EXPLORING POLICY OPTIONS TO STIMULATE BIO LNG IN THE NETHERLANDS

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The social costs and benefits of a sustainable heavy road transport fuel

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SUMMARY

In the Netherlands the Socio-Economic Council (SER) has signed an Energy Agreement where Dutch parties have laid out a basis for a broadly supported, robust and future proof energy and climate policy. In the joint vision on the future energy mix, LNG and bio LNG are being referred to as important opportunities for the Dutch economy to sustain heavy road transport fuels. A transition from diesel to LNG and bio LNG is capital intensive, because gas trucks are more expensive and there is no infrastructure or bio LNG production capacity yet. If the Netherlands wants to cut heavy road transport emissions, policies have to be developed to stimulate alternative clean fuels. The question arises what the effects of a transition to bio LNG will be for the Dutch economy and society. This thesis is going to answer the following main research question:

Which policies and regulations can be used to stimulate bio LNG and what is the value of SCBA in providing more insight in the effects of these policies?

The research question is answered by using several methods, firstly a literature review is conducted on current support schemes and regulations towards bio LNG on a national and European level. The next step is to conduct interviews with actors currently involved in (bio) LNG. Meetings of The National Working Group bio LNG in combination with conferences and project visits are used to compose a view on current and possible future measures to stimulate bio LNG.

Now the context is well established, the building of a SCBA model can begin. The first step is to compose a “business as usual” (BAU) case. The next step is to define the possible policy alternatives to stimulate bio LNG. The alternatives are composed by combining measures found in the previous phase. The number of trucks of different alternatives are based on sources found in literature. The alternatives go into the SCBA model and effects are calculated. The net present value of the effects is determined by the model and alternatives will be compared to the BAU case.

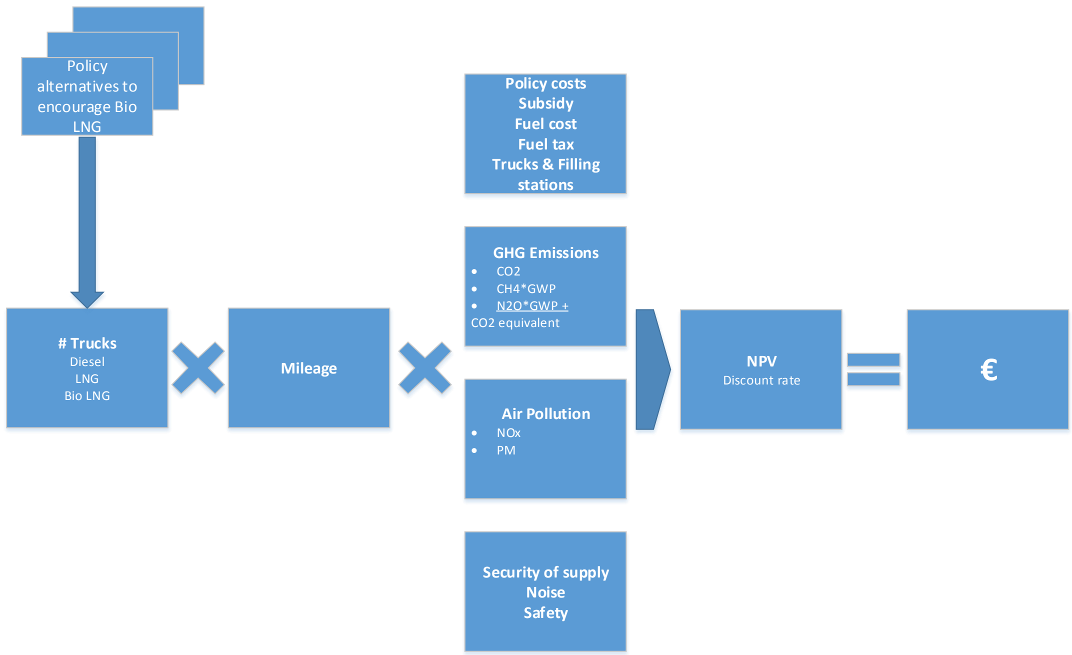
The use of the method SCBA in spatial-infrastructure projects to support ex ante go or no go decisions is well established. In this research the SCBA will be used to explore effects of policy alternatives in a very early stage of policy development. The SER proposed a future energy mix, but how to get there (measures) is not clear yet. The transition to alternative, currently not used fuels inherently imposes more uncertainties to the SCBA than in a more traditional SCBA practice. In this research the introduction of bio LNG is used to elaborate on the value of SCBA in exploring highly uncertain environmental policies.

From literature and interviews four measures to stimulate bio LNG are identified:

- Fuel tax increase or decrease
- Regulations on minimal amount bio LNG blending in LNG for transport
- Subsidize mitigated CO2 emissions in transport
- Virtually green bio LNG through certificates

These measures are combined in four policy alternatives; Gas, FQD, Diesel Tax and CO2 subsidize alternative. The alternatives result in certain shares of (bio) LNG trucks, based on sector forecasts and

assumptions. The figure below shows how the effects of the policy alternatives is calculated using the SCBA.



The timeframe is according to the SER Energy Agreement set to 2050. After the calculation and discounting, all effects are grouped to get more insight in the distribution of the effects for different actors. Calculating and adding all the effects results in the numbers presented in the table below.

Alternative	*Net Present Value BLN €*
BAU (reference)	0
Gas	1,4
FQD	0,8
Diesel tax	1,5
CO2 tax reduction	0,4

The model outcomes show that all alternatives score better than the BAU reference, this is mainly caused by the forecasted growing gap between the diesel and LNG fuel prices. LNG and bio LNG shares are strongly connected. The positive external effects of the policy alternatives increase relatively to the number of LNG and mainly bio LNG trucks. The Gas alternative scores high on macro-economic effects, but has the lowest governmental revenue.

The figure below shows how the effects are distributed over transporters, the fuel market, government revenue and external effects. From a governmental point of view the “Diesel tax” alternative seems interesting, but this alternative will increase costs for transporters. The by the sector proposed “Gas” alternative brings the least tax revenues for the government. This is mainly caused by a high number of LNG trucks and lower LNG tax than diesel tax. The transport sector faces the lowest costs in the Gas alternative. Figure 20The effects for the “fuel market” are not significant, this can be explained by the way the CBA model is built, in the input variable fuel price profit margins are included.

The SCBA method forces the researcher to value all effects and make them comparable. Detailed information about effects is crucial to perform calculations. In this research an “Effect data sheet of different fuels” of a consortium of research institutes is used as input data. Even though detailed information was available, a lot of assumptions have been made to reach the outcomes. The field of bio LNG is in a pilot plant stage, surrounded by many uncertainties.

Communication about the uncertain outcomes is important to value the SCBA in the decision process. This SCBA is executed in an ex ante policy development stage, not as a decision support tool (go or no go). The method is used for systematic data gathering and comparison of effects. SCBA increases the insight in the usefulness and feasibility of policy alternatives to stimulate bio LNG. This prevents policies that have a negative effect on the welfare to be developed. SCBA can result in a better understanding of the different effects of policy alternatives for policy makers. Decisions can be made on the basis of a better understanding of all the societal aspects of policy measures. The SCBA gives insight in the distribution and order of magnitude of different effects. The method exposes the real trade-offs. The distribution shows where problems can occur when policy alternatives are implemented. SCBA enhances discussions in the early stage of exploring policy alternatives by providing objective and independent information.

The SCBA is used in an undeveloped area of a possible transition to bio LNG where policy alternatives are not developed yet. This setting revealed some weaknesses of the SCBA method. The quality and bandwidth of input data is uncertain. Some variables are more certain than others, so there is a data asymmetry. Accumulation of assumptions and shortcuts can lead to biased results. The presentation of the outcomes is difficult, a generalized table only shows aggregated information.

