendations regarding the emissions and possibilities for reduction of impacts are presented in Chapter 6.

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[9] SimaPro is a life cycle analysis software which uses underlying databases to provide input for the modeling

2 Chains included in modelling

SimaPro is a 'life cycle' software which uses extensive databases as resource. The selected bioenergy chains are modelled in this software, using the underlying databases and Ecofys updates on estimates towards 2020.

2.1 Selection of chains

Within BOLK air polluting emissions within the Netherlands are the main topic. Air polluting emissions have to be reduced to comply with the mandatory European national emissions ceilings and air quality limit values. Thus the most relevant bioenergy chains with contributions to air pollutant emissions within the Netherlands have been selected for life cycle analysis within BOLK.

The selection of chains for this project is based upon the results of the BOLK I studies and on biofuel-scenario's for 2020 as defined by CE/TNO[10] .

In this study four types of chains will be taken into account:

- Liquid biofuels for transport (6 chains);
- Liquid biofuels for heat & power (1 chain);
- Solid biomass for heat & power (1 chain);
- Co-digestion of biomass (2 chains).

In the first study (BOLK I) 6 of these chains were already evaluated:

- 2 liquid biofuel chains replacing diesel (biodiesel from palm oil and rapeseed);
- 2 liquid biofuel chains replacing gasoline (ethanol from sugar cane and sugar beet);
- 1 liquid biofuel for heat & power production (palm oil replacing natural gas);
- 1 solid biofuel chain for heat & power production (wood pellets replacing coal).

The selection of additional chains for BOLK II is:

- Advanced bioethanol based on straw (from near locations) and wood pellets (import through the Rotterdam harbour) with the production located in Rotterdam;
- Advanced Fischer-Tropsch diesel based on wood pellets with production location Rotterdam;
- Electricity from biogas based on co-digestion of manure and organic waste produced in the Netherlands;
- Upgraded biogas as transport fuel based on co-digestion of manure and organic waste produced in the Netherlands.

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[10] BOLK II study 'Impact biofuels on emissions of air pollutants' by CE/TNO 2009

The supply chains analysed have been modelled to represent cases which are relevant for impacts in the Netherlands. Conversion installations for biofuels are modelled with production locations in the Netherlands, while this in reality could also take place in other countries, and even for the larger part outside Europe. Furthermore feedstock production for several chains was located in the Netherlands in the modelling (for example rapeseed, sugar beet and straw). It is however not very probable that this will all actually take place within the Netherlands (because of the limited space available within the Netherlands for energy crops[11] and high competition on feedstock like straw[12]).

Using the scenarios as determined by CE/TNO[13], the remaining four chains are set. In a meeting with TNO, CE, VROM, PBL and Ecofys the general features of these scenarios were outlined, resulting in the following main choices for the remaining chains:

- 2 advanced biofuel chains for transport
- 2 co-digestion chains of which one produces biogas for transport and the other electricity

Cellulose biofuel chains

Within the scenarios a role is laid out for cellulose[14] biofuel chains. These types of chains are currently not commercially available and innovations are still necessary, however stimulation (on European as well as national level) is included in regulations and policies. Through the option of double counting of innovative chains as currently set in the Renewable Energy Directive and the perception of cellulose biofuel chains being 'more sustainable', it is expected that these chains will be present in the biofuel spectrum in the Netherlands in 2020.

Cellulose ethanol chains are based on a similar production process as currently commercial ethanol chains, but will need alterations in feedstock treatment or processing. Because of similarities in the processes of current and cellulose ethanol chains, stepwise innovations are possible, aiming at different pre-treatment or changes in the first steps of the process. In this way currently existing installations can stay in use while innovations are introduced and tested.

In biodiesel production fewer innovations are expected. The only innovations that are currently foreseen are more radical from a technical perspective. Considerable investments will have to be made to realise initiatives with a scale large enough to be able to reach economically feasible production.

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[11] EEA 2007 'Estimating the environmentally compatible bioenergy potential from agriculture' EEA Technical report No 12/2007

[12] There is quite a high availability of straw in the Netherlands and direct surroundings, but price of straw is high due to competing uses like animal bedding material.

[13] BOLK II study 'Impact biofuels on emissions of air pollutants' by CE/TNO 2009

[14] Often the terminology "second generation" is used, but this definition holds the suggestions that "second generation" would perform better in many respects. Since that is not necessarily the case and because measurements and reporting enable to compare chains on their actual performance, we will refer to these chains as cellulose biofuel chains. With cellulose biofuel chains, we refer to those technologies currently not yet commercially available. Current biofuel chains refer to those commercially available.

Therefore it is expected that the first cellulose biofuel chains will be based on ethanol rather than biodiesel. To take both types into account, a cellulose bioethanol and a cellulose biodiesel chain will be analysed in this study.

Cellulose ethanol chains

Cellulose ethanol chains are based on types of feedstock where cellulose and hemi cellulose material are more difficult to release. Examples of these feedstock types are straw, other agricultural residues or wood. Releasing the sugars in these feedstock types and converting it to ethanol demand several innovations in the production process. As mentioned before, part of these innovations can be introduced in a step wise manner, for example by setting up pre-treatment processes which break the structure of the feedstock. Commercial production processes for cellulose ethanol chains are not available yet. A number of important initiatives that could cover a relatively large part of the future cellulose ethanol market are:

- American initiatives based on straw;
- Brazilian initiatives based on bagasse;
- European initiatives based on agricultural residues and woody feedstock types.

A lot is expected especially from the first two initiatives mentioned, because of already existing large ethanol industry, amount of subsidies and availability of feedstock.

Within Europe the subsidy level for these types of initiatives is relatively low, but several large companies in the transport fuel industry (or ethanol market) are working on these types of innovations.

Cellulose biodiesel chains

There are several main routes shared among the name cellulose biodiesel chains, such as:

- HVO – Hydrotreated Vegetable Oil (like Next-BTL);
- Gasification routes and Fischer-Tropsch (FT) diesel.

The first mentioned route, HVO, will mainly base itself on available liquid oils like palm oil or waste oils. The gasification and FT routes will use more woody biomass streams.

Co-digestion chains

Within the Netherlands digestion is mostly used to convert manure (a waste product) in biogas, to combine waste treatment with energy production. Often manure is not digested on its own, but in combination with another product or substance to increase biogas production. Then the term co-digestion is used.

Within the Netherlands there are several types of products which are used in co-digestion, like:

- Corn;
- Glycerine;
- Residues from the agro and food sector (like potato peels).

Biogas produced in a digester is currently mostly applied for the production of electricity, heat or both (through a CHP).

With the (foreseen) increasing use of natural gas as a transport fuel, biogas is seen as an interesting alternative for a transport fuel of biogenic origin and based on waste treatment.

2.2 Description of new chains

The chains new in BOLK II compared to the selection of chains in BOLK I are described in the following sections. For a description of the chains which were already analysed in BOLK I, we refer to the BOLK I report[15]. Only a short description is given, stating the main aspects of the supply chain.

Co-digestion

In BOLK II, two co-digestion chains have been analysed. In these chains, manure and a co-substrate (e.g. potato skins or corn) are combined in a digester to produce biogas. The first chain uses this biogas from co-digestion to produce electricity and heat, while the second chain uses the biogas to produce a transport fuel.

Co-digestion for electricity and heat production

Illustration 2 - 1 shows the process where the feedstock is converted into electricity and heat by using a combined heat and power installation. The data used for the calculations are derived from a study of SenterNovem[16] and represent Dutch average values of co-digestion installations.

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[15] Ecofys 2008, 'Quick scan local emissions biofuel scenarios' commissioned by PBL under the BOLK I program

[16] SenterNovem 2008, 'Bundeling van resultaten van de mestvergistingprojecten van de ROB-subsidieregeling'

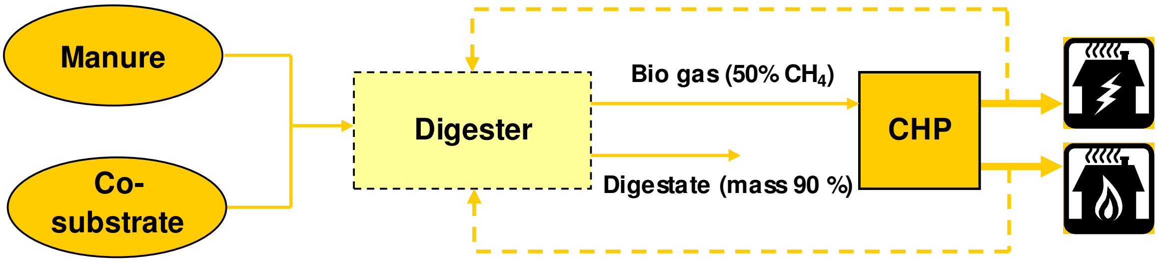

Illustration 2 - 1 Simplified supply chain Co-digestion.

Assuming the digester is located where the manure is produced, i.e. at the farm, transportation of manure is not required[17]. For the co-products on the other hand, an average transportation distance of 50 km is included in the calculations. The caloric value of 1 m^3 methane is 10 kWh. With a methane concentration of 50% and 1 TJ electricity produced out of 0.14 Mm^3 biogas an electrical efficiency of 40% is achieved. In Table 2 - 1, the characteristics of the production of 1 TJ of electricity from the co-digestion CHP chain can be found. Note that the CHP system also generates 1.46 TJ residual heat for each TJ electricity, which normally is not used (or only for a small part). Still, a CHP system is needed because the digestion process requires heat. In this study therefore all impacts are allocated to the production of electricity. For the reference situation however (electricity from a natural gas fired CHP system) an allocation question needs to be answered. If both heat and electricity are used (that's the basic idea behind CHP) e.g. in the greenhouse sector, allocating all impacts to electricity would be unreasonable. Therefore the economic value of heat and electricity is used to allocate the impacts between electricity and heat.

Table 2 - 1 Co-digestion CHP data.

Co-digestion characteristics for the production of 1 TJ electricity		
Manure	716	tonne
Co-product	549	tonne
Digestate	1136	tonne
Biogas	139,749	m^3
Electricity for digester	0.07	TJ
Heat, not used	1.46	TJ
Heat for digester	0.25	TJ
Electricity to grid	1	TJ

Co-digestion for biogas as transport fuel

In the second co-digestion chain that is included in this study, the biogas is purified (Illustration 2 - 2). The first part of the chain resembles the co-digestion chain, including the average of 50 km for co-product transportation. After digestion however, the produced biogas is purified (for which heat and electricity is used), resulting in

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[17] In several cases, the production of manure and the production location of biogas are not at the same geographical location, which would lead to transport of manure (for example in intensive pig farms).

100% methane. The flow scheme of purified biogas production is presented in Illustration 2 - 2.

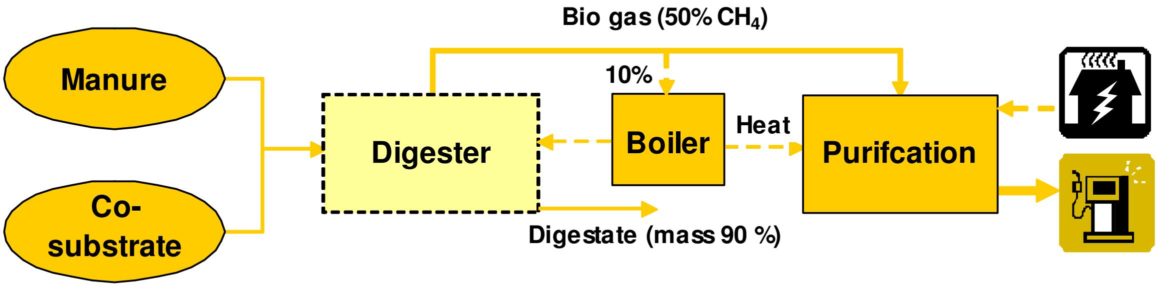

Illustration 2 - 2 Simplified supply chain Co-digestion purification.

In Table 2 - 2 the corresponding data for the production of 1TJ purified biogas is presented. As there is no loss for conversion to electricity, the amount of biogas needed to produce 1 TJ purified methane is 50% lower than the amount needed to produce 1 TJ of electricity (0.07 Mm^3). The fossil reference for this chain would at the moment be CNG (compressed natural gas). Currently natural gas is promoted as an alternative to diesel. It therefore is expected that in 2020 the biogas used for transportation will have replaced mainly diesel[18].

Table 2 - 2 Co-digestion purification data.

Co-digestion characteristics for the production of 1 TJ purified biogas		
Manure	355	tonne
Co-product	273	tonne
Digestate	564	tonne
Biogas	69,395	m^3
Electricity for purification	0.04	TJ
Heat for purification	0.12	TJ
Heat for digester	0.13	TJ
Purified biogas	1	TJ

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[18] Expert judgment R. Winkel (Ecofys transport)

2.2.1 Cellulose biofuels

The two cellulose biofuel chains considered in this project are advanced ethanol from lignocellulose feedstock and Fischer-Tropsch diesel from woody feedstock.

Cellulose ethanol

The cellulose ethanol chain has two variations in feedstock type (and their related production location).

The two types of feedstock and the main geographical assumptions are shown in Illustration 2 - 3. If straw is used, it is assumed this is produced in the Netherlands (in the local surroundings of the production location). If wood pellets are used, it is assumed that they are imported through Rotterdam harbour and come from North America or Russia.

In all cases production location is situated in Rotterdam, as to demonstrate a sort of worst case regarding local air polluting emissions within the Netherlands.

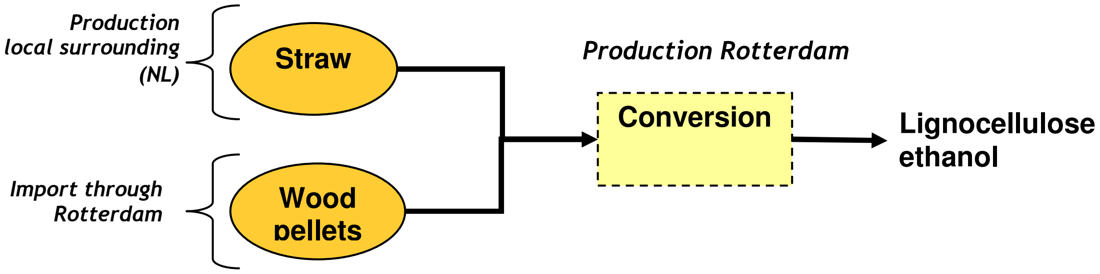

Illustration 2 - 3 Simplified supply chain cellulose ethanol chain.

Table 2 - 3 Input characteristics for the lignocellulose ethanol supply chain

Input characteristics for 1 GJ lignocellulose ethanol		
Straw[19]	2.37	GJ
Wood pellets[20]	2.91	GJ
Excess electricity	0.052	GJ
Lignocellulose ethanol	1	GJ

Fischer-Tropsch diesel

The Fischer-Tropsch diesel is based on wood pellets (Illustration 2 - 4), which like the wood pellets in the cellulose ethanol, are imported through Rotterdam harbour from North America. The same sub-chain for wood pellets is used in the cellulose ethanol chain, the FT diesel chain and the chain for wood pellets used for electricity.

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[19] LHV of straw is assumed 17.2 GJ/ton

[20] LHV of wood pellets is 34 GJ/m3

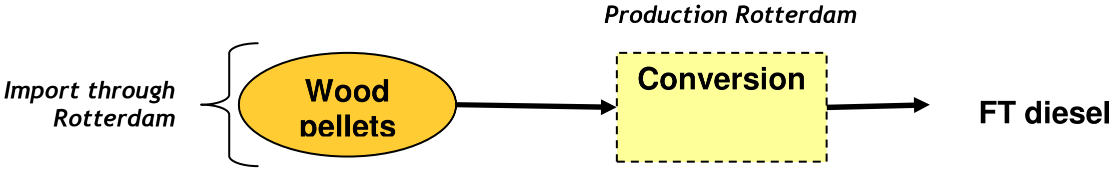

Illustration 2 - 4 Simplified supply chain cellulose biodiesel chain.

For the other chains (co-digestion but also the chains modelled in BOLK I) input data was where possible based on actual data combined with literature or agricultural statistics. Since detailed data on actual production of advanced ethanol or FT diesel is available in detail, the inputs and outputs of the chains are set according to the values presented by the Joint Research Centre[21].

Table 2 - 4 Input characteristics for the lignocellulose ethanol supply chain

Input characteristics for 1 GJ FT diesel		
Wood pellets[22]	2.08	GJ
FT diesel	1	GJ

2.3 Summarising chains selected

To generate a complete overview all chains analysed in this project including their fossil references are given in Table 2 - 5.

Table 2 - 5 Summarizing overview of selected chains and their reference.

Bioenergy chains	**Fossil reference**	**New in BOLK II**
Biodiesel from rapeseed	Diesel	
Biodiesel from palm oil	Diesel	
FT diesel from wood pellets	Diesel	√
Ethanol from sugar beet	Gasoline	
Ethanol from sugar cane	Gasoline	
Ethanol from straw	Gasoline	√
Ethanol from wood pellets	Gasoline	√
Biogas as transport fuel	Diesel	√
Palm oil for heat and power	Natural gas	
Wood pellets for electricity	Coal	
Biogas for electricity	Natural gas	√

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[21] Excel workbooks on which report JRC 2008, 'Well-to-Wheels analysis of future automotive fuels and power trains in the European context: WELL-TO-TANK Report' Version 3.0 November 2008 is based

[22] LHV of wood pellets is 34 GJ/m3

3 Update relevant emissions and processes

Technological innovations, policy & regulation or process changes could all lead to changing (especially decreasing) emissions in individual steps of the bioenergy supply chains. The most relevant processes (with respect to local emissions) are reviewed for possible changes towards 2020.

3.1 Selection of relevant emissions

Only those processes with a significant impact on the total emissions of the chain are taken into account for updates towards 2020. The selection of these 'relevant' processes was done quantitatively based on the results from BOLK I and where necessary qualitative assessment could be added if large policy changes or technological improvements were foreseen.

The quantitative assessment of relevant emissions factors was based on a cut off value of an impact of 5% on the overall results for that chain-emission combination. This assessment of relevant emissions factors was done for all chains and all emissions considered in BOLK I.

In Illustration 3 - 5, the example of the quantitative assessment of relevant emissions is given for the case of biodiesel from rapeseed reviewing NO_x emissions. SimaPro can give overviews of the supply chain in network or tree format, indicating those parts of a supply chain, that contribute to more then a certain cut off value (in this case 5%).

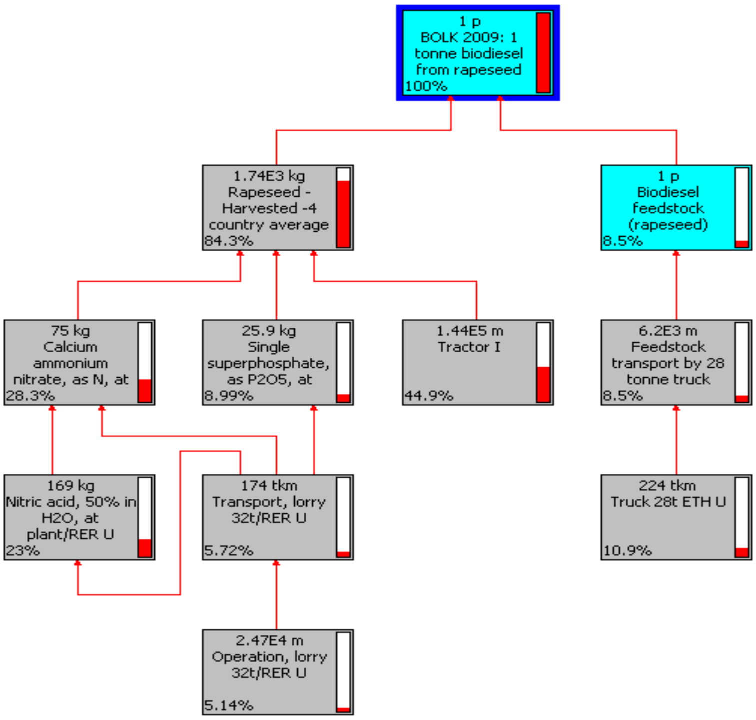


Illustration 3 - 5 Example results biodiesel from rapeseed chain on NO_x (BOLK I).

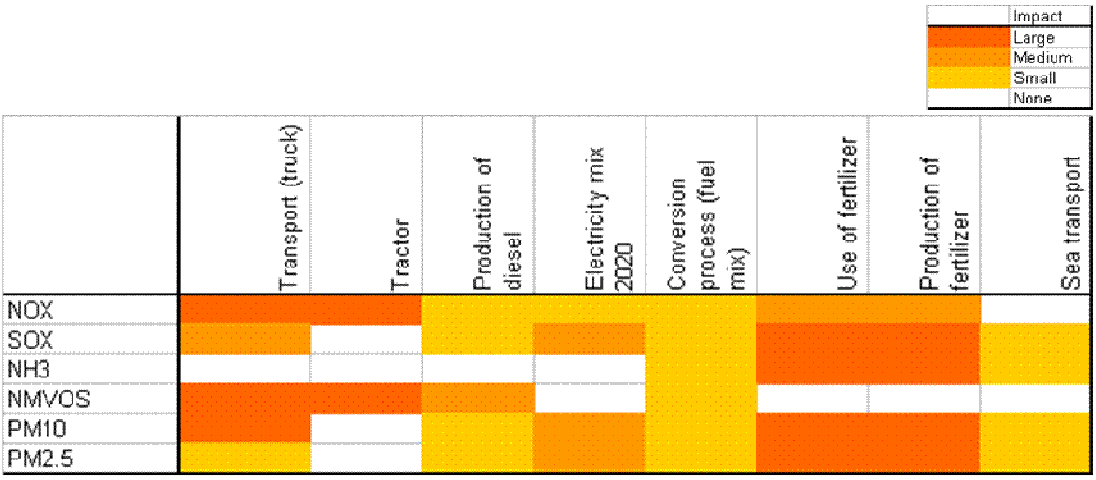
The figure shows how much the different steps contribute to the overall emissions in the chain. In this example of NO_x emissions in the rapeseed supply chain, it shows that the use of a truck contributes 10.9% to the total emissions. Not all interlinkages and sub-processes are shown because a cut off value of 5% is used (processes contributing to less then 5%, are not shown in the picture).

As shown in the figure above, there is only a limited number of parts from the supply chain contributing more then 5%, of which the main are gathered among the harvesting part of rapeseed (use of tractor and production of nitric acid). In this way main contributors for each chain are identified.

The processes selected as relevant contributors to the overall emissions of the various supply chains are:

- Transport NL and World (truck and sea);
- Tractor NL and World;
- Electricity mix 2020 NL and World;
- Conversion process (fuel mix);
- Use of fertilizer;
- Production of fertilizer.

For each air polluting emission, the processes which are most significant vary. An overview of the impact of each part of the supply chain on the various emissions is shown in Illustration 3 - 6.



	Impact
🟥	Large
🟧	Medium
🟨	Small
⬜	None

	Transport (truck)	Tractor	Production of diesel	Electricity mix 2020	Conversion process (fuel mix)	Use of fertilizer	Production of fertilizer	Sea transport
NOX	🟥	🟥	🟨	🟨	🟨	🟧	🟧	⬜
SOX	🟧	⬜	🟨	🟧	🟨	🟥	🟥	🟨
NH3	⬜	⬜	⬜	⬜	🟨	🟥	🟥	🟨
NMVOS	🟥	🟥	🟧	⬜	🟨	⬜	⬜	⬜
PM10	🟥	⬜	🟨	🟧	🟨	🟥	🟥	🟨
PM2.5	🟨	⬜	🟨	🟧	🟨	🟥	🟥	🟨

Illustration 3 - 6 Combination emissions and their main contributors.

Some emissions are influenced by a larger number of aspects in the supply chain, while others are determined by a more limited number of aspects. It should be remembered that the cut off value is set as a percentage of total value, not as an absolute. It could be that a small contribution in percentage for a specific chain still is higher amount than a relatively high contribution in another chain. This is however not taken into account in this analysis[23].

3.2 Approach for update of relevant processes

Two approaches are combined in updating the relevant processes:

- Updating the emissions as given in SimaPro for 2009 (or most recent year available);
- Using policies to forecast emissions or process alterations towards 2020.

The first approach focuses on finding current emissions levels in literature, industry estimates, permits or BREF[24] documentation. The second part examines policies and other future trends to identify main alterations in a more qualitative way.

For some of the processes the update led to new data, for others reasoning was taken to keep emissions as they are currently or as they were in SimaPro for older processes (for example because no clear trend towards 2020 is visible, no changes are expected or new information is not compatible with the data currently in SimaPro). In general where new information is available and compatible with the process as modelled in SimaPro the new data is used for the update.

3.3 Updates as applied to BOLK II

In this section, each of the aspects updated is discussed focussing on the main changes compared to BOLK I and the argumentation for doing so. Literature sources or references are given where available.

Truck transport NL and World

Truck transport emissions are updated in BOLK II, both for the Netherlands as for Brazil and Indonesia. Truck life cycle emissions can be split into 2 phases:

- Well to tank;
- Tank to wheel.

In the first BOLK study, pre 1996 data has been used for both phases. The tank to wheel emissions part of these emissions (emissions in the exhaust gases) is updated, using figures from TNO[25]. It is the European Unions' regulation, the Euro 1-6 emission stages for vehicles that force new build vehicles to have lower CO, NMVOC, NO_x and PM emissions. Also improved composition of the fuel contributed to the decline of some emissions. Euro I was adopted in 1992, Euro V in 2008 and Euro VI will go into

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[23] One of the arguments not to consider this is that it is not possible to compare the absolute amounts of the different emissions. Furthermore looking at updates and improvements, it is easier and more relevant for each chain to look at the contribution percentage based.

[24] BREF is a 'Best Available Technology' reference document as set up by the IPCC

[25] Personal communication with N. Ligterink, TNO Industrie en Techniek, August 2009. Data based on TNO measurements and EU regulation.

force in 2013. Euro V values are used to determine state of art emissions (2009), Euro VI standards combined with expert judgement is used for the 2020 emission profile.

The well to tank emissions (fossil fuel refining and truck & infrastructure construction) are assumed to remain constant. There is no new data available, nor is there specific regulation in place that reduces emissions in this phase.

Emission data for tank to wheel in the Netherlands (presented in Table 3 - 6) are based on the following conditions and assumptions:

- Total truck weight is 23 tonne, carrying a load of 13 ton
- The truck is loaded with 70% of its maximum load (compared to 40% in ESU-ETH)
- Highway driving only. Emissions will be slightly higher if a percentage of city driving would be included. Most of the operational time, the truck will however be driving on the highway.
- **CO_2** emissions remain constant over time, there has been little to no improvement in terms of fuel efficiency.
- **CO** emissions drop dramatically in Euro V and VI compared to Euro 1. This is achieved by treatment of the exhaust gases, not because of more efficient engines. The CO emissions of city driving are up to 4 times higher.
- **NO_x** emissions dropped with 50 % between 1993 and 2009 and expectedly will drop with another 50 % by 2020. The improvements in Euro VI will be achieved by cleaner engines.
- **PM** has significantly improved between EURO I and EURO V. Similar to NO_x, a 50 % improvement for EURO VI is expected.
- **NMVOC** emissions also have been reduced (a factor 40) between 1993 and state of the art. A further decline is however not expected.
- **SO_x** decreased 10 fold between 1993 and 2009, caused by a steep decrease of sulphur in diesel. Already in 2010 the sulphur content will be further reduced from 30 mg/kg diesel to 10 mg/kg diesel. It is assumed that the sulphur level remains constant on 10 mg/kg until 2020. The SO_x level is practically only dependent on the fuel sulphur content and hardly on the engine technology. A further reduction of 10 % can be expected as a result of vehicle efficiency.
- **NH_3** emissions are not included in the 2020 emission profile although SCR catalyst technology will cause some NH_3 emissions. Expert judgment indicates that these emissions are however minor: 10 percent of the NO_x emissions[26].

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[26] Personal communication Ruud Verbeek, TNO 4 November 2009

Table 3 - 6 Tank to Wheel Emissions Truck Transport Netherlands.

Emissions Truck NL	**CO_2**	**CO**	**NO_x**	**PM**	**NMVOC**	**SO_x**	**NH_3**	**Unit**
ESU-ETH Database	135	0.374	1.72	0.0946	0.185	0.112		g/ton_load/km
Euro I (1993)	60	0.0644	0.45	0.018	0.048	0.01368	n/a	g/ton_load/km
Euro V (state of the art)	60	0.00364	0.24	0.0018	0.0012	0.001368	n/a	g/ton_load/km
Euro VI (2020)	54	0.00328	0.108	0.00081	0.00108	0.00041	n/a	g/ton_load/km

Sea transport NL and World

The emissions from sea transport from BOLK 1 are decreased for SO_x, NO_x and PM in the 2020 chains. The reductions are based on Marpol Annex VI calculations. The maximum sulphur content of diesel for oceanic tankers currently is 4.5% and will be reduced to 0.5% in 2020 for all international waters. Regulation for SO_x in so called SECAs (SO_x Emission Control Areas) like the North sea and the Baltic sea is much stricter – 1.5% in 2008 and 0.1% in 2015. As most of the travelled distance lies outside these areas, the international standards are used for the 2020 chains. As for truck and tractor emissions, the reduction only considers tank to wheel emissions, or in the case of ocean transport, tank to propeller.