Practically this SCBA is the first to examine the effects of a transition of heavy road transport to (bio) LNG. The outcomes of this research approves further development of (bio) LNG according to the SER fuel mix suggestions. If the policy measures are more crystalized out and the actual production of bio LNG is starting up the advice is to perform a more detailed SCBA in combination with a transport model to support final go or no go decisions about bio LNG stimulation.

Preface

This research report, on the effects of stimulation measures for bio LNG is the result of my graduation internship at Energy Valley and is part of the Master System Engineering Policy Analysis and Management.

Primarily I want to thank the graduation committee for their feedback and constructive criticism.

Of course I want to thank my colleagues at Energy Valley and Ruud Paap in particular, his knowledge about biogas and his network of field experts are of great value for this research project. The visits to bio LNG pilot plants made the subject more tangible. I also want to thank the National "Werkgroep bio LNG" of the LNG Platform, participation in this cluster of involved actors brings in lots of insight in the subject. The possibility to join the meetings of the working group enabled me to learn different aspects of bio LNG in a short notice. The National LNG Platform organizes several meetings which focus on different aspects of LNG, an opportunity to gather lots of information.

Furthermore I want to thank my parents, friends and family for their support.

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Bio LNG	Liquefied biogas
Bio methane	Upgraded biogas / green gas to >95% methane
Biogas	Mixture of different gasses produced by breakdown of organic matter in absence of oxygen
Biomass	Biological material derived from recent living organisms, used to produce biogas
CH_4	Methane
CO_2	Carbon dioxide
Green gas	Upgraded biogas with natural gas quality
GWP	Global warming potential
HBE	Former bioticket
LBG	Liquefied Bio Gas
LBM	Liquefied Bio Methane
LNG	Liquefied Natural Gas
NOx	Nitrous oxides
PM	Particulate matter
SCBA	Social cost benefit analysis
SDE+	Subsidy for sustainable energy (Stimulering Duurzame Energieproductie)
SNG	Substitute Natural Gas
TTW	Tank Too Wheel
WTW	Well Too Wheel

Exploring policy options to stimulate bio LNG in the Netherlands

THE SOCIAL COSTS AND BENEFITS OF A SUSTAINABLE HEAVY ROAD TRANSPORT FUEL

1. INTRODUCTION

The European transport sector is facing stricter emission rules. In their fight against climate change governments try to restrain harmful emissions and improve the air quality. Transport is responsible for a quarter of the European Union's greenhouse gas emissions (TNO ECN CE Delft, 2013). Transport in Europe is 94% dependent on oil, 84% of it being imported, with a bill up to EUR 1 billion per day (EC, 2015). The predominantly fossil fueled transport sector has to find new alternatives to meet stricter emission control measures. The need to switch to more sustainable energy sources is also triggered by depleting natural resources, concerns about increasing energy prices and desirable lower dependency on the Middle East and Russia.

Globally policy makers are searching for affordable, secure and sustainable energy sources to fuel their economies. Strategic choices are made to insure stable energy supply in the future. The Netherlands is currently facing challenging emission targets, the White Paper states that: "in order to drastically reduce world greenhouse gas emissions (…) a reduction of at least 60% of GHGs by 2050 with respect to 1990 is required from the transport sector" (EC, 2011). At the same time transport volumes for trucks are forecasted to increase between 7% and 30% from 2015 to 2030 (RR 2012 & NEV 2014).

In 2014 a number of organizations including governments, employers, labor parties and environmental organization presented "The sustainable fuel mix of the Netherlands" (Een duurzame brandstofvisie met LEF) (SER, 2014). The document is a part of a broader Energy Agreement for sustainable growth directed by the Socio Economic Council (SER) and signed in 2013. The agreement lays out a "broadly supported, robust and energy and climate policy". In The sustainable fuel mix for the Netherlands LNG and bio LNG are being referred to as important opportunities for the Dutch economy to sustain heavy road transport fuels.

Bio LNG is presented as a sustainable alternative for diesel to reduce emissions, air pollution and noise nuisance, but currently there is no significant bio LNG production capacity available. Biogas production facilities run on SDE+ subsidies and LNG is in its early development stage. Gas trucks are more expensive than diesel trucks and there is no national filling station infrastructure for LNG. It seems that bio LNG as successor for LNG justifies the transition to another (slightly cleaner) fossil fuel. There has not been a quantitative research to the effects of bio LNG in heavy road transport yet. The question arises what the effects of a transition to bio LNG will be for the Dutch economy and welfare. There are a numerous uncertainties concerning bio LNG at the moment.

Another uncertain factor that influences the effects of bio LNG is policy, for instance tax levels. The use of fossil fuels leads to CO2 emissions and air pollutions for which no market price is being paid (externalities). Governments can try to incorporate such externalities to a certain extend with taxes. Current tax levels for (bio) LNG are lower than for diesel and the government uses other incentives to steer fuel demand. Biofuels are (still) more expensive than their fossil counterparts, the market is not going to make the switch to bio LNG by itself. If the Netherlands wants to cut heavy road transport emissions, policies have to be developed to stimulate alternative clean fuels. Which policies to stimulate bio LNG and what their effects will be is going to be researched in this thesis. The main question is:

Which policies and regulations can be used to stimulate bio LNG and what is the value of SCBA in providing more insight in the effects of these policies?

This thesis will provide an overview of current measures on a national and European level that influence the introduction of bio LNG. These insights in combination with sector views on the development of bio LNG will be used to develop policy alternatives. If the policies are set the effects on welfare are being explored using a cost benefit analysis. This method is being used to gain more insight in the effects and the distribution of the effects of more bio LNG for the society.

Transition in energy infrastructures

Energy infrastructures are the backbone of our society, fundamental for many of our daily activities. Due to high capital intensity and long technical lifetime, infrastructure projects need to be planned to avoid suboptimal performance. Not only economic issues have to be addressed, but also environmental and social sustainable issues have to be taken into account.

In order to safeguard public values in heavy road transport the Energy Agreement proposes a transition from diesel to gas trucks. Gas engines tend to be cleaner and less noisy, and moreover, research shows limited positive environmental effects on PM, NO_x and SO_x emissions (TNO ECN CE Delft, 2013). CE Delft classifies the transition to gas trucks as a “no regret option” and stepping stone for the use of bio LNG (TNO ECN CE Delft, 2014).

The main disadvantage of gas is its volumetric energy content compared to oil products. In its liquid phase the volume of natural gas is reduced by a factor of more than 600, to liquefy natural gas it needs to be cooled down to -162°C {Kumar, 2011 #10}. The volumetric energy density of liquefied natural gas (LNG) is 2,4 times higher than of Compressed Natural Gas (CNG) and 60% compared to diesel {Arteconi, 2013 #23}. LNG powered engines have a reasonable range compared to diesel engines. The reduced volume of liquefied natural gas can have more advantages, for instance the ability to store the gas and transport the gas to off grid locations.