Furthermore NO_x and PM emissions are reduced in 2020 by 20% compared to the Annex VI standard, based on regulation for new build ships that is enforced in 2011. As of 2016, a reduction of 80% for new ships compared to Annex VI is required in ECA's. Again, because of the relative small part of the total journey from Brazil or Indonesia, this reduction is not integrated in the 2020 emission standard.

For the other emission factors no data about future regulation is available and therefore no changes to BOLK I values are made.

Tractor NL and World

Tractor emissions of BOLK I are updated for the agriculture processes in The Netherlands and Europe (rapeseed, sugar beet and wheat). Previously for these biomass chains the emissions from Tractor use were based on 1995-1999 data from CBS. The emission data in SimaPro was presented in g/km based on a 0.28 kg diesel use, which for tractor operation is not very adequate. Diesel use of tractors depends more on work delivered than on distance travelled. The updated values for tractor use therefore are based on emissions in g/GJ and the typical energy requirements per hectare of crop. Using average data from KWIN[27], the energy use for the production of 1 ton agricultural product (rapeseed, sugar beet and wheat), is determined. The yield per hectare and the energy use per hectare are presented in Table 3 - 7.

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[27] KWIN 2009 (Kwantitatieve Informatie akkerbouw en vollegrondsgroenteteelt). Praktijkonderzoek Plant en Omgeving, Wageningen.

Table 3 - 7 Yield and energy use per hectare (2008).

Yield and energy use per hectare for the Dutch biofuel crops			
Sugar beet	Rapeseed	Wheat	Unit
100.3	91.0	211.5	Litre diesel/hectare
66.5	4.0	8.1	tonne main product/ha

In addition to the different approach, also 2008 CBS emission data have been used for state of the art technology, see Table 3 - 8. For 2020 changes to these values are based on European non-road diesel engines regulation for CO, NO_x, PM and SO_2 which will entry into force in 2014[28]. These emission limits show an exponential decrease between 1999 and 2014. Compared to 1995 most emissions have dropped 40-50%, except for CO_2, NH_3 and NO_x. As for truck emissions the reduction is achieved by the use of cleaner diesel and better engines. For the tractors used outside Europe, no updated emissions were applied, because it is assumed that strict air quality regulations for those regions will not be as strict as in Europe or the Netherlands.

Table 3 - 8 Tractor emissions 2008 (g/work delivered).

Tractor emissions 2008 (CBS)				
Emission factor	1995	2008	2020	Unit
CO_2	74	74	67	gram/MJ
CO	224	139	97	gram/GJ
NO_x	964	769	33	gram/GJ
SO_2	80	41	14	gram/GJ
NH_3	0.23	0.23	0.21	gram/GJ
NMVOC	133	76	69	gram/GJ
PM_{10}[29]	78	42	2	gram/GJ
$PM_{2,5}$	74	39	2	gram/GJ

Production of diesel

No concrete data was found on possible improvements or changes in the diesel supply chain, therefore data as used in BOLK I was used again for the modelling in BOLK II.

Electricity mix 2020 NL and World

The electricity mix for the Netherlands and Europe as used in BOLK I is based on statistics from 2003 or before (depending on the modelling in SimaPro). For 2020 several changes are expected here, for example an increased share of renewable energy.

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[28] http://www.dieselnet.com/standards/eu/nonroad.php

[29] Excluding PM2.5

For the Netherlands, the electricity mix as used by ECN for the integration phase (estimation of total effects on air polluting emissions from the use of bioenergy in 2020) is used for the update. These represent the 2020 case. Although The Netherlands will become a net exporter of electricity, a small part will still be imported.

For Europe, the update of the electricity mix for 2020 is based on knowledge of Ecofys (not published) and includes policy and economic developments. Composition of the electricity mix for BOLK 1, the Netherlands and the EU is given in Table 3 - 9.

Table 3 - 9 Composition of the electricity mix.

Electricity generation by fuel type (%)	BOLK I	EU 2020	NL 2020
Nuclear energy	4.0	21.2	2.6
Coal	26.7	31.0	35.3
Oil	3.5	2.0	2.7
Natural gas	49.4	25.2	39.2
Hydro	0.3	8.2	0.1
Wind	0.0	6.6	5.2
Biomass & waste	0.0	4.8	2.9
Other	0.0	0.0	5.9
Imported	16.2		6.2

In the 2020 cases no electricity input is used outside Europe for the biodiesel from palm oil chain and the ethanol from sugar cane chain. However in the case of excess electricity in the ethanol from sugar cane chain, the current Brazilian electricity mix is used (no data is available on the Brazilian electricity mix in 2020, but the overall impact of this part of the chain will be small).

Conversion process (fuel mix)

For all bioenergy chains, the conversion processes were updated towards 2020 focussing on the fuel mix. For both palm oil and sugar cane, process energy is provided by combustion of biomass on site (and only for a limited part by external energy supply). For ethanol from sugar cane this is already quite common practice and we expect this trend to apply to all ethanol production locations based on sugar cane (combustion of bagasse for heat and excess electricity). For biodiesel from palm oil this is currently less common practice but rising fossil fuel prices, increased focus on greenhouse gas balances of biofuel chains and abundance of local biomass will probably cause the replacement of current external fossil fuels with local available biomass.

Therefore, in the supply chain for biodiesel from palm oil, use of biomass/waste (in the form of fibre) is used for energy provision. Emissions resulting from this combustion are included in the analysis and deducted from a 2008 study assessing the environmental performance of various palm oil mills in Malaysia[30].

In all other processes fuel oil was replaced by other fuels like natural gas, biomass or other fuels.

Use of fertilizer

For most of the emissions the use and production of fertilizer is a large contributor to the total emissions (see Illustration 3 - 6). The main emissions result from the production of fertilizer, but of course reducing the use of fertilizer will also reduce the total emissions per chain.

Organic farming (not using fertilizers, but often using more land) is not expected to take off large scale within the Netherlands (lack of space mainly); therefore complete absence of fertilizer in the Dutch agriculture in 2020 is not expected.

Agricultural systems in the Netherlands are already highly optimised due to long experience, strong regulations and high costs. Radical improvements in the field of yield increase are therefore not expected in the near future. Furthermore application of fertilizer within the Netherlands is already regulated, leaving little room for increased use of (chemical based) fertilizers. There is a direct and strong relation between fertilizer application and yield. Due to high optimization of Dutch agriculture no strong changes in this relation are too be expected. Therefore in the modelling in SimaPro, no updated forecasts on yield and fertilizer use are currently taken into account. It is thus assumed that fertilizer use in relation to yield will not diminish considerably in the Netherlands towards 2020.

For the agricultural systems outside the Netherlands (sugar cane and palm oil) currently literature yields are used which originate not from average yields but from specific and probably good performing plantations. The crops taken into account in this study (sugar cane and palm oil) are grown in tropical or semi-tropical areas. In these areas improvements in agricultural practices towards 2020 are expected (due to better access to knowledge, technology, impulses from global market and a lot of room for improvements available etc.). For these countries (average) FAO projections on yield increase in non-OECD countries are applied to determine a 2020 yield for sugar cane and palm oil. Fertilizer use is not altered indicating a shift in relation between fertilizer use and yield due to better agricultural management practices.

Production of fertilizer

The production of fertilizer is an energy intensive process with substantial emissions with an impact on local air quality. No literature is available on process alterations for fertilizer production towards 2020. However fertilizer plants usually have a reasonably long life time. Therefore current Best Available Technologies can be used to simulate an average 2020 case. To generate information on the current Best Available Technologies, two sources are used. First of all the BREF documentation on emissions

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[30] Subramaniam et al 2008, 'Environmental performance of the milling process of Malaysian Palm Oil using the Life Cycle Assessment Approach' Malaysian Palm Oil Board & University of Malaysia

from fertilizer production facilities, which indicates current average practice but also best available technology and emissions related to this best practice case. The second document used is a study from the International Fertilizer Industry Association (IFA 2009) indicating energy consumption and greenhouse gas emissions related to various types of fertilizer production facilities. Best Available Technology for new plants today indicates the energy consumption expected, which in this project is used as average energy consumption for fertilizer production facilities in 2020. No division is made between fertilizer production facilities in different geographical locations, because it is assumed that regarding energy, all fertilizer production facilities will attempt to apply energy efficiency measures to reduce costs. The international BAT however does not differ that much from the fertilizer production as already used in SimaPro.

4 Results of 2020 chain analysis

4.1 Introduction

In the preceding chapters, a description of the various chains modelled and the updates compared to the BOLK I project was given. The current chapter presents the results for these chains. We will make the following comparisons:

- BOLK II chains with their fossil reference;
- BOLK II chains with the BOLK I chains.

In the following sections each of the above mentioned comparisons and combinations is described and main results/ data are given. To assess the complete picture, first greenhouse gas emission savings are given.

4.2 Typical greenhouse gas emissions reductions

Greenhouse gas emissions reductions are not the specific topic op this study, but they are presented here to indicate the range of GHG reductions possible for several chains. The greenhouse gas emission reductions, presented here are the typical values as presented by the European Commission in the Renewable Energy Directive[31]. The typical values are shown here in stead of the default. The typical value is an estimate of the representative greenhouse gas emission saving for a particular biofuel production pathway, so represents the 'average in industry'. The default values are closer to a worst case in stead of the average in industry. It is assumed that current typical values are applicable to all chains in 2020.

For the available chains the typical greenhouse gas emissions are given in Illustration 4 - 7, including the emission reduction as compared to their fossil reference. The illustration shows the typical greenhouse gas emissions per step in the supply chain (cultivation, processing and transport & distribution as indicated by the colours). The height of the fossil reference (the grey column) indicates the 100% emission line. With these the greenhouse gas emission reductions are presented by the percentages indicated above each column (the reduction achieved by the chain in comparison with the fossil chain).

The red dotted lines in the illustration indicate the minimal greenhouse gas emission reduction that needs to be achieved by the chains as currently indicated in the Directive to be counted towards the targets of each country. The minimum savings are increased over time (represented by the three dotted lines below each other).

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[31] Analysis of GHG emissions with the same modeling in SimaPro was not done because of the facts that methodologies for analyzing GHG emissions are a further developed and would not be covered by the methodology applied in this study. Furthermore, the European Commission presented default values in the Renewable Energy Directive, which are taken as an indication of GHG emissions reduction for this study.

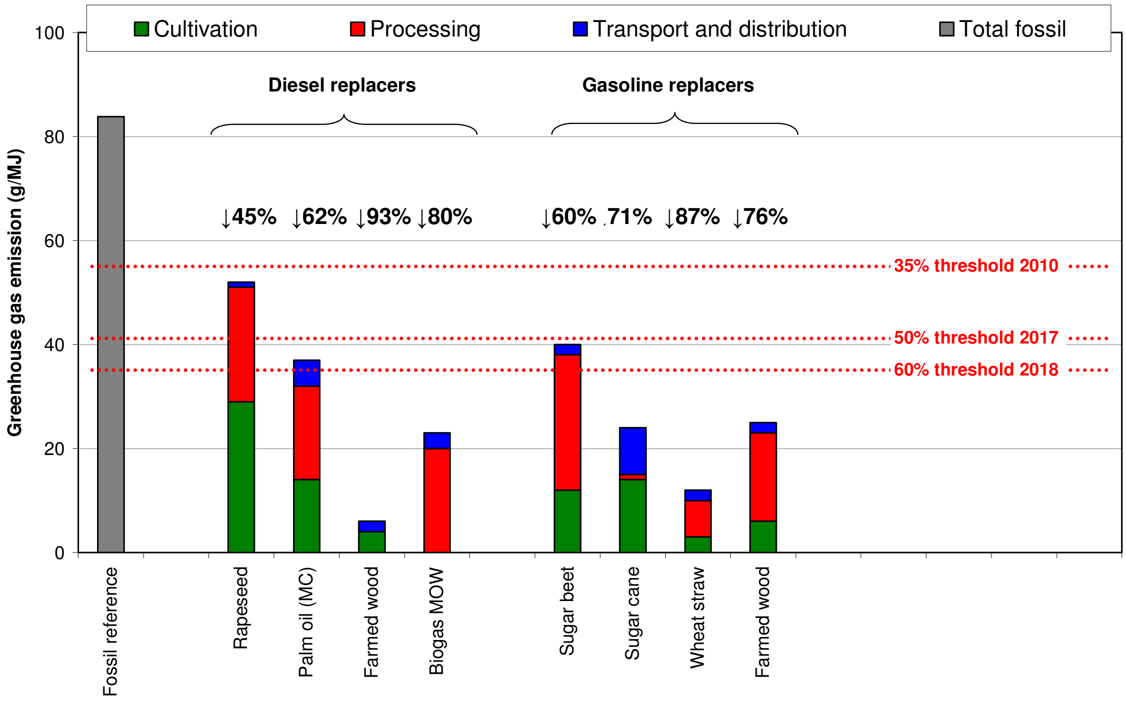

Illustration 4 - 7 Typical GHG emissions bioenergy chains according to RED[32].

4.3 Results of 2020 chains compared to fossil reference (2020)

Some of the chains modelled in this project are updates compared to BOLK I, but some are completely new. For each chain a fossil reference is identified. In this section a short comparison will be made of each chain to its fossil reference to indicate on what emissions applying bioenergy has positive or negative on the overall supply chain emissions. The comparison to the fossil reference is given in the following tables (Table 4 - 10, Table 4 - 11 and Table 4 - 12). After each table some remarks on the emissions presented are given[33].

Table 4 - 10 2020 Emissions for diesel replacers and their reference.

Emission	**Unit**	**Biodiesel from rapeseed**	**Biodiesel from palm oil**	**FT diesel from wood**	**Biogas as transport fuel**	**Diesel reference**
NOx	**g/GJ**	42.88	46.08	17.18	21.14	42.80
SOx	**g/GJ**	21.60	30.86	10.16	13.26	96.29
NH3	**g/GJ**	51.10	23.14	0.07	0.23	0.14
PM10	**g/GJ**	14.81	5.82	0.95	1.14	2.24
PM2.5	**g/GJ**	3.89	2.18	1.38	0.46	4.36
NMVOC	**g/GJ**	13.74	7.45	13.32	9.71	27.09

The newly modelled chains FT diesel and biogas for transport perform better on all emissions than their reference Diesel. On most emissions they perform better than all

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[32] 'Renewable Energy Directive' as set by the European Commission in 2009

[33] In each of the presented tables PM10 excludes the emissions of PM2.5, which are presented separately.

other chains (except on NMVOC). Biodiesel from rapeseed and palm oil have in general higher emissions than the fossil reference except for SO_x and NMVOC (and palm oil scores better on PM2.5). Regarding NH_3, it is very logic to see that chains with a large agricultural contribution (rapeseed and palm oil) have high emissions there.

Table 4 - 11 2020 Emissions for gasoline replacers and their reference.

Emission	Unit	Ethanol from sugar cane	Ethanol from sugar beet	Ethanol from straw	Ethanol from wood	Gasoline reference
Nox	**g/GJ**	130.60	56.11	10.61	-8.15	50.53
SOx	**g/GJ**	40.79	49.63	66.00	53.82	133.07
NH3	**g/GJ**	3.77	6.79	25.17	-0.58	0.16
PM10	**g/GJ**	9.08	8.97	6.24	0.45	2.67
PM2.5	**g/GJ**	1.62	2.88	1.56	0.98	5.29
NMVOC	**g/GJ**	39.95	41.94	13.57	13.83	27.75

The remarkable aspects of the table are the negative NO_x and NH_3 emissions of the ethanol from wood chains. These are caused by the excess electricity generated in the ethanol conversion process and therefore replace electricity from the grid. This has a high impact on this supply chain. Also for gasoline (like diesel) the SO_x emissions are higher than all its possible biofuel replacements. Furthermore gasoline gives high emissions on PM2.5 and NMVOC. The advanced ethanol chains perform compared to the other relatively well, although on SO_x emissions they score low compared to the ethanol from sugar cane and sugar beet. One remark that should be made here is on the PM emissions for the innovative ethanol chains. Current information on innovative ethanol processes indicates that there would be a considerable contribution of PM emissions, because of the use of lime in the conversion process. According to JRC’s current data on the conversion process, lime is applied to neutralise the acids used for the conversion of the lignocellulose material in the process. However current trends in industry already indicate that acids are more and more recycled in stead of neutralised. Therefore, for 2020 we assume no lime is used in both production processes of advanced ethanol because of recycling of acids in stead or because of the application of enzymatic technologies in stead of acids. This is taken into account in the current calculation and analysis.

The agricultural part in ethanol from sugar cane and sugar beet causes relatively high NH_3 and NO_x emissions (fertilizer and tractor use). For sugar beet reduction of use of tractor and for sugar cane reductions of emissions per use of tractor might give improvements.

Table 4 - 12 2020 Emissions for bio-based electricity chains and their fossil reference.

Emission	Unit	Palm oil (CPO)	Biogas	Natural gas reference	Wood pellets	Coal reference
Nox	**g/GJ**	37.22	9.51	21.72	18.23	67.50
SOx	**g/GJ**	24.80	4.41	24.40	16.28	15.84
NH3	**g/GJ**	20.75	0.00	0.02	0.17	5.91
PM10	**g/GJ**	4.93	0.42	0.93	1.14	3.80
PM2.5	**g/GJ**	1.76	0.00	0.97	2.17	3.58
NMVOC	**g/GJ**	5.05	7.79	17.80	7.57	9.82

For electricity production, the biogas and wood pellets chains have the lowest air polluting emissions compared to not only their fossil references (natural gas and coal) but also the palm oil chain. The wood pellets to electricity chain scores better than coal on all except SO_x emissions, with especially large differences in NO_x. The biogas chain has lower emissions than its fossil reference on all the six types of emissions analysed. The biogas chain for electricity purposes is also lower on emissions than the biogas for transport chain. This is due to the gas cleaning step necessary for use in transport.

The coal and palm oil supply chains have the highest emissions of all the chains producing electricity, except on NMVOC and SOx where the natural gas chain has high emissions. The high NMVOC and SOx emissions for the natural gas chain are caused by emissions in the production process of natural gas (mainly in the step ‘sweetening of natural gas’).

4.4 Results of 2020 chains compared to BOLK I

Most of BOLK I chains had mixed input data ranging backwards from 2007 till for example 1996. A short comparison with the BOLK I chains is given here, to indicate the main effects of the updates applied.

The chains are not compared to their fossil reference but only to their BOLK I chain as to show main changes and explain their causes.

In general all 2020 chains have lower emissions compared to BOLK I. Not all reductions can however be explained by the same indicator changes. In the following sections we will indicate what are the causes of the main changes in the air polluting emissions between BOLK I and BOLK II.

General

- The Dutch rapeseed and sugar beet yield is updated using KWIN 2009. For rapeseed this has relatively small consequences (a little bit higher yield) but the yield of sugar beet is significantly lower compared to BOLK I. In BOLK I French averages were used from literature, which are currently replaced by actual Dutch production data for recent years. The effects of improved processes (truck and tractor) therefore are less pronounced in total emissions of the sugar beet chain;

- In BOLK I, tractor use was calculated in km travelled per hectare. For 2020 the Dutch chains tractor used is calculated based on the diesel use per hectare (based on KWIN 2009). The relatively high moisture content of sugar beet compared to rapeseed and wheat result in higher emissions per kg product harvested for sugar beet;
- The ethanol from sugar cane chain already used bagasse burning in BOLK I to fulfil their process energy needs. In BOLK II it is assumed that on top of that, the excess bagasse will also be burned and the electricity generated from this will be supplied to the national grid (replacing average Brazilian electricity mix). This causes air polluting emissions for sugar cane in general to be higher in BOLK II than in BOLK I. This is caused by the fact that the electricity replaced is usually produced with cleaner sources than bagasse burning. This effect is most noticeable in NO_x and PM emissions;
- A comparison with BOLK I can only be done for those chains included in BOLK I. The chains newly analysed in the BOLK II project, are included in the graphs below, but only to see how they fit in the range of absolute emissions.

NO_x

For NO_x emissions the BOLK I and BOLK II results are compared in Illustration 4 - 8. It shows a variation in NO_x emissions over the chains selected, with the chains which including an agricultural part of the supply chain mostly at the high end. The exception is coal (where oceanic transport of coal has a large effect on the total emissions).

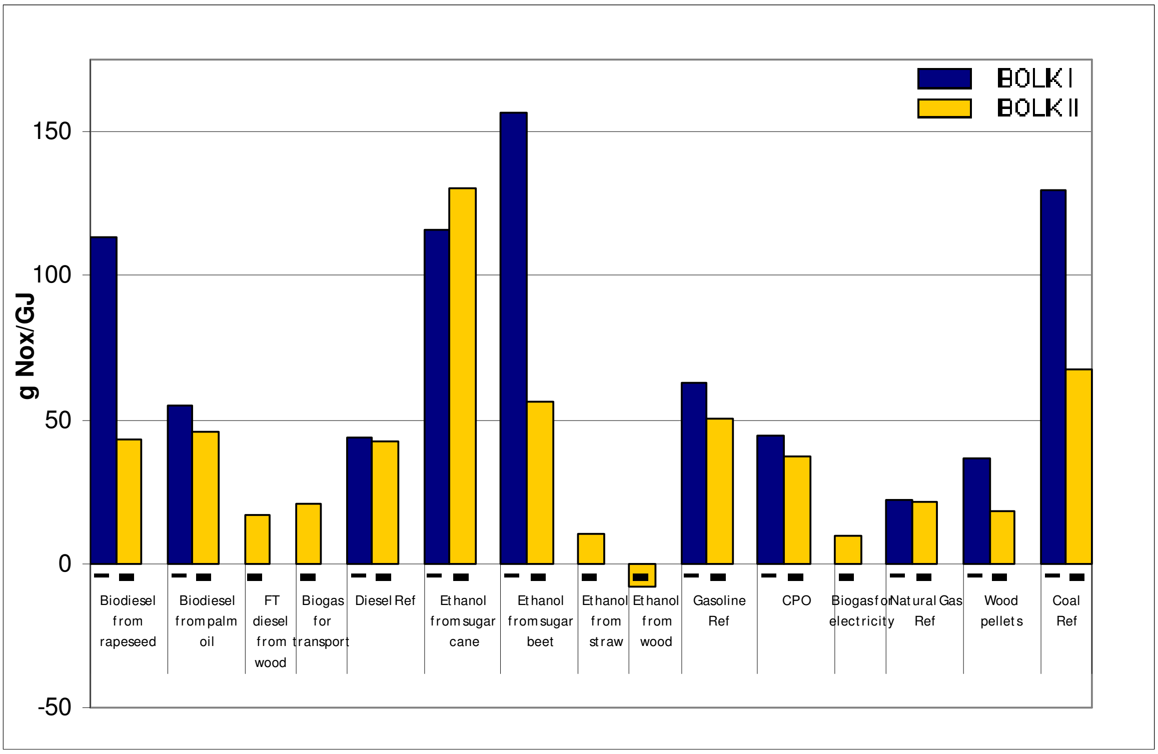

Illustration 4 - 8 Alterations in NOx emissions from BOLK I to BOLK II.

Some remarks on the comparison given in Illustration 4 - 8:

- NO_x emissions for truck and tractor decline considerably within the Dutch chains (not in palm oil and sugar cane) because of more efficient engines;
- NO_x emissions in the sugar cane and palm oil chains are in general lowered by a slight yield increase and lower emissions of oceanic transport. However for sugar cane this is not visible, because of increased NO_x emissions resulting from increased bagasse burning (alteration in production process of ethanol) and use of all bagasse within the supply chain;
- For the fossil reference chains the NO_x emissions reduce for diesel and gasoline because of fuel transport by truck. The coal chain benefits from lower emissions in sea transport due to new Imo regulations. For natural gas hardly any changes are visible because the chain as modelled in SimaPro uses pipelines for transport and therefore does not benefit from lower emissions in truck or sea transport.

SO_x

Illustration 4 - 9 shows the comparison between BOLK I and BOLK II chains for SO_x emissions.

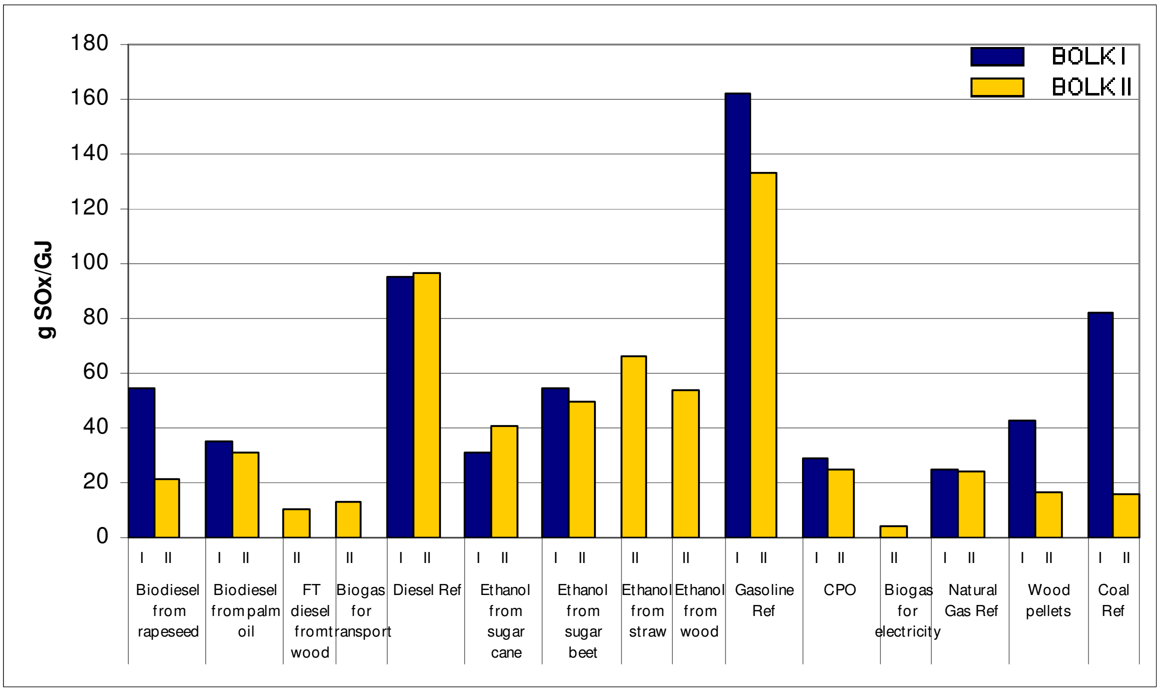

Illustration 4 - 9 Alterations in SOx emissions from BOLK I to BOLK II.

Some remarks:

- The emission reduction for trucks in the Dutch chains is also valid for SO_x emissions. The lower SO_x emissions result from decreased sulphur content of the truck fuels;
- This reduction in transport emissions is not applied in chains outside the EU (palm oil and sugar cane) and thus no large reductions resulting from transport emissions are seen. The yields of these two chains did increase, indicating for the palm oil chain a slight reduction. The reduced SO_x emission from the yield increase in the sugar cane chain does not compensate sufficiently for the additional SO_x emissions from use of all bagasse for electricity generation (and no allocation to bagasse as co-product);
- No direct reduction in SO_x emissions from the use of low-sulphur diesel in tractors is shown from the Dutch chains, because overall emissions from trucks use did not always decrease in these chains, for example emissions resulting from tractor use increased for ethanol from sugar beet. This resulted from the fact that in BOLK II CBS data is used. These are considered more accurate compared to the previously used tractor emissions from the Idemat database, but for some cases result in higher emissions because they are calculated based on GJ fuel use and not based on hectare;
- The large reduction of SO_x in the coal and wood pellets chains is mostly due to reduction in SO_x emissions during transoceanic transport.

PM

The PM emissionsin this paragraph comprise of PM_{10} including $PM_{2.5}$[34], for which the comparison to BOLK I is grouped in Illustration 4 - 10.