The LNG sector is in an early development stage, in the short to medium term the transition from oil based fuels to LNG can lead to lower emissions in heavy transport. On the longer term the switch from LNG to bio LNG can cut emissions further (SER, 2014). In the Netherlands there are currently around 250 LNG fueled trucks on the road (LNG Platform, 2015). To fuel LNG trucks an infrastructure is needed. In Rotterdam an additional harbor basin to enable LNG distribution for small scale LNG is build next to the GATE terminal (GATE, 2014). Shell is planning to build seven new LNG tank stations in the Netherlands (TVDT, 2014). The investments in LNG infrastructure are high. Regulations and fiscal schemes are being

used to accelerate the use of more sustainable energy sources. According to Brynolf the environmental profit to switch to more LNG is significant {Brynolf, 2014 #12}, when natural gas is being replaced by biogas transportation can become even more sustainable.
There is some discussion about the term bio LNG, liquefied biogas (LBG) and liquefied bio methane (LBM) refer to the same product, in this research the term bio LNG is being used. Bio LNG has some interesting advantages:

- Almost CO2 neutral (Masterplan LNG, 2012)
- High purity of methane
- Can be produced locally, which decreases energy dependencies
- Can be mixed 0-100% with fossil LNG to gradually improve sustainability

The main disadvantage of bio LNG is its price. The cost price of bio LNG is higher compared to fossil LNG. Governments can introduce incentives for the production of bio LNG, like for instance SDE+ and biotickets / HBE's for biogas production in the Netherlands. Incentives can have positive effects on the cost price of bio LNG production. The introduction of incentives is a way to influence contemplated behavior and to price some positive or negative external effects. The reduction of CO2 emissions can be seen as a positive externality which is partly compensated by biotickets.

Externalities are difficult to price and can be positive as well as negative. An example of a negative externality is the effect of air pollution caused by the transport sector. The emissions impose health effects to the society. Insight in these effects can be important to set a policy towards bio LNG. A way to determine all these effects of locally produced bio LNG compared to imported LNG is to conduct a social cost benefit analysis.

Company profile

The research is carried out for Energy Valley, a network organization which aims to encourage knowledge, employment, innovation and business in clean energy in the Northern Netherlands Region. Virtually the entire Dutch gas production on land takes place in the Energy Valley area. On a European level only Russia and Norway produce more gas. Energy Valley is a non-profit organization funded on project basis by businesses, local and regional governments. Their goal is to support projects in the sustainable energy sector. There are three main areas of activities of the foundation:

- Knowledge & Internationalization
- Bio Energy & Gas
- Modern Power Systems & Grids

This research is carried out within the Bio Energy & Gas department.

Research problem

The SER agreement about the sustainable future fuel mix is clear about the possible potential of renewable gas for the Dutch economy and society (SER, 2014). The document is the product of cooperation between different organizations and based on joint efforts to come to a shared vision about future sustainable transportation. The proposed directions has to be translated into policy and the agreements will be further translated into a plan of action. It is not clear yet which tax schemes, regulations or incentives will be implemented to support the switch to Bio LNG.

The LNG sector in the Netherlands is in its early development, one of the first bio LNG production plants was opened end 2012 in Haarlem (GGS, 2012). Another small scale liquefaction plant in Wijster which processes biogas into bio LNG is currently in its test phase (GGNL, 2014). There are risks and uncertainties about the performance of the new production plants. What is the production price of bio LNG and what is the lifecycle of a production plant? In order to be competitive as a fuel biogas production, polishing and liquefaction cost have to decline, therefore it is important to monitor innovations. The competitiveness is also influenced by fossil fuel prices. Currently the biogas is mainly used in combined heat and power units (CHP), in district heating plants, or for injection in a natural gas grid {Raven, 2010 #13}. The total available biomass to produce biogas is limited, different routes to utilize biogas are competing with each other.

There are numerous effects currently not or not completely valued in the price of fuel. What is the effect of more bio LNG on CO2 emission? What is the value of lower nuisance levels of truck for society, and what are the effects of the introduction of bio LNG on security of supply? All the effects should be valued to compare alternatives and make a well-considered choice between policy alternatives. The effects are currently not known.

There are different effect valuation methods, should we compare well to wheel performance or tank to wheel performance between fuels? If a well to wheel performance is used the distribution system also influences the total utility. The current LNG market is based on high volume low frequency, but how is the distribution network of bio LNG going to be?

Social and Scientific relevance

Insight in the effects of different policy alternatives regarding the transport fuel mix of the future can contribute to a more efficient policy and a higher social wellbeing. Not only economic growth will be addressed but also other public values like air quality and security of supply. If the introduction of more bio LNG in the Netherlands results in higher social benefits than costs, policies can be adapted to actively support locally produced biogas and liquefaction units and associated investments. On the other hand, if the analysis shows more costs than benefits, the funds to support Bio LNG can be used in another way to increase social wellbeing.

The outcomes of this research can also be used to communicate the compiled complex system of effects that the introduction of more bio LNG can have on the Dutch society. More insight in for instance noise reduction, emissions and security of supply and their distribution can lead to more efficient policy.

There are many techniques for appraising policies and projects that impact the environment e.g.; Environmental Impact Assessment, Cost Effectiveness Analysis, Scenario Analysis, Risk Assessment Analysis and the Cost Benefit Analysis {Hanley, 1993 #14}. CE Delft has performed LCA studies about emission reduction of different alternative fuels. In long term strategic choices for fuel sources a comparison has to be made between alternatives and their total effects on society. In an ideal world all the alternative fuels have to be compared and scored on their welfare effects. This thesis focusses on bio LNG because it is appointed to be favorable option and time scale for the research is limited.

To value economic, social and environmental impacts on society a cost benefit analysis can be used. “A key aspect of CBA is correctly measuring and valuing environmental and social (non-market) goods such as effects on human health and environmental integrity” (EPA, 2014). In this research the cost benefit analysis (CBA) will be used because non market goods like energy security of supply and clean air are important effects which are currently not valuated in bio LNG prices. The CBA is an economic analysis which can be used for efficient decision making. Main areas where the technique is being used are; transport, environmental policy and healthcare (OECD, 2006). The cost benefit analysis dates back to the 19th century where Jules Dupuit describes a technique to measure utility of public works in 1844, used in an infrastructure appraisal in France (Dupuit, J. 1844).

The idea of performing a cost benefit analysis is to determine the effects of different project or policies to human wellbeing (utility). In economics perfect markets have a self-regulative behavior which drives them to efficiency, which is what Adam Smith calls the “invisible hand” {Smith, 1887 #19}. There are examples of situations where market behave imperfect for instance in the case of externalities, natural monopolies and public goods. Stiglitz points out that the invisible hand is invisible in the case of externalities {Stiglitz, 1991 #20}. Clean air is an example of a public good and air pollution can be an example of an externality. The costs of the air pollution for the rest of the society is neither compensated for the producers or users of motorized transport.

The goal of this research is to explore current measures to stimulate (bio) LNG and abstract policy alternatives from literature and interviews. These alternatives are valued and compared to a reference case using a SCBA. Traditionally CBA’s are used as decision supportive instruments in comparing infrastructure projects. The S is SCBA refers to the goal of the method to incorporate not only financial effects, but all social effects. Examples of effects that can be incorporated in a SCBA are emissions, air pollution and safety costs.

Investments in infrastructure projects have different characteristics compared to environmental policies concerning energy transitions. Policies can influence consumer behavior and curtail demand. Investments or subsidies are instruments, but there is also the possibility to regulate the use of certain products. The effects of policies are inherent more uncertain than the results of investments projects.

There are more differences between infrastructure projects and environmental policies. The uncertainties on the costs and benefits differ. The benefits of environmental policies are generally external effects. There are no market prices for these external effects, what is the social cost of emitting a kilogram of carbon dioxide? With the discount rate the net present value is calculated of the interest of future generations, environmental effects can be discounted other than economic investments in for instance trucks. The challenge is to be able to conduct a CBA in a system that is surrounded by uncertainties. In the reflection of this thesis the method in relation to this problem is further discussed.

This research aims to use the method SCBA to develop more insight in the effects of different policies to stimulate bio LNG on the society. Performing a CBA can also be helpful in this early stage to select feasible alternatives and build a framework to evaluate innovation policy (SEO, 2006). The method to come to the policy alternatives is by a literature review, interviews and working group meetings.