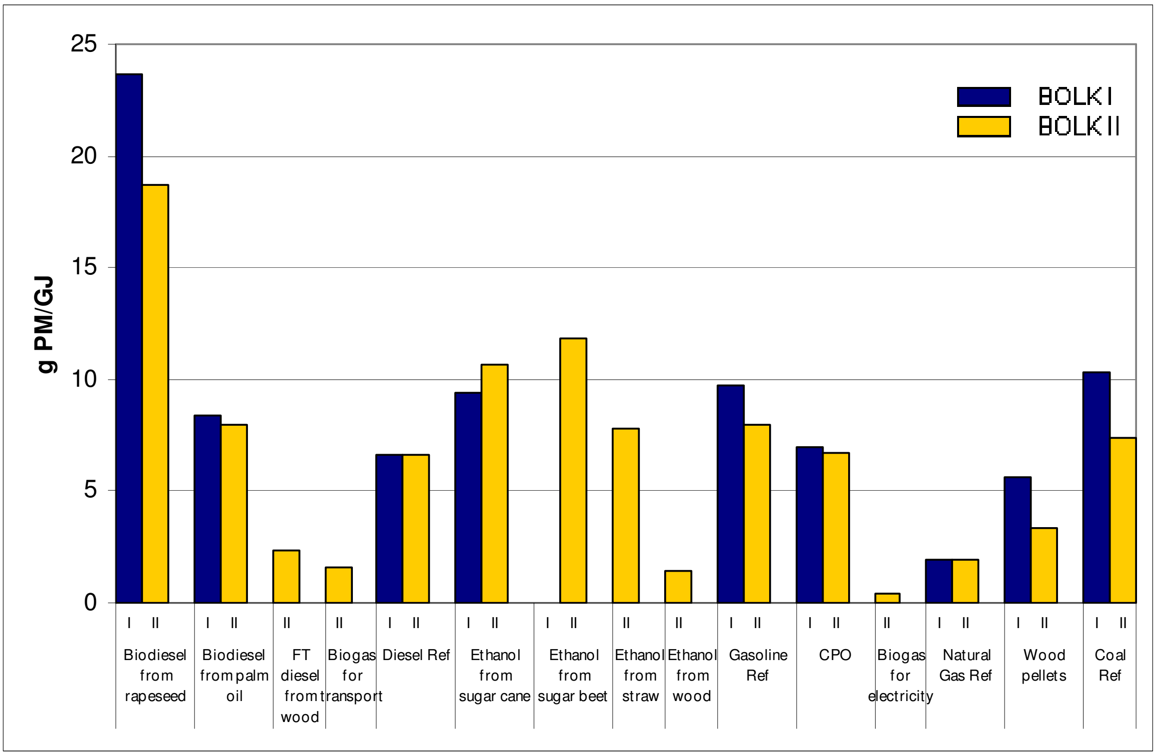

Illustration 4 - 10 Alterations in PM emissions from BOLK I to BOLK II.

For most chains PM emissions lowered in BOLK II because of the updates done in SimaPro. Some short remarks:

- The increase of PM emissions in the sugar beet chain is caused by the use of tractor data from CBS in BOLK II. In BOLK I Idemat data was used. The CBS data does include PM emissions, while in the Idemat these emissions were lacking. For rapeseeds this does not show up in the graph because the reduced truck emissions are larger;
- For sugar cane and palm oil no improvements of tractor emissions are expected and therefore the ‘old’ BOLK I tractor data is still used there (based on Idemat database in SimaPro). Because PM is missing in the Idemat tractor the palm oil and sugar cane chains have optimistic PM emissions compared to the Dutch chains. The PM emissions in the sugar cane chain increased however due to extra bagasse burning;
- PM emissions of the fossil chains of coal and gasoline decreased due to improvements in fuel quality (low sulphur) and IMO regulations.

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[34] PM10 in the total study refers to all particle matter emissions smaller than 10 micrometer, but excluding those emissions smaller then 2.5 micrometer. These latter are separated in the category PM2.5. In this paragraph they are presented summed.

NH_3

Ammonia emissions are only considerable in those chains with a strong agricultural component in the supply chain. This is shown in Illustration 4 - 11, where the NH3 emissions from the fossil references and the wood based chains are relatively small.

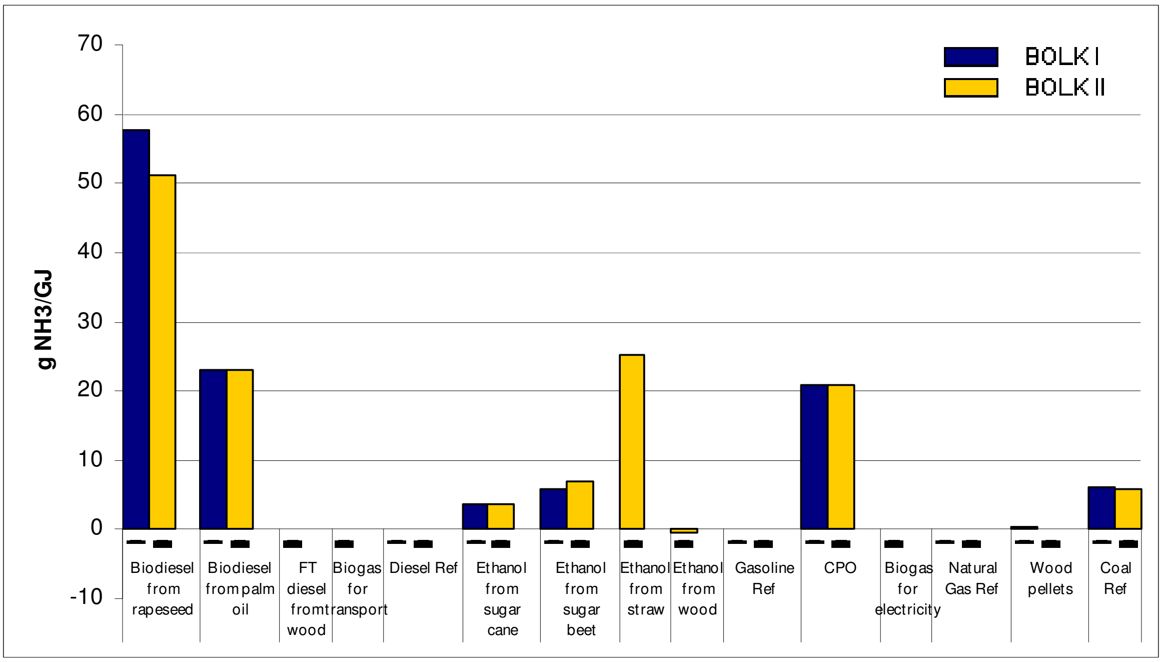

Illustration 4 - 11 Alterations in NH_3 emissions from BOLK I to BOLK II.

Higher emissions for NH_3 in the sugar beet chain can be explained by the lower yield of sugar beet per hectare (Dutch average for 2020 in stead of French average in BOLK I). The effect of the increased yield of rapeseed explains the slightly lower NH_3 emissions. The negative emissions for the ethanol from wood supply chain are caused by excess electricity production, replacing a small Dutch electricity supply mix.

NMVOC

The NMVOC category is a group of emissions which are not shown separately here, but includes among others benzene, styrene and ethene. Illustration 4 - 12 shows the variation in NMVOC emissions for all chains between BOLK I and BOLK II. Most chains show a reduction of NMVOC due to reductions in NMVOC emissions for transport (truck and ship). However the only chain that does not follow this pattern is the ethanol from sugar cane chain. This is caused (as mentioned before) by the use of all bagasse within the supply chain (with electricity as extra output) in stead of allocating part of the emissions to bagasse as co-product.

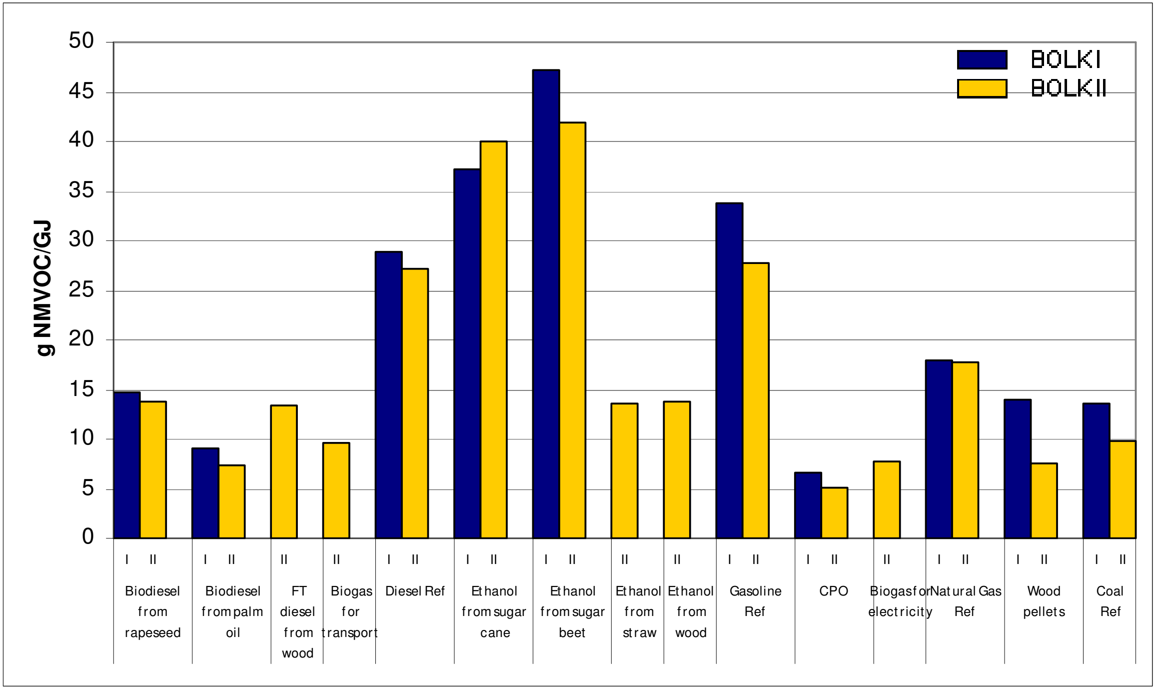

Illustration 4 - 12 Alterations in NMVOC emissions from BOLK I to BOLK II.

4.5 Conclusions

The updates in the modelled chains mainly caused a reduction in air polluting emissions in the supply chain due to improvements in transport, tractor, yields and production processes. For some chains (like ethanol from sugar cane) the future expectations caused slight increases in emissions. A general conclusion is that the bioenergy chains with a small agricultural part (residue and wood chains) have lower supply chain emissions than the bioenergy chains with agricultural crop production. These chains with agricultural crop production also have the most pronounced ammonia emissions. Regarding SO_x emissions the fossil chains in general have higher emissions than the bioenergy chains.

5 Geographical split & impact 2020 in the Netherlands

5.1 Methodology applied

Air polluting emissions are emissions which cause negative effects on local surroundings. They do not, like greenhouse gas emissions convey their effects on global environment. Therefore it is of importance to identify (where possible) the main locations where these air polluting emissions take place.

The specific interest of this project (BOLK II) is to see if policy aimed at reducing global greenhouse gas emissions does not result in negative effects on air polluting emissions for the Netherlands, especially keeping in mind the emission ceilings for these air polluting emissions. In this chapter we will combine BOLK II chains with scenarios on application of chains and a geographical split to determine overall impact in 2020 in the Netherlands.

Therefore the emissions as presented in chapter 4 are split geographically. The three main regions applied in this process are:

- The Netherlands (NL)
- Europe (EU)
- Outside Europe/Rest of the world (W)

Some of the chains occur completely within the Netherlands, but most of the chains partly take place in the Netherlands, and partly outside.

In Table 5 - 1 and Table 5 - 2 a summarising overview is given of the main locations connected to the steps in the different supply chains. If a certain step is not present in the identified supply chain, no location is given. Where a certain step is spread over multiple locations as defined within the project (the Netherlands, Europe, World), multiple locations are given.

Table 5 - 1 Overview geographical locations bioenergy chains.

Bioenergy chain	**Feedstock production**	**Transport**	**Conversion**	**Transport**
Biodiesel from rapeseed	NL/EU	EU/NL	NL	NL
Biodiesel from palm oil	W	W/EU/NL	NL	NL
FT diesel from wood pellets	EU/W	W/EU/NL	NL	NL
Ethanol from sugar beet	NL	NL	NL	NL
Ethanol from sugar cane	W	W	W	W/EU/NL
Ethanol from straw	NL	NL	NL	NL
Ethanol from wood pellets	EU/W	W/EU/NL	NL	NL
Biogas as transport fuel	NL	NL	NL	NL
Palm oil for heat and power	W	W/EU/NL	NL	-
Wood pellets for electricity	W	W/EU/NL	NL	-
Biogas for electricity	NL	NL	NL	-

Table 5 - 2 Overview geographical locations fossil energy chains.

Fossil reference chain	**Extraction & refining**	**Transport**
Diesel (transport fuel)	W/EU/NL	W/EU/NL
Gasoline (transport fuel)	W/EU/NL	W/EU/NL
Natural gas for electricity	EU/NL	EU/NL
Coal for electricity	W/EU/NL	W/EU/NL

The approach taken in this study to quantify the impacts for the Netherlands in 2020 is relatively straight forward. The total amount of emissions is divided by step in SimaPro. For each step where only one geographical location is given, 100% of these emissions are related to that location. For each step where several geographical locations are mentioned, a percentage wise division will be applied to indicate the contribution of emissions to each location.

There are parts of a step in the supply chain, which could occur in completely different locations (like fertilizer or chemicals production). This is qualitatively taken into account in the percentages applied to the split of each step over the geographical locations. No quantitative assessment is done in this case. This is done in an attempt to include loop effects in the geographical split up of emissions.

The approach for the geographical split is shown in the following example of biodiesel from palm oil (Illustration 5 - 1). A short description of each step and the percentages obtained is given below.

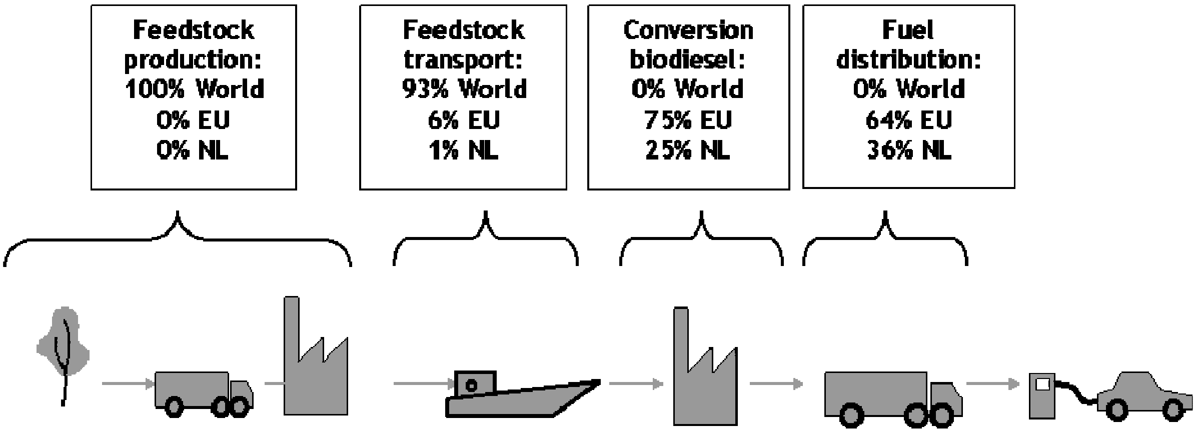

Illustration 5 - 1 Detailed geographical split for supply chain from palm oil biodiesel.