The scientific relevance is not to only to conduct a CBA, but to explore the feasibility of the method in a highly uncertain field of a transition to an alternative fuel. In order to estimate the effects of policy alternatives and how they are distributed, it is necessary to gain insight in; involved actors their behavior in the system; policy alternatives; tax schemes and regulations and technical system decomposition.

Research questions and methodology

This thesis provides more insight for policy makers in the long term effects of a partial transition in heavy road transport from diesel to bio LNG for the society. Questions that will be addressed are; what are the greenhouse gas effects of bio LNG trucks, which incentives can be used to stimulate bio LNG and what are the projected fuel costs. In order to build the research in a structured manner, the following Main Research Question (MRQ) and sub questions are formulated:

Which policies and regulations can be used to stimulate bio LNG and what is the value of SCBA in providing more insight in the effects of these policies?

Sub questions:

1. What is bio LNG?
2. Which important drivers and barriers can be identified for bio LNG?
3. Which actors are involved and what are their interests?
4. What is the current national and European policy (status quo) towards bio LNG?

5. What are possible and feasible policy alternatives?
6. How can CBA be used to valuate policy alternatives towards bio LNG?
7. What is the influence of different scenarios on the model outcomes?
8. What are the social costs and benefits of different policy alternatives?
9. What is the value of SCBA in this research?

Purpose

In this research an ex-ante calculation is made to test the feasibility of different policy alternatives. The sum of costs and benefits can be used as an indication of the total effects and their distribution of certain policies to stimulate bio LNG in road transport on society. It is not the intention that this research can be used as blueprint for policy makers, while results are dependent on choices the researcher makes. The inputs needed to build a CBA are uncertain especially in new innovative fields, like bio LNG production. A structured review of effects and costs can be helpful for realistic comparisons between energy carriers and road transport modalities.

Research structure

The research will be build up as represented in Figure 1. First of all a literature review will be conducted about the subject bio LNG. Throughout the research several meetings with the National Working Group bio LNG are planned where the latest developments about the subject will be discussed. Interviews with pioneers in the bio LNG sector are conducted and a few project visits to production facilities will take place to make the subject more tangible. Figure 1 shows the graphical representation of the research structure.

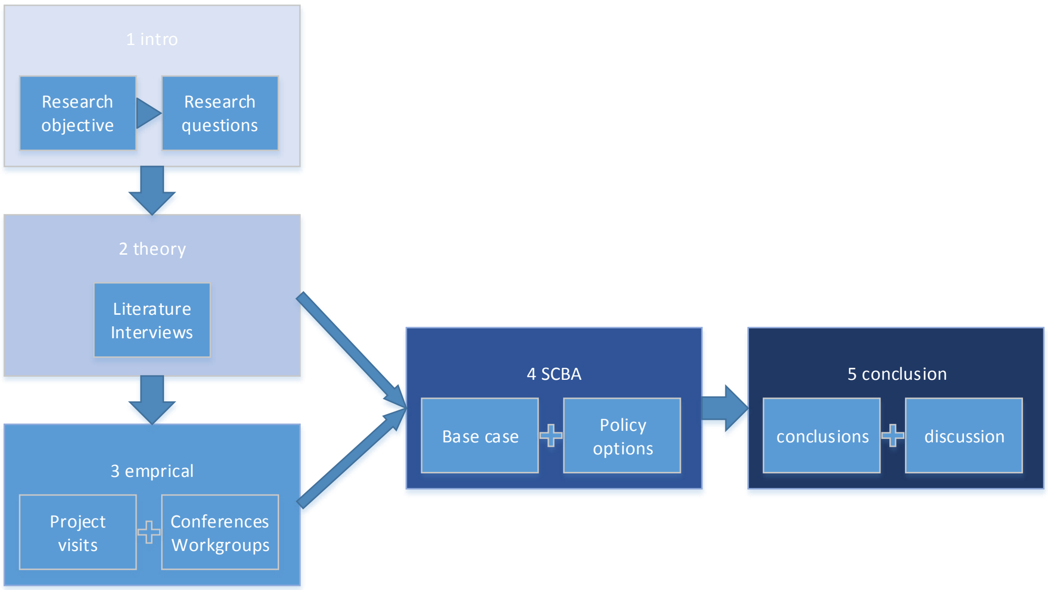

FIGURE 1 RESERACH STRUCTURE

Research method

Goal of this research is to get a better overview of the feasibility of bio LNG in the Netherlands, in a structured manner. The Cost Benefit Analysis is used as a framework to research direct and indirect and external effects of bio LNG to the society. As a guidance the "OEI leidraad" and update {Eijgenraam, 2000 #24} (CPB & PBL 2013) and "Leidraad MKBA in milieubeleid" (CE Delft, 2007) are being used. The steps to conduct a cost benefit analysis force the researcher to develop a broader understanding of current regulations, important actors, other project options and policy effects.

Multi criteria analysis (MCA) is often used to compare alternatives, the CBA is used in this research to develop more insight in the real tradeoffs generated by the policy. According to Mouter the CBA in the Netherlands has two roles: {Mouter, 2013 #42}

- a role in the appraisal of spatial-infrastructure projects,
- Ex ante evaluation to support "go or no go" decisions for investments in classic infrastructure projects and spatial projects over a situation in which no ex-ante decision-support system (like CBA or MCA) is used.

In this research the method is more used as an exploration tool or platform for systematic information. Mouter also points out that "there is no standardized approach and hardly any tradition in the valuation of environmental 'goods' in the Netherlands".

A CBA model is used to value all costs and effects of different policy options on a systematic way. Information about effects and costs of different measures can help policy makers to choose in their design for measures that have a positive total societal effect. Different alternatives can be realized against certain costs and have different effects on society. To value policy alternatives the societal effects have to be prized. Certain assumptions are made that cannot be scientifically grounded for instance; future extra investment of gas trucks, biogas production mix in 2030, discount rates and price of emissions. These assumptions result in aggregated costs and benefits that are not absolute. After the monetization of all the relevant societal effects, the net present value of these effects is calculated to a certain point in time, normally t=0. The different steps are based on the guideline CBA in environmental policy (CE Delft, 2007)

POLICY COSTS

To get an accurate estimation of the effects of policies, the effectiveness of some measures have to be taken into account. Policy interventions can impact the target groups on a technical, organizational or other level as can be seen in Figure 2.

The demand for fuels is strongly driven by taxation. Governments can introduce price incentives to stimulate a change in fuel mix. In the passenger car market this is already happening, gasoline, petrol and LPG can substitute each other. In the truck market LNG can substitute diesel which is currently the dominant fuel carrier. Diesel trucks cannot run on liquefied gas, but there can be a retrofit to use LNG next to diesel as a dual fuel set up. There are dedicated gas trucks which can be fueled by LNG and/or bio LNG.

The responsiveness on policy measures is not completely rational, therefore the correlation between measures to stimulate bio LNG and the number of actual bio LNG trucks is uncertain. The calculations in the SCBA are based on number of trucks and their emission factors, predictions of the "Deelrapport wegvervoer duurzaam gasvormig" are used as input. In this document several connected actors have developed a joined view on future number of LNG and bio LNG trucks. Policy measures that have to be taken to realize these numbers are also described.