Each step in the supply chain is given percentages to indicate the split over the three geographical regions as defined within the scope of this study. These percentages are obtained through a combination of qualitative and (where possible) quantitative assessment, where possible taking into account very relative sub-steps:

- **Feedstock production:** Production of palm oil takes place outside Europe, currently mostly in countries like Malaysia and Indonesia. Because of the fact that oil palm grows best in more tropical region, it is not expected that in 2020 part of this production will take place within Europe. One of the main components which could have a different production location is fertilizer production. For this the 'Global fertilizer trade map'[35] is used, which shows that in Malaysia and Indonesia import their fertilizer from the USA. Thus also the production of fertilizer takes place outside the EU.
- **Feedstock transport:** Feedstock transport consists of a sea ship travelling from country of origin to Europe. The larger part of this journey takes place outside the EU (93%) and only at delivering to the conversion plant a part can be contributed to NL[36]. As stated at the section conversion, one third of the biofuel is processed within the NL, the rest outside the NL but within the EU.
- **Conversion:** The basic assumption is that 25% of the palm oil is converted into biodiesel within the NL, the rest in other countries in Europe

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[35] The 'Global fertilizer and trade map' is produced by ICIS (information provider for the Chemical Industry) in partnership with IFA (International Fertilizer Industry Association) http://www.fertilizer.org/ifa/Media/Files-Public/Fertilizers-and-the-industry/map-ICIS-IFA

[36] Percentages on ship travelling are estimated roughly by using http://www.distances.com/ for shipping distances from port to port around the world.

- **Fuel distribution:** Transport distances for the 25% produced in the NL are completely attributed directly to NL and further a 15% of the transport distances for the biofuel produced on other locations in Europe, resulting in 36%.

The geographical split in percentages per supply chain is given in Appendix A.

For the fossil reference chains the quantification of the geographical split required an extra step in the methodology. The fossil reference chains as modelled in SimaPro are not split explicitly over the steps extraction, refining or transport. Therefore assumptions were made concerning this split as to make the geographical split possible.

In the following matrices (Table 5 - 3, Table 5 - 4 and Table 5 - 5) the assumptions for the diesel, gasoline and coal supply chain are shown. The sum of all values in the table is 100%. Regarding extraction data is used from SimaPro and CBS to indicate the crude oil or coal supply at the base of fossil consumption in the Netherlands. The geographical split of refining and transport are based on expert estimations using background data, for example on refining statistics in the Netherlands and distances of main ports. The split of the emissions over extraction, refining and transport is based on detailed emissions analysis[37] of the sub-steps of the fossil chains.

Table 5 - 3 Geographical and process split diesel supply chain

Diesel supply chain	**Extraction (65%)**	**Refining (20%)**	**Transport (15%)**
World	38.81%	0.00%	8.25%
Europe	26.00%	4.00%	5.25%
Netherlands	0.20%	16.00%	1.50%

Table 5 - 4 Geographical and process split gasoline supply chain

Gasoline supply chain	**Extraction (45%)**	**Refining (30%)**	**Transport (25%)**
World	26.62%	0.00%	13.75%
Europe	18.18%	6.00%	8.75%
Netherlands	0.14%	24.00%	2.50%

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[37] Of air polluting emissions

Table 5 - 5 Geographical and process split coal supply chain

Coal supply chain	**Extraction (40%)**	**Transport (60%)**
World	35.72%	54.00%
Europe	4.28%	4.80%
Netherlands	0.00%	1.20%

5.2 Results geographical split

For each supply chain the geographical split per process step is multiplied with the emissions of that process step. For NO_x emissions, the results of this calculation are given in Illustration 5 - 2.

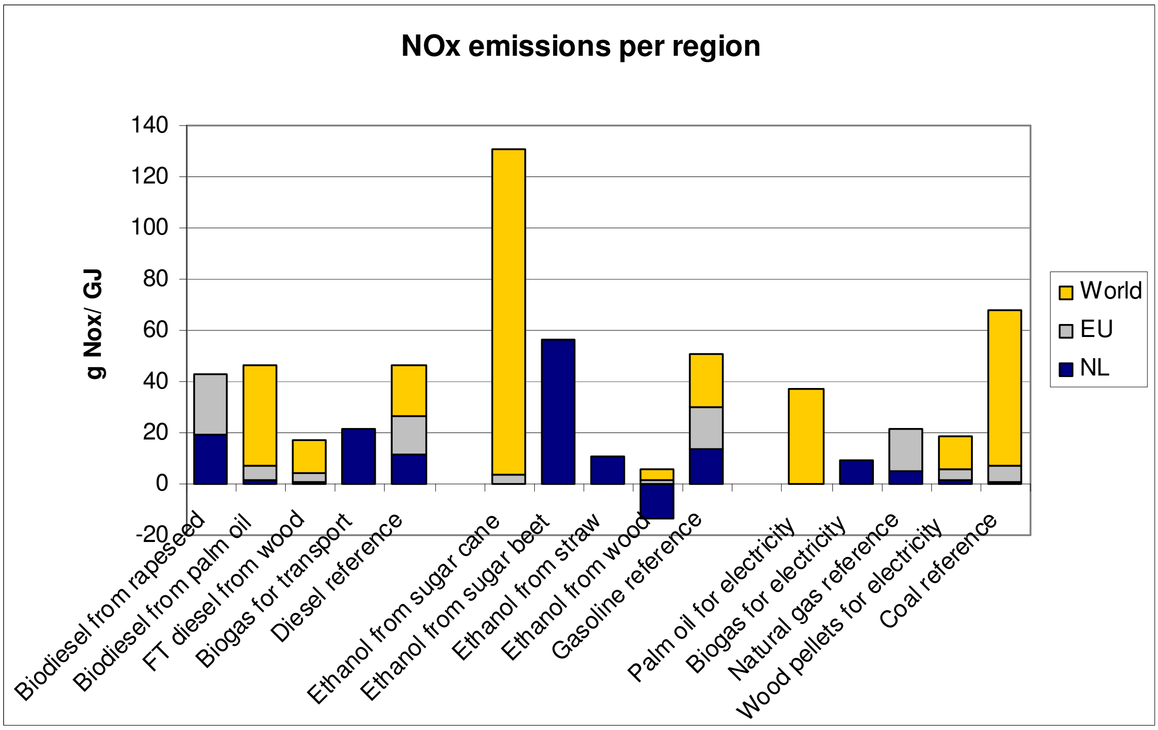

Illustration 5 - 2 Results of geographical split for NO_x emissions.

By splitting the results over the geographical locations where they take place, an overview is generated of the emissions occurring within the Netherlands in 2020 of each chain. This is presented in the following tables (Table 5 - 6, Table 5 - 7 and Table 5 - 8).

Table 5 - 6 2020 Emissions for diesel & its replacers in the Netherlands.

Emission	**Unit**	**Biodiesel from rapeseed**	**Biodiesel from palm oil**	**FT diesel from wood**	**Biogas as transport fuel**	**Diesel reference**
NOx	**g/GJ**	19.27	1.77	0.67	21.14	11.43
SOx	**g/GJ**	10.97	0.98	0.64	13.26	25.67
NH3	**g/GJ**	15.39	0.01	0.00	0.23	0.04
PM10	**g/GJ**	4.88	0.09	0.06	1.14	0.60
PM2.5	**g/GJ**	1.46	0.06	0.00	0.46	1.16
NMVOS	**g/GJ**	6.29	0.63	1.13	9.71	7.26

Table 5 - 7 2020 Emissions for gasoline & its replacers in the Netherlands.

Emission	**Unit**	**Ethanol from sugar cane**	**Ethanol from sugar beet**	**Ethanol from straw**	**Ethanol from wood**	**Gasoline reference**
Nox	**g/GJ**	0.181	56.11	10.61	-13.92	13.474
SOx	**g/GJ**	0.094	49.63	66.00	48.33	35.456
NH3	**g/GJ**	0.003	6.79	25.17	-0.58	0.041
PM10	**g/GJ**	0.013	8.97	6.24	-0.08	0.712
PM2.5	**g/GJ**	0.011	2.88	1.56	0.98	1.408
NMVOS	**g/GJ**	0.032	41.94	13.57	4.09	7.417

Table 5 - 8 2020 Emissions for electricity chains and their replacers in the Netherlands.

Emission	**Unit**	**Palm oil (CPO)**	**Biogas**	**Natural gas reference**	**Wood pellets**	**Coal reference**
Nox	**g/GJ**	0.018	9.51	5.21	1.76	0.81
SOx	**g/GJ**	0.003	4.41	5.86	0.84	0.19
NH3	**g/GJ**	0.000	0.00	0.00	0.01	0.07
PM10	**g/GJ**	0.000	0.42	0.22	0.14	0.05
PM2.5	**g/GJ**	0.000	0.00	0.23	0.14	0.04
NMVOS	**g/GJ**	0.001	7.79	4.27	0.36	0.12

For the emissions attributed to the EU and World as geographical locations, the tables are presented in Appendix B.

One of the main aspects caused by the geographical split is that of the fossil reference supply chains only a very limited part occurs within the Netherlands. The chains which are specifically selected for their Dutch focus (biogas, rapeseed and sugar beet) of course have almost all their emissions within the Netherlands. Also choices for production locations within the Netherlands caused a larger part of the bioenergy supply chain emissions to be contributed to the Netherlands. However for other reasons than air polluting emissions local production of bioenergy can still be favourable. Furthermore production within the Netherlands also increases possibilities to stimulate improvements which are more difficult with supply chains outside of the Netherlands.

5.3 Total impact of BOLK II bioenergy chains in 2020 in the Netherlands

To assess the total contribution the bioenergy chains will have to overall air polluting emissions in 2020, the potential application of each of the chains in 2020 has to be known. There are two main different types of chains reviewed in this report, namely bioenergy chains applied in transport and bioenergy chains applied for electricity and heat.

Biofuel scenarios

For the bioenergy chains applied in transport, scenarios as developed by CE/TNO are applied. CE/TNO estimate the total effect on the end use emissions of various biofuel chains and for consistency reasons it is logical that the same scenarios as applied for these are applied here to estimate the supply chain emissions.

The three scenarios as developed by CE/TNO are:

- Scenario 1: Current biofuels - continue with mature types of biofuels as we have today with a small part of advanced biofuels from waste and a modest growth of electric transport.
- Scenario 2: Ambitious development of advanced biofuels - strong growth advanced biofuels, mainly ethanol, with limited amount of current biofuels and a modest growth of electric transport.
- Scenario 3: Local air quality - Heavy use of biogas, BTL and HVO and a relatively high share of electric transport.

The shares of the different types of fuels in the three scenarios are depicted in Illustration 5 - 3.

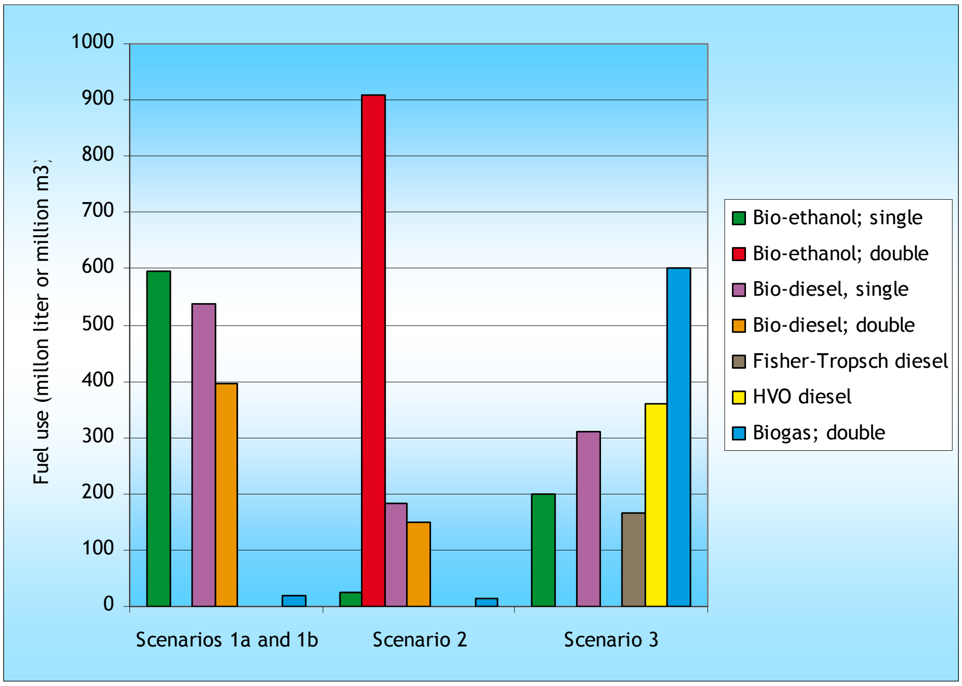

Illustration 5 - 3 Overview composition scenarios for biofuel use 2020[38].

For a full description of the scenarios as developed for BOLK II, we refer to the report of CE/TNO for the BOLK II programme. The following table (Table 5 - 9) indicates the total amount of each biofuel as estimated for each scenario in 2020, and indicates the contribution of the different feedstock types to each biofuel category. The chains not included in this study on the supply chain are not taken into account in assessing the total impact for the Netherlands in 2020, this mainly concerns HVO diesel and Biodiesel from waste streams ('bio-diesel, double').

Table 5 - 9 Composition biofuel spectrum for the Netherlands in 2020.