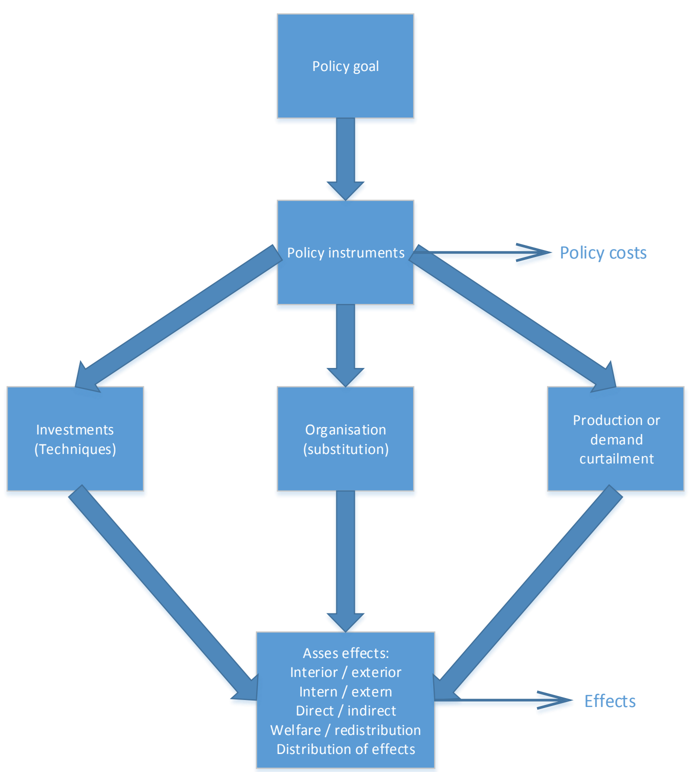

FIGURE 2 ASSES POLICY EFFECTS AND COSTS (ADJUSTED FROM LEIDRAAD)

DATA ANALYSIS

It is only possible to calculate total benefit of a policy option if there is detailed information available of actual projects. While in the production of bio LNG is in a pilot project phase, production costs will vary significant between locations. The focus of the research will not be on the “profitability” of different policy options, but on the description of the complex socio system, its actors and dependencies.

The input variables for the CBA are derived from several sources. Most of the data is found in literature by a desk research, for input of the CBA that can’t be found in literature some experts will be interviewed. Data which is not available in literature and cannot be given by experts is being estimated. The focus will not be on the exact outcome of the CBA, but more on the structured steps to come to a CBA. Goal is to develop a better understanding of effects which are currently valued and not valued in the price of fossil and bio LNG.

The Dutch LNG Platform consists of five working groups; Regulations & Safety, Road Transport, Shipping, Strategic Environment Management and bio LNG. Participants of the workgroup bio LNG currently involved in bio LNG developments are; Rolande, Port of Amsterdam, PrimaGaz, Air Liquide, Linde and Energy Valley. The Port of Amsterdam, GroenGas Nederland, Rolande and Energy Valley already promised to contribute to this research by providing information about bio LNG production. Via the working group several documents will be available that are used to calculate the energy agreement of the SER. In case of unclear or ambiguous data contact stakeholders will be contacted.

Production facilities in Apeldoorn (Osomo) and Wijster (GTS) can be used as case studies for data input of the CBA. In the CBA calculation different variables are used to forecast the cost and benefits of different policy options. The forecasts of emission factors or oil prices consists mostly of a few points in time with their assigned values, the space between those data points will be interpolated. Table 1 shows the information needed for this research and how the data is gathered.

INFORMATION GAP	RESEARCH TYPE	SOURCES
BIO LNG PRODUCTION	Literature, interviews, plant visits, European biogas conference	
CURRENT POLICY MEASURES	Interviews, literature, Working Group Bio LNG, LNG platform meetings	European directives, national regulation and incentives
BUSINESS AS USUAL (BAU)	Literature, interviews, LNG platform meetings	RR 2012, NEV 2014, SER
TRANSPORT DEMAND	Literature	RR 2012, NEV 2014
GAS ALTERNATIVES	Literature, interviews	Deelrapport wegvervoer duurzaam gasvormig

FQD, DIESEL TAX, CO2 ALTERNATIVES	Assumptions based on Gas alternative	
EFFECTS	Interviews, literature	PMC's. TNO, ECN, CE Delft
FUEL PRICES	Literature	World Energy Outlook, NEV 2014, ECN, SDE+ prices
EMISSION FACTORS	Literature	TNO, CE Delft
SHADOW PRICES	Literature	CE Delft

TABLE 1 DATA NEEDED FOR THIS RESEARCH AND SOURCES

DEMARCATION

In this research resources and time are limited, to answer the main question and sub questions within the timeframe the system needs to be demarcated. It is not possible to describe all variables and their determining factors. In this research the main choices to simplify the analysis are described below. Further research can broaden the system and include more variables and sectors.

Bio LNG has potential in two sectors, shipping and heavy road transport according to the Energy Agreement (SER, 2014). The usage of bio LNG for transport is favorable where electric drive or propulsion is not an alternative, because of the limited capacity of batteries. During meetings with the National Workgroup bio LNG it becomes clear that the current potential for heavy duty trucks is higher than for shipping. The lifecycle of barges is longer than of trucks, some trucks are replaced within 5 years. The focus will be on heavy duty road transport trucks. In team discussions it becomes clear that the introduction of bio LNG can also boost fossil LNG developments and vice versa (Werkgroep bio LNG, 2014). The SCBA model has to deal with the correlation of LNG and bio LNG.

There are mainly two types of gas trucks. Dual fuel and single fuel gas trucks. Dual fuel gas trucks operate with different shares of gas and diesel mixtures. The share of LNG can be continuously adjusted from 0-75% (TvdT, 2014). To increase simplicity and overview only single fuel gas trucks and single fuel diesel trucks are incorporated in this research.

Emission factors play an important role in this research, what are the emissions of a gas or diesel truck? Not only powertrain efficiency, but also fuel production pathways have to be included. "A shift to renewable/low fossil carbon routes may offer a significant greenhouse gas reduction potential but generally requires more total energy. The specific pathway is critical" (JEC, 2014). In this research the well to tank (WTT) plus tank to wheel (TTW) emission factors are used.

The geographical demarcation is set to the Netherlands. This relates to the demarcation used in the SER energy agreement. The Dutch government acts in a European context but can design own policies to encourage the use of renewable energy. "Because of the size of the Netherlands it is not realistic to try to force the development of new engine techniques or fuel sources" (SER, 2014). Choices made by governments to stimulate certain fuels in the fuel mix can be strategic, to stimulate a sector or to safeguard national interests. The effects of policies to encourage bio LNG are assessed in this research.

SCALE OF THE MODEL

Along with the SER sustainable growth report the timescale will be set to 2050, in yearly steps. In environmental policies it is important to choose a timescale corresponding to environmental problems. Alternatives to reduce CO2 emissions do not pay off in 5 years. Air pollution is partly a local problem and partly global, CO2 is for instance a global problem while NOx or PM are more local problems.

The influence of more bio LNG trucks in the Netherlands on diesel or oil prices can be neglected, because the Dutch market is relatively small. It could be that more bio LNG trucks can lead to more biodiversity but the impacts will be small compared to other pollutants.

DISCOUNT RATE

The discount rate of environmental effects is set to 2,5% according to the advice in CE guidance (CE, 2007). Costs to restrict emissions are mostly upfront while positive effects of lower emissions can last for decades, also the longer period to calculate the effects allow a low interest rate. In the sensitivity analysis different rates will be applied to get a feeling of what the impact will be on the profitability of policies. A risk premium of 3% is set on the discount rate for investments with macro-economic risks; trucks, fuel costs and fueling stations. The discount rate for investment other than environmental is set at 5,5%, this is in line with the Dutch CBA guidance (CPB, PBL 2013).

POSSIBLE OUTCOMES

More insight in the effects of more bio LNG for the Dutch economy and society. A broader understanding of the socio technical system. The current Dutch policy and regulations towards bio LNG will be evaluated. On the basis of trends, drivers and barriers two or three scenarios will be drawn. After the identification of the scenarios a number of policy alternatives with resulting amounts of bio LNG penetration will be evaluated with a cost benefit analysis. The effects of bio LNG on CO2 emissions, air quality, security of supply, employment and noise reduction will become clearer.

A possible outcome of this evaluation can be that regulations on blending bio LNG might be a cheap option to increase the use of bio fuels, reduce CO2 emissions and stimulate local economy. On the other hand if the CBA shows that bio LNG has a low societal utility, governments do not need to stimulate bio LNG. The tax schemes could be revised. The guideline to perform a CBA for not proven technologies could be improved, the method can be used more as a structured framework than a calculation tool.

2. CONTEXT & CURRENT SYSTEM

To answer the main and sub questions a better understanding of the production of bio LNG is essential, this chapter elaborates on the source, production, upgrading and liquefaction of bio LNG. The different routes of biogas are explained. The movement away from fossil fuels to more renewable biofuels can be seen in a broader perspective of the bio based economy. Currently we are dependent on fossil fuels for food, feed, chemicals, energy and fuel production, while in a bio based economy biomass will be used as an input.

What is bio LNG?

Bio LNG is composed of two words, bio which comes from the Greek word “bios”, which means life and LNG which is an abbreviation of liquefied natural gas. The composition is confusing because natural gas is a fossil fuel while “bio” indicates that geologically recent carbon fixation in the form of living organisms is meant. Natural gas is formed when layers of buried plants, gases, and animals are exposed to heat and pressure over thousands of years. Other terms that are being used are liquefied biogas (LBG) and liquefied bio methane (LBM). Where biogas consists primarily of methane and CO2, and liquefied biogas only consists of a few percent of CO2 this term LBG is also not correct. Liquefied bio methane is the term that is the most correct, but bio LNG is used in industries and communication.

BIO LNG BLEND

In the industry the definition of bio LNG is not clear yet (Werkgroep bio-LNG, 9-2014). Practically it is not likely that pure bio LNG will fuel trucks, it will probably be a blend. “Worldwide, many governments now require that a minimum percentage of transportation fuels sold consist of Biofuels” {De Gorter, 2009 #32}. Blending fossil fuels with biofuels is a common practice, with blending the fuel quality can be kept stable while batches of fossil- or biofuel can differ in quality. In the Netherlands there is a legal obligation that 5,5% of the transport fuels has to be a biofuel in 2014 (I&M, 2013). In the EU there is a directive that prescribes that in 2020 10% of the transport fuel has to be renewable (EU FQD, 2009).

BIOMASS

The chemical composition of bio LNG is almost purely methane CH4, with small traces of CO2, H2S and H2O. The source of this methane is biomass. Biomass consists of living organisms or recent living organisms. Plants and plant based material or lignocellulose biomass can be used as an energy source and input to produce biogas. The conversion of biomass into biofuels can be done through chemical, biochemical and thermal conversion methods. Figure 3 gives an overview of different sources of biomass and processing techniques, as well as more options to use the end products of biomass.

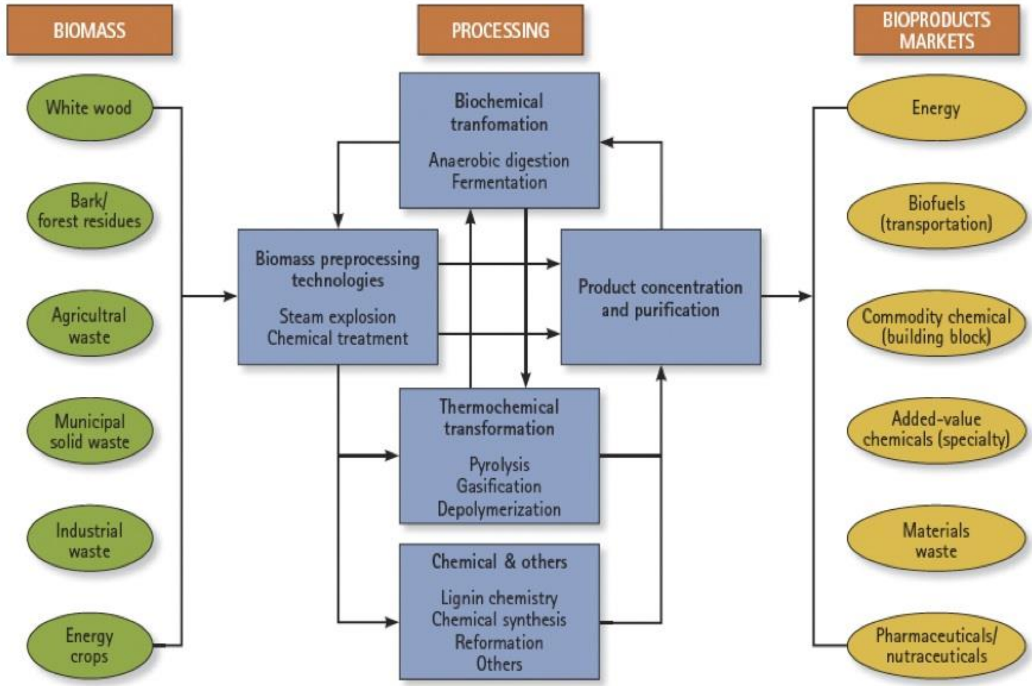

FIGURE 3 BIOMASS PROCESSING

As can be seen in Figure 3 different routes can be taken in biomass processing to bio products. The main route for biogas in the Netherlands is currently grid injection and combined heat and power production. The advantage of direct use in CHP is that the raw biogas can be used, the disadvantage is the low value of biogas see Figure 8.The input determines what kind of bio product it becomes, in the Netherlands the use of energy crops is hardly not used due to concerns about food competition. Dutch biogas mainly originates from waste streams. The path of biochemical transformation is widely used (De Meerlanden, Schoteroog, AEB). In waste biomass there is a distinction between wet and dry biomass, the water content in the biomass determines which processing technique is favorable to transform biomass in biogas (Figure 4). Currently biogas production is mainly done by the anaerobic digestion of wet biomass, from 2030 ECN expects that thermal conversion will become the price setting technology (Interview Marc Londo – ECN).

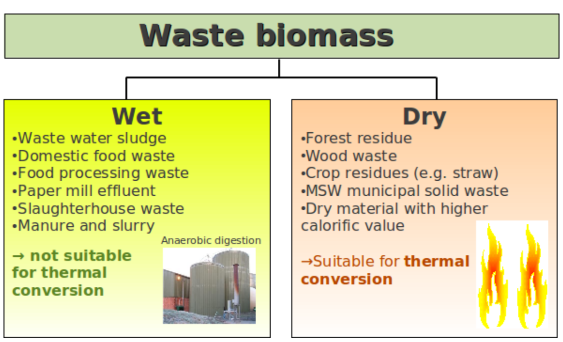

FIGURE 4 TYPE OF WASTE BIOMASS DETERMINES CONVERSION STEPS

Hoefnagels et al indicates that depending on the technological developments and substitution level a significant share of the biomass needs to be imported, up to 80% by 30% substitution of fossil fuels {Hoefnagels, 2013 #34;Hoefnagels, 2009 #35}. The share is dependent on various variables, green gas grid injection, biogas CHP usage and the use of compressed biogas in cars.

BIOGAS

In this research the focus is on LNG produced from biomass. The step in between is to produce biogas which is liquefied. As can be seen in Figure 3 biogas can be combusted directly to produce heat or in a combined heat and power (CHP) plant to produce power as well, but can also be converted into various forms of biofuel. The dominant method used to produce biogas from biomass is anaerobic digestion. Biogas is a mixture of gasses produced by the breakdown of organic matter in the absence of oxygen and consists primarily of methane 40-75% and CO2 15-60% {Ryckebosch, 2011 #26}. Figure 6 Biomass to bio methane shows the necessary steps to produce bio methane from biomass.