Necessary fuels in TJ)	**Scenario 1a&1b**	**Scenario 2**	**Scenario 3**	**Remarks**
Bioethanol (current)	12,651	546	4,249	25% sugar beet, 50% sugar cane (rest is ethanol from wheat)
Bioethanol (advanced)	0	19,250	0	50% wood pellets, 50% straw
Biodiesel (current)	17,296	5,897	9,978	60% rapeseed, 20% palm oil (rest is ethanol from soy)
Biodiesel (waste)	12,759	4,825	0	Not included in this study
FT diesel	0	0	5,963	100% from wood pellets
HVO	0	0	12,820	Not included in this study
Biogas	171	437	19,055	100% from co-digestion

In section 4.3, the effects of the various biofuel chains compared to their fossil references are indicated. In the following tables the scenarios are applied to assess

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[38] Graph comes from BOLK II study 'Impact biofuels on emissions of air pollutants' CE/TNO 2009

the total supply chain emissions caused by the use of biofuels in the Netherlands compared to the fossil reference. As mentioned, not all the biofuels as assessed in the scenarios are included. The fossil reference scenarios were only included for those biofuels that are taken into account. Therefore the scenarios can not be well compared among each other. For example in scenario 1 & 2 biodiesel from waste is absent, therefore also no diesel reference is included in the fossil scenario. The same holds for the use of HVO in scenario 3, for which no fossil reference is included in scenario 3. This is one of the reasons that the fossil scenarios vary in size and spread over diesel and gasoline. The second reason is that the fossil type of fuel is chosen based on the biofuels used. For example scenario 3 is based for a large extent on biogas and biodiesel, thus resulting in high use of diesel in the fossil reference scenario.

The total effect of the use of biofuels in the Dutch transport sector in 2020 is shown in Table 5 - 10.

Table 5 - 10 Total emissions in tonne per fuel-scenario for Dutch biofuel use 2020.

Fuel type	**Emission**	**Scenario 1**		**Scenario 2**		**Scenario 3**	
		Biofuel	**Reference**	**Biofuel**	**Reference**	**Biofuel**	**Reference**
Diesel replacers	NOx	608	650	215	239	854	1,532
	SOx	333	1,467	119	540	504	3,455
	NH3	610	2.17	208	0.80	357	5
	PM10	174	34	60	13	128	80
	PM2.5	48	67	17	24	45	157
	NMVOC	170	409	62	150	361	963
Gasoline replacers	NOx	1,004	478	67	991	337	161
	SOx	415	1,261	1,171	2,613	139	424
	NH3	45	1.47	239	3.05	15	0.49
	PM10	86	25	68	52	29	8
	PM2.5	19	50	25	104	6	17
	NMVOC	385	262	280	542	129	88

- The main conclusion from Table 5 - 10 is that the use of biofuels generates more air polluting emissions related to the supply chains in 2020 than the use of fossil fuels for NH_3 and PM_{10} emissions.
- SO_x and $PM_{2.5}$ emissions from the biofuel scenarios are lower then the fossil scenarios for both diesel replacers and gasoline replacers;
- Regarding the NO_x and NMVOC emissions, there is in most cases a reduction of emissions in the biofuel scenarios compared to fossil ones, except for the gasoline replacers in scenario 1 and 3. In these scenarios current ethanol fuels are used which have higher NO_x and NMVOC supply chain emissions then natural gas, while the advanced ethanol fuels applied

in scenario 2, show a strong reduction in these emissions compared to the fossil fuel use. The lower emissions in the advanced ethanol chains are caused by the co-generation of electricity during the process and the absence of an extensive agricultural part in the supply chain;

Taking the geographical split into account the impact of the use of biofuels on air polluting emissions within the Netherlands can be analyzed. Table 5 - 11 presents the total impact on air polluting emissions from the supply chains of the use of biofuels in the Netherlands in 2020. It is explicitly mentioned here that no end-use emissions (tank to wheel) are included and only those emissions taking place in the Netherlands are taken into account.

Table 5 - 11 Total emissions in tonne per fuel-scenario for the Netherlands 2020.

Fuel type	**Emission**	**Scenario 1**		**Scenario 2**		**Scenario 3**	
		Biofuel	**Reference**	**Biofuel**	**Reference**	**Biofuel**	**Reference**
Diesel replacers	NOx	210	160	79	59	526	377
	SOx	119	360	46	132	324	847
	NH3	160	0.53	55	0.20	97	1
	PM10	51	8	18	3	51	20
	PM2.5	15	16	5	6	18	38
	NMVOC	69	102	27	37	231	240
Gasoline replacers	NOx	179	128	-24	265	60	43
	SOx	158	336	1,107	697	53	113
	NH3	22	0.39	238	0.81	7	0.13
	PM10	28	7	61	14	10	2
	PM2.5	9	13	25	28	3	4
	NMVOC	133	70	176	146	45	24

- The main conclusion from Table 5 - 11 is that the use of biofuels generates more air polluting emissions related to the supply chains in the Netherlands in 2020 than the use of fossil fuels for NO_x, NH_3 and PM_{10} emissions. Regarding the increased NO_x emissions, there is one exception in the biofuels scenario 2 where a substantial contribution from the chain ethanol from wood results in less NO_x emissions because of the excess amount of electricity produced with by-products within that chain;
- SO_x emissions from the biofuel scenarios are lower then the fossil scenarios for diesel replacers and gasoline replacers. There is one exception in the biofuels scenario 2, where for the larger part advanced biofuels are applied. For these advanced biofuel chains, SO_x emissions result for the larger part from the conversion process (use of sulphuric acid) and are thus geographically located in this study in the Netherlands (production

facilities for lignocellulose ethanol on straw and wood are assumed to be located in Rotterdam);

- For $PM_{2.5}$ the emissions from the fossil scenarios are somewhat higher for all scenarios;
- NMVOC chain emissions of biofuels scenarios replacing fossil gasoline are higher. NMVOC chain emissions of biofuels scenarios replacing fossil diesel replacers are lower.

Stationary applications

For the total use of stationary biomass applications in 2020, the estimations as made by ECN/TNO are used. The project of ECN/TNO deals with estimating the overall end-use emissions of stationary biomass applications and for consistency reasons the same scenarios are applied for the supply chains emissions as reviewed in this report.

For a full description and argumentation of the scenarios as developed on stationary biomass applications for BOLK II, we refer to the report of TNO/ECN. Here only a short review of the data used for the estimation of total impact is given.

The following table (Table 5 - 12) is based on the results from the report of ECN/TNO and the data it contains is used to estimate to overall effect of the supply chain on air quality.

Table 5 - 12 Summary of results with regard to co-firing in coal fired power plants and small scale biomass CHP plants by TNO/ECN[39].

Plant	**Fuel use 2020 'low' (present study)**		**Fuel use 2020 'high' (present study)**	
	[PJ]	[%] [a]	[PJ]	[%] [a]
Co-firing coal-fired power [b]	86.9	2.2	86.9	2.2
Co-firing gas-fired power	-		-	
Biomass combustion CHP [c]	41.8	1.1	50.6	1.3
Biogas from waste tips				
Biogas from AWZI/RWZI [d]				
Agricultural biogas installations				
Other biogas installations				
Total anaerobic digestion	36.6	0.9	49.7	1.3
Bio-oil for power or CHP	5.5	0.1	5.5	0.1
Based on PPO [e]	P.M.		P.M.	
Based on animal fats [e]	P.M.		P.M.	
Based on palm oil	P.M.[f]		P.M.[f]	
Co-firing cement factory [g]	0		0	
Waste-to-power (CBS data) [h]	40.7	1.0	40.7	1.0

a	Percentage renewable energy of the projected primary energy demand in 2020 in the reference scenario of Daniëls and van der Maas (2009).
b	Based on a generating efficiency of 38% for existing coal-fired plants and 46% for new coal-fired capacity, and co-firing of 3,750 kt/a biomass in 2020.
c	Based on a electric conversion efficiency of 30%.
d	Afval Water Zuivering Installatie c.q. Riool Water Zuivering Installatie.
e	PPO = Pure Plant Oil. There are a few projects based on PPO or animal fat, among which a CHP plant based on bio-oil (animal fats) for heating for a swimming pool in Ermelo (Vliet, 2009).
f	Currently, there are no incentives (SDE) for power generation based on palm oil. Therefore, it is assumed that power generation based on palm oil will not be implemented.
g	Based on (Wilde et al, 2006). According to (Stam and Erbrink, 2008), ENCI in Maastricht would terminate their industrial activities (cement production) in 2010.
h	Of which 48% renewable (biogenic). Projection 2020 based on (SenterNovem, 2009).
Sources:	Vliet, 2009; SenterNovem, 2009; Wilde et al, 2006; Stam and Erbrink, 2008.

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[39] Table comes from BOLK II study 'stationary applications of biomass' by ECN/TNO 2009.

The level of detail as given in Table 5 - 12 does not exactly match the bioenergy supply chains as regarded within this study. To relate them several assumptions are made:

- All bio-oil for power or CHP uses palm oil as feedstock;
- All anaerobic digestion is based on co-digestion;
- All co-firing and biomass combustion uses wood pellets as feedstock;
- Waste to power is not regarded for supply chain effects on air quality.

These assumptions indicate some loss of detail but make it possible to connect main trends in supply chain impacts on air quality to the actual use of these supply chains in the Netherlands. This results in the following table (Table 5 - 13) indicating the application of the bioenergy supply chains as regarded within this study in the Netherlands 2020. For the calculation of the fossil reference scenarios the biofuel scenarios as indicated in Table 5 - 13 were combined with their direct fossil reference. The variation between scenario 1 and 2 is based on a change of split between anaerobic digestion and biomass combustion CHP, resulting in different fossil scenarios (split over natural gas and coal combustion).

Table 5 - 13 Use of biomass for electricity in 2020 in the Netherlands.

(PJ)	**Scenario 1**	**Scenario 2**
Palm oil for electricity	5.5	5.5
Biogas for electricity	36.6	49.7
Wood pellets for electricity	128.7	137.5

Applying the scenarios results in total emissions caused by the use of bioenergy in the Netherlands compared to the fossil energy. This total effect is shown in Table 5 - 14.

Table 5 - 14 Total emissions in tonnes per bioenergy-scenario for Dutch biofuel use 2020.

	Emission	**Scenario 1**		**Scenario 2**	
	(tonne)	**Biofuel**	**Reference**	**Biofuel**	**Reference**
Stationary applications	NOx	870	781	1,010	857
	SOx	490	459	556	538
	NH3	116	42	116	42
	PM10	67	40	73	43
	PM2.5	38	39	40	42
	NMVOC	399	323	504	380

- The table shows that supply chain emissions of NO_x, NH_3, PM_{10} and NMVOC occurring within the Netherlands from bioenergy chains are higher than those from fossil reference chains.

- SO_x and $PM_{2.5}$ emissions do not differ much between bioenergy and fossil energy chains. SO_x emissions are slightly higher, while $PM_{2.5}$ emissions are slightly lower for the biofuel scenarios compared to the fossil scenarios.

Combining this information with the geographical split to estimate the effects of air polluting emissions from these chains compared to their reference in 2020. These total emissions are given in Table 5 - 15.

Table 5 - 15 Total emissions in tonnes per bioenergy-scenario for the Netherlands 2020.

	Emission	**Scenario 1**		**Scenario 2**	
	(tonne)	**Biofuel**	**Reference**	**Biofuel**	**Reference**
Stationary applications	NOx	575	324	715	399
	SOx	269	271	334	349
	NH3	1	9	1	10
	PM10	34	15	41	19
	PM2.5	17	15	19	19
	NMVOC	332	195	437	252

- The table shows that supply chain emissions of NO_x, PM_{10} and NMVOC occurring within the Netherlands from bioenergy chains are higher than those from fossil reference chains.
- SO_x and $PM_{2.5}$ emissions do not differ much between bioenergy and fossil energy chains.
- NH_3 emissions resulting from the supply chain are the exception in this case, which are lower for the bioenergy chains. NH_3 emissions from the biofuel supply chain almost all take place outside of the Netherlands, they are namely mostly in the feedstock production phase (wood pellets and palm oil are imported). The NH_3 emissions of the fossil reference scenarios result from a small part of the supply chains emissions of coal attributed to the Netherlands (see Table 5 - 5). The main NH_3 emissions in the coal supply chain result from the mining part of the chain (blasting). As mentioned before in SimaPro however no differentiation is present between the extraction and transport phase for the coal supply chain. Therefore, a small part of the NH_3 emissions is attributed to the Netherlands.

6 Conclusions

Overall results emissions from bioenergy supply chains

There is quite some diversity in the performance of bioenergy supply chains compared to their fossil reference, namely between the different chains (some perform better than others) but also between different types of emissions.

The innovative biofuel chains in general perform better on air polluting emissions than the fossil references but also compared to the current biofuel chains. The supply chains of FT diesel, lignocellulose ethanol from wood and biogas have lower emissions on all air polluting substances than the fossil references and the current ethanol and biodiesel chains. The current biodiesel and ethanol chains perform better then the fossil references diesel and gasoline on SO_x and $PM_{2.5}$, but worse on NH_3 and PM_{10}. This is mainly caused by emissions in the agricultural part of the current biofuel chains (which is often absent with innovative and fossil chains).

Regarding electricity production, the supply chains of biogas and wood pellets have lower air polluting emissions than the coal, natural gas and palm oil supply chains. The palm oil and coal chains have highest air polluting emissions in their supply chain.

The updates as done on the various supply chains resulted in general in lower air polluting emissions with small exceptions for example for the supply chain of sugar cane ethanol. The comparison between BOLK I and BOLK II shows that recent improvements in sub-chains (like transport or production processes) already have a considerable influence on the total emissions of the supply chains.

Influencing air polluting emissions in the supply chain is difficult for the part of the supply chains that occurs outside the Netherlands. Especially the agricultural production and transport emissions are main causes of air polluting emissions, and for several chains larger parts of these emissions occur outside the Netherlands. In this study no improvements in truck and tractor emissions outside Europe were included. Also extensive improvements in agriculture (for example increase of organic farming or reduction of fertilizer) were not specifically taken into account, because these trends are not expected before 2020 on a large scale. Current focus on sustainability might have an impact on air polluting emissions due to reductions in the use of fertilizers, transport or process energy. Replacing fossil sources with biomass sources for energy provision during the conversion process, is positive from the greenhouse gas emission perspective, but often has a negative effect on air polluting emissions.

Overall impact of Dutch bioenergy scenarios

There is no strict overall trend in the use of bioenergy compared to the fossil energy use. The application of the Dutch bioenergy scenarios results in more air polluting emissions related to the supply chains in 2020 than the use of fossil fuels for NH_3 and PM_{10} emissions (both for stationary and transport applications). Regarding NO_x and NMVOC the emissions resulting from the bioenergy scenarios were higher than those from the fossil scenarios for the stationary applications. For the use of biofuel they were mostly lower compared to the fossil fuel use, except for the cases where current ethanol chains have a large part of the biofuel scenario. There the emissions on NO_x and NMVOC are higher than the fossil reference.