Before the biogas can be chilled to liquefy it needs to be cleaned and upgraded. CO2 and other contaminations have to be separated from the methane to prevent condensation which causes damage to the equipment. To clean and upgrade biogas different techniques can be used:

- Pressurized Swing Adsorption PSA
- Absorption with water, solexol or a chemical reaction
- Membrane separation
- Cryogenic process

Raw biogas differs in composition dependent on the sources where the biogas is originated as can be seen in Figure 5.

Component	Concentration in	Biogas plant	Sewage plant	Landfill
Methane	%	60 - 70	55 - 65	45 - 55
Carbon dioxide	%	30 - 40	balance	30 - 40
Nitrogen	%	< 1	< 1	5 - 15
Hydrogen sulphide	ppm	10 – 2000	10 - 40	50 - 300

FIGURE 5 TYPICAL RAW BIOGAS COMPOSITION (SGC, 2001)

Methane is the main energy carrier in natural gas and is like other fossil fuels carbon based. The advantage of methane is that is currently widely used. Bio methane contains typically 95‑97% CH4 and 1‑3% CO2 {Ryckebosch, 2011 #26}. The raw biogas needs to be upgraded to 99% methane before it can be liquefied, if the cryogenic technique is used hydrogen sulfide and water needs the removed first. If the biogas is upgraded to natural gas specifications it is called green gas, this green gas can be injected in the grid without causing problems in appliances.

Apart from biomass there is another source to produce biogas: Power to Gas (PtG / P2G). PtG is defined as “the production of a high-energy density gas via electrolysis of water” {Bünger, #31} Synthetic methane can be produced by a reaction between hydrogen produced by electrolysis and CO2. If the source of carbon is from a recent living organism and the electricity used is renewable, bio LNG can be produced with Power to Gas. If the electricity is produced by sustainable sources, synthetic methane can be sustainable. If the processes are carried out exclusively with renewable electricity (RE), the product is labelled renewable Power-to-Hydrogen or renewable Power-to-Methane {Bünger, #31}. PtG can be used in times of wind energy surplus. Currently the investments are too high to be competitive (PtG workshop Energy Convention, 2014). If the availability of biomass becomes a problem PtG can become an option to produce biogas that can be used in transport.

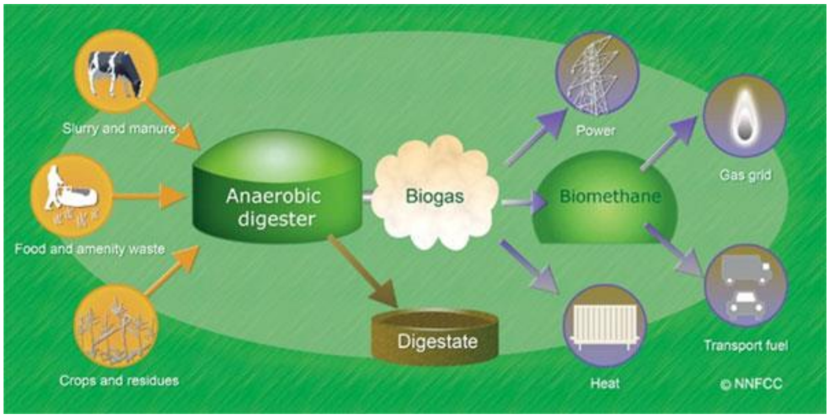

FIGURE 6 BIOMASS TO BIO METHANE

There is a distinction between different generations of biofuels. First generation biofuels or conventional biofuels are made from sugars and vegetable oils that can be easily extracted from arable energy crops. Where first generation biofuels can threaten food supplies, land use and bio diversity, second generation biofuels are more sustainable. Second generation biofuels or advanced biofuels are produced from various types of biomass like woody crops, agricultural residues or waste. It is harder to extract the required fuel from lignocellulose biomass. In biogas there is an analogy on biofuels as can be seen in Figure 7. In the Netherlands biogas is currently produced by anaerobic digestion.

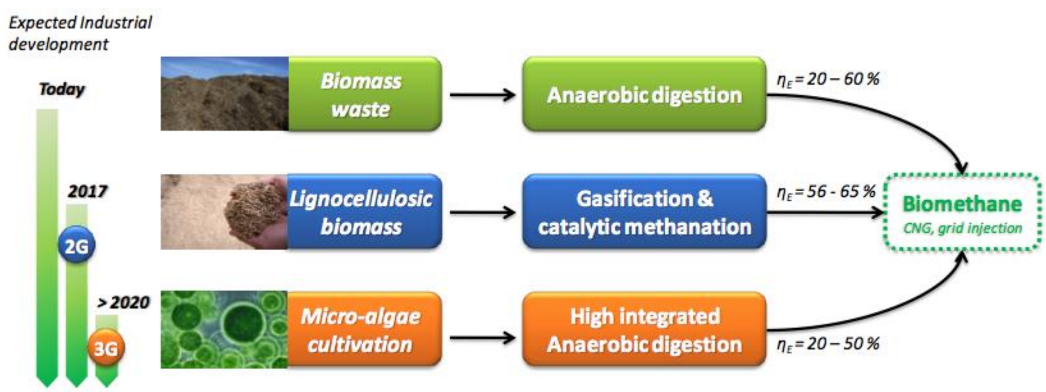

FIGURE 7 GENERATIONS OF BIOGAS

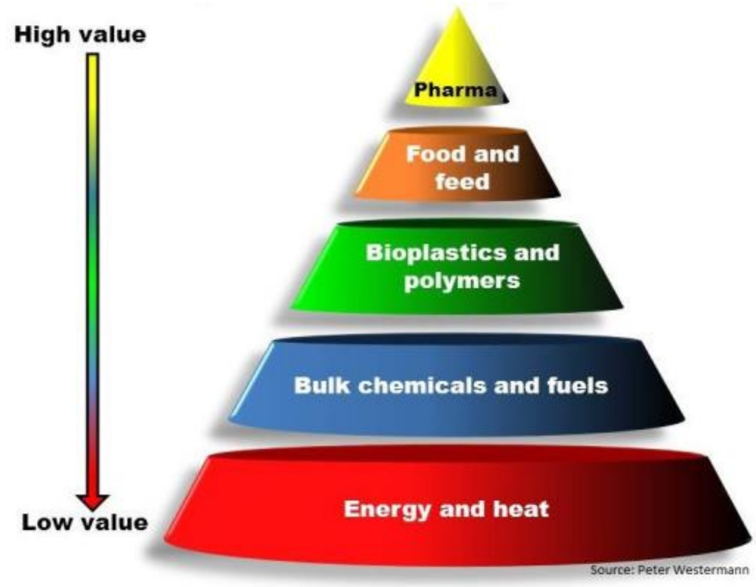

FIGURE 8 VALUE CASCADING SYSTEM

LIQUEFACTION

Biogas can be used higher in the cascade (Figure 8) for transport in cars and trucks. One of the problems is the volume of biogas. If the biogas is cooled and liquefied it can be used in heavy transport. Before the liquefaction the biogas has to be upgraded to contain less than 25 ppm of CO2, 4 ppm of H2S, and 1 ppm of H2O, to prevent dry ice formation and corrosion {Yang, 2014 #28}.

GREEN GAS HUBS

In biogas production, cleaning, upgrading and liquefaction economies of scale emerge. In Figure 9 the upgrading and liquefaction costs of raw biogas are shown in function of the scale of the plants in Nm3/hr. The bigger the plants the lower the price. To efficiently use the available liquefaction capacity biogas stream can be combined to form a green gas hub. Attero is Wijster participates in such a green gas hub, Attero has an anaerobic digester where biogas is produced which feeds a biogas liquefaction unit installed by Rolande. Neighboring farmers can connect to the local biogas grid and provide Attero and Rolande biogas that can be liquefied and used for transport (Interview Carlijn Lahaye - Attero). Combining multiple biogas feeds result in lower upgrading and liquefaction costs as can be seen in Figure 9.