Regarding SO_x and $PM_{2.5}$ emissions, the biofuel scenarios give lower emissions then the fossil scenarios for both diesel replacers and gasoline replacers. The stationary application of bioenergy does not give very different result for the bioenergy scenarios compared to the fossil scenarios.

Impact in the Netherlands of Dutch bioenergy scenarios

Compared to the fossil supply chains, a larger part of the bioenergy chains is located in the Netherlands. This has possible positive effects on aspects like employment, security of supply and greenhouse gas emissions savings, but is less positive regarding local air polluting emissions.

The overall effect of the use of bioenergy on air polluting emissions resulting from the supply chain in the Netherlands compared to the fossil supply chains is therefore negative. The total variation in air polluting emissions by the increased use of biofuels in 2020 inside the Netherlands is maximum a couple of hundred tonnes per year.

A possible solution to reduce the impact of air polluting emissions from the bioenergy supply chains in the Netherlands could be to select those chains which take for the larger part place outside the Netherlands. However this is not reducing the actual emissions but moving them to another country. Furthermore having larger part of the supply chains outside of the Netherlands could have unfavourable side effects (less control, employment, deterioration of biodiversity, economic effects etc).

Appendix A Geographical split per chain

For each chain a specific geographical split was set, based on the production locations of each part of the supply chain. The geographical split as used in the analysis of this study is given per chain in the following figures.

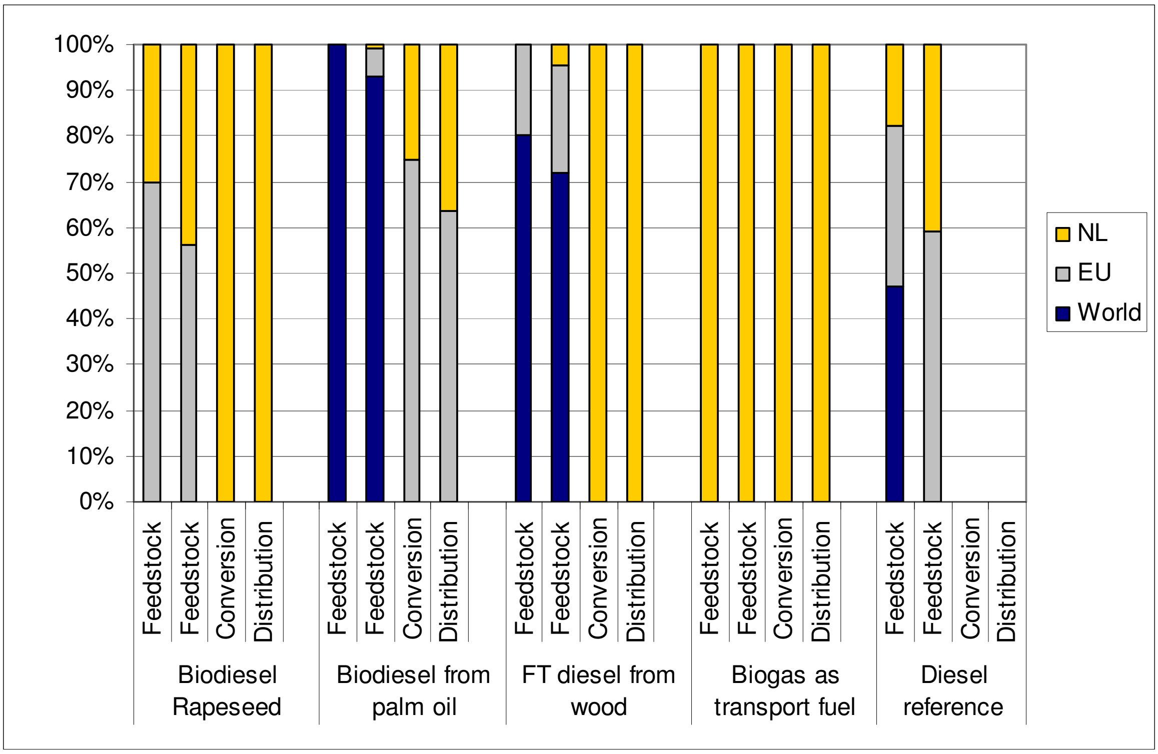

Illustration 6 - 1 Geographical split diesel & its biofuel replacements.

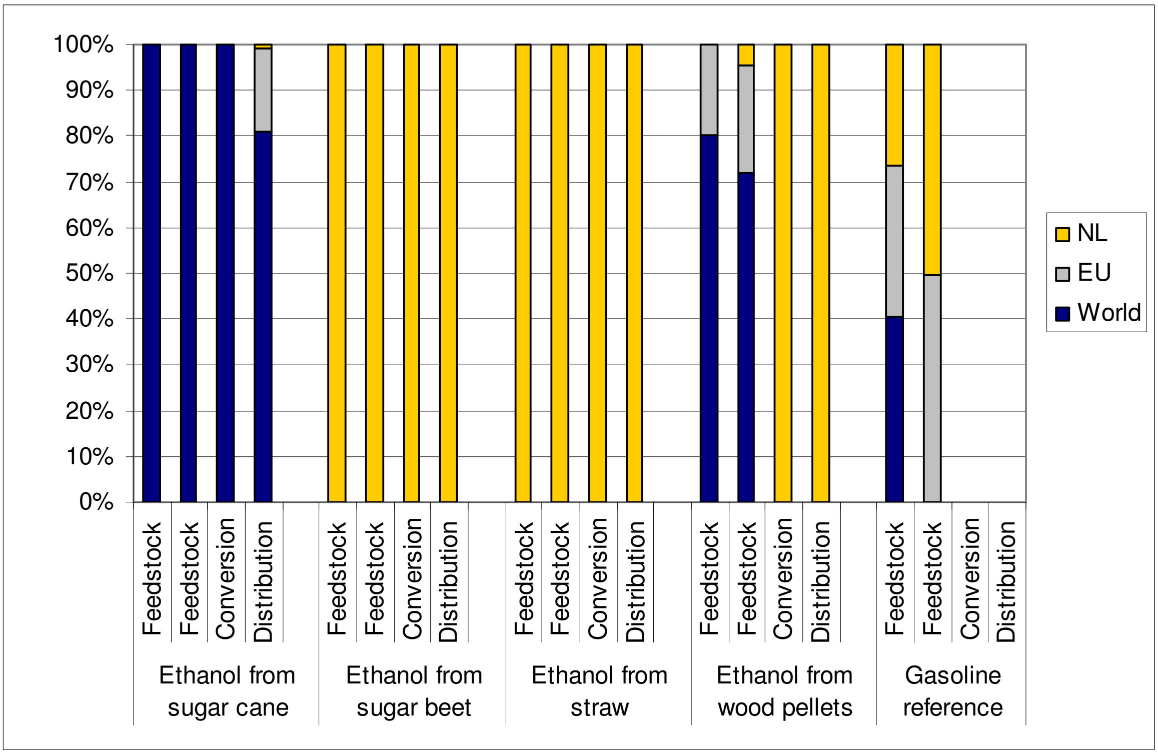

Illustration 6 - 2 Geographical split gasoline & its biofuel replacements.

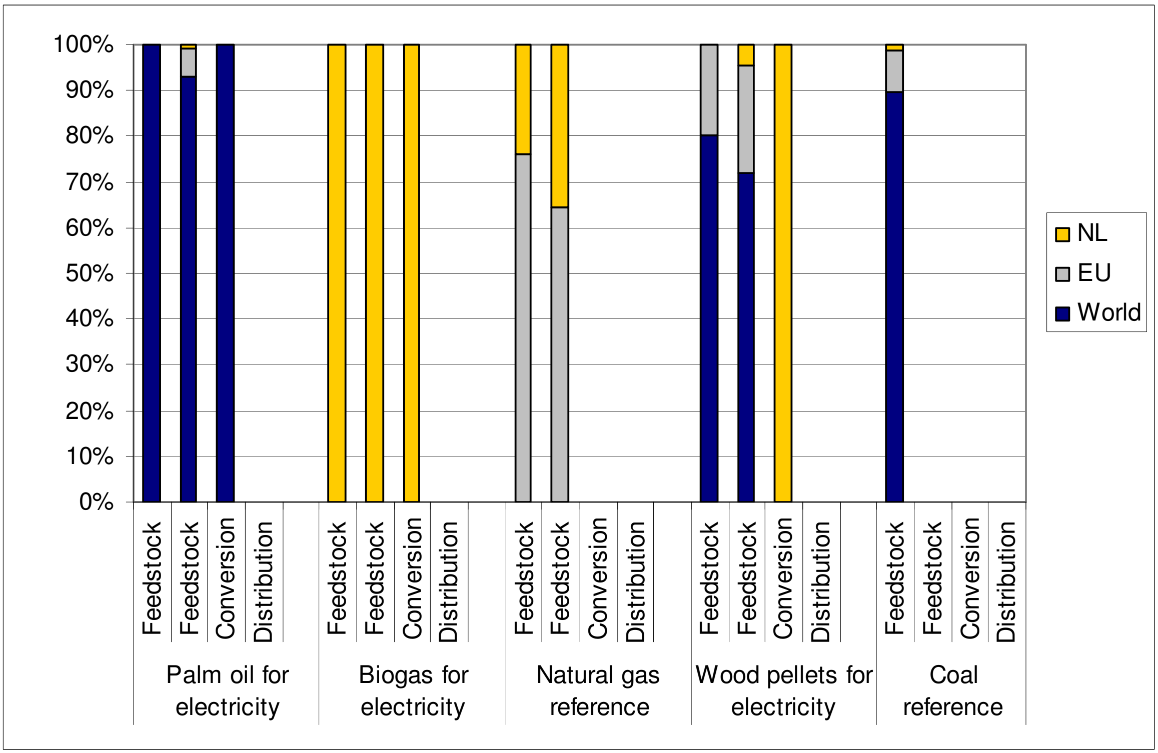

Illustration 6 - 3 Geographical split electricity chains & its biofuel replacements.

Appendix B Results geographical split EU & World

The results for the combination of the geographical split with the emissions per part of the supply chain for the EU (outside Netherlands) and World (not including EU & NL) are given in the following tables.

Europe (not including the Netherlands)

Table 6 - 1 2020 Emissions for diesel & its replacers in the EU.

Emission	Unit	Biodiesel from rapeseed	Biodiesel from palm oil	FT diesel from wood	Biogas as transport fuel	Diesel reference
NOx	**g/GJ**	23.62	5.11	3.49	0.00	15.08
SOx	**g/GJ**	10.64	2.76	2.08	0.00	33.94
NH3	**g/GJ**	35.71	0.02	0.01	0.00	0.05
PM10	**g/GJ**	9.94	0.26	0.20	0.00	0.79
PM2.5	**g/GJ**	2.44	0.18	0.28	0.00	1.54
NMVOC	**g/GJ**	7.45	1.53	2.75	0.00	9.54

Table 6 - 2 2020 Emissions for gasoline & its replacers in the EU.

Emission	Unit	Ethanol from sugar cane	Ethanol from sugar beet	Ethanol from straw	Ethanol from wood	Gasoline reference
Nox	**g/GJ**	3.26	0.00	0.00	1.42	16.64
SOx	**g/GJ**	1.68	0.00	0.00	1.35	43.81
NH3	**g/GJ**	0.06	0.00	0.00	0.00	0.05
PM10	**g/GJ**	0.24	0.00	0.00	0.13	0.88
PM2.5	**g/GJ**	0.20	0.00	0.00	0.00	1.74
NMVOC	**g/GJ**	0.57	0.00	0.00	2.39	9.13

Table 6 - 3 2020 Emissions for electricity chains and their replacers in the EU.

Emission	Unit	Palm oil (CPO)	Biogas	Natural gas reference	Wood pellets	Coal reference
Nox	**g/GJ**	0.11	0.00	16.51	3.97	6.13
SOx	**g/GJ**	0.02	0.00	18.55	3.72	1.44
NH3	**g/GJ**	0.00	0.00	0.02	0.04	0.54
PM10	**g/GJ**	0.00	0.00	0.70	0.24	0.34
PM2.5	**g/GJ**	0.00	0.00	0.74	0.50	0.33
NMVOC	**g/GJ**	0.00	0.00	13.53	1.65	0.89

World (not including the Netherlands and Europe)

Table 6 - 4 2020 Emissions for diesel & its replacers in the World.

Emission	Unit	Biodiesel from rapeseed	Biodiesel from palm oil	FT diesel from wood	Biogas as transport fuel	Diesel reference
NOx	**g/GJ**	0.00	39.20	13.03	0.00	19.92
SOx	**g/GJ**	0.00	27.11	7.45	0.00	45.10
NH3	**g/GJ**	0.00	23.11	0.06	0.00	0.07
PM10	**g/GJ**	0.00	5.47	0.70	0.00	1.04
PM2.5	**g/GJ**	0.00	1.94	1.10	0.00	2.05
NMVOC	**g/GJ**	0.00	5.29	9.44	0.00	12.37

Table 6 - 5 2020 Emissions for gasoline & its replacers in the World.

Emission	Unit	Ethanol from sugar cane	Ethanol from sugar beet	Ethanol from straw	Ethanol from wood	Gasoline reference
Nox	**g/GJ**	127.16	0.00	0.00	4.36	20.29
SOx	**g/GJ**	39.01	0.00	0.00	4.15	53.64
NH3	**g/GJ**	3.71	0.00	0.00	0.00	0.06
PM10	**g/GJ**	8.83	0.00	0.00	0.40	1.07
PM2.5	**g/GJ**	1.41	0.00	0.00	0.00	2.14
NMVOC	**g/GJ**	39.34	0.00	0.00	7.35	11.02

Table 6 - 6 2020 Emissions for electricity chains and their replacers in the World.

Emission	Unit	Palm oil (CPO)	Biogas	Natural gas reference	Wood pellets	Coal reference
Nox	**g/GJ**	37.07	0.00	0.00	12.50	60.56
SOx	**g/GJ**	24.77	0.00	0.00	11.72	14.21
NH3	**g/GJ**	20.75	0.00	0.00	0.12	5.30
PM10	**g/GJ**	4.93	0.00	0.00	0.76	3.41
PM2.5	**g/GJ**	1.76	0.00	0.00	1.54	3.21
NMVOC	**g/GJ**	5.02	0.00	0.00	5.55	8.81

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