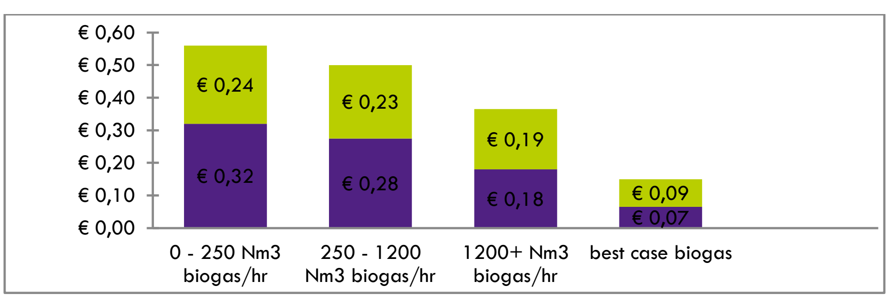

FIGURE 9 COST OF UPGRADING (BLUE) AND LIQUEFACTION OF BIOGAS (GREEN) IN DIFFERENT PLANT SIZES (PAAP, R. 2014)

Drivers and barriers

By interviewing field experts and during meetings with the National Working group bio LNG some trends are identified that can influence the business case for bio LNG.

FOSSIL FUEL PRICES

Fossil fuel prices are increasing, the UK Department of energy and climate change forecast that the oil price will rise with 40% to 2035 (UK DECC, 2014). According to the UK DECC gas prices will rise with 23% in the same period 2015-2035.

EMISSIONS

The importance to cut emissions is growing. The European emission standards are becoming stricter, extra measures have to be taken to meet the requirements for NOx and PM emissions e.g. ad blue and diesel particulate filters (DPF) (Nationale Werkgroep bio LNG). The use of LNG in road transport can lead to small emission reductions, the introduction of bio LNG trucks in road transport significantly reduce WTW CO_2 emissions (Interview René Laks – Groen Gas Nederland).

EFFICIENCY & TECHNOLOGICAL DEVELOPMENTS

Due to technological developments, efficiency of energy production and usage is growing. Gasification of biomass has potential in the longer term, this can lower bio LNG production costs towards 2030 (Interview Marc Londo – ECN).

BIO BASED ECONOMY

The use of biomass instead of oil products is growing. The reduction of waste streams is becoming more important, a circular economy where the waste loops are closed is under attention (Interview Carlijn Lahaye - Attero). The cascading model shows that the value of chemicals and bioplastics is higher than of transport fuels, Attero is involved in a project to produce bioplastics from biomass. The ability to use biomass for products higher in the cascading model can form a barrier for bio LNG (Interview Carlijn Lahaye - Attero).

TRANSPORT DEMAND

In transport alternative fuels are under development, the number of electric vehicles on Dutch roads is growing. In heavy road transport the options to switch to alternative fuels are few. The amount of energy that is needed to fuel heavy transport is substantial and not easy to contain. The transport demand is projected to grow, especially the heavy road transport. The combination of a growing demand and stricter emission targets is a driver for alternative fuels in road transport.

AVIATION AND SHIPPING

The potential of biofuels in shipping is higher than in heavy road transport. In aviation the options to shift to sustainable fuels are less. In aviation and shipping the use of biofuels is next to efficiency improvements the most important way to cut emissions, these sectors are potentially going to use increasing shares of liquid biofuels (CE Delft, 2014). This growing share can influence prices and availability of biofuel for other sectors. The reduction of harmful emissions by the replacement of heavy fuel oil by bio LNG in shipping is bigger than in road transport (Interview Jan Fransen - Natuur en Milieu). The substitution of heavy fuel oil in shipping oil instead of diesel in road transport is more expensive (Interview René Laks – Groen Gas Nederland).

HIGH INVESTMENTS

Transitions in energy infrastructures are capital intensive. Bio LNG production and liquefaction plants are costly. The extra investments in LNG trucks are currently €25.000-€35.000, the LNG storage tank accounts for a significant part of the extra costs (Nationale Werkgroep bio LNG).

LNG DEPENDENCY

Interviews with several actors revealed the dependency on LNG developments, a transition to bio LNG can only take place if a LNG infrastructure and gas trucks are present. On the other hand a transition to LNG would be socially more acceptable if bio LNG is developed in parallel (Nationale Werkgroep bio LNG).

Conclusions about the context of the current system

This chapter gives answers to the following sub-questions:

- What is bio LNG?
- Which important drivers and barriers can be identified for bio LNG?

Bio LNG is liquefied biogas, geologically recent carbon fixation in the form of living organisms (biomass) is used as feed. The production of bio LNG is currently done with biogas from anaerobic digesters. Thermal conversion of biomass can be price setting from approximately 2030. Different routes of biogas are competing with bio LNG and the available biomass is limited. Power to Gas can in the future be used as a source for bio methane, but investment costs have to decrease significantly to be price competitive. In upgrading and liquefaction costs economies of scale emerge, in green gas hubs multiple biogas streams can be combined to fuel a larger upgrading and liquefaction unit.

Prices of fossil fuels are expected to rise and the transport sector is facing stricter rules on GHG emissions and air pollutants. Transport demand is forecasted to grow. In transport the options to shift to alternative fuels are limited due to high energy demand for trucks. In aviation and shipping the emission reduction potential of bio LNG can be bigger than in road transport, while the price for heavy fuel oil is lower than for diesel. Technological developments can lower bio LNG production prices. Investments in LNG infrastructure and trucks are a requirement for further bio LNG developments.

3. CURRENT POLICIES

In order to be able to develop policy alternatives that can be valuated with a CBA, insight in current measures and regulations is essential. A policy alternative is a combination of different measures and regulations to reach a policy goal. A policy alternative has to fit in the context. This chapter elaborates on the context of measures and regulations.

To reach the policy goals broad consensus, robust and future proof energy and climate policies are needed. The SER agreement between national government, employers, trade unions, environmental organizations, other civil society organizations and financial institutions aims to reduce investment uncertainties for citizens and businesses. A long term perspective and agreements for the short and medium term should create trust. The main goals of the agreement are energy conservations, boosting energy from renewable sources and job creation.

Policy of the Netherlands and possibilities to encourage bio LNG

In order to get a better understanding of current policies on the interface of bio LNG and transport, the focus has to be wider. Therefore the energy policy of the Netherlands and the deriving fiscal schemes and subsidies will be explained.

The main principle of the Dutch energy policy is that in the long term (2050) the economy must switch to sustainable, low carbon energy supplies (GON, 2014). The Dutch government wants to reduce its dependence on coal, oil and gas. There are often trade-offs between public values {Bruijn, 2006 #37}. Sustainable energy supplies come at a cost. According to the European Energy Union there are three main objectives:

- We want secure energy supplies to ensure the reliable provision of energy whenever and wherever needed
- We want to ensure that that energy providers operate in a competitive environment that ensures affordable prices for homes, businesses, and industries
- We want our energy consumption to be sustainable, through the lowering of greenhouse gas emissions, pollution, and fossil fuel dependence

Fossil fuels will continue to play an important role in the country's energy supply in the decades ahead because of these trade-offs. Highly reliable or sustainable systems for instance come at a cost. The government encourages a balanced mix of energy sources, reducing the country's dependence on any single source while keeping the system affordable (GON, 2014).

Natural gas delivers about half of total energy consumed in the Netherlands. Dutch gas reserves are declining and the Netherlands will become a net importer of natural gas by about 2025 (GON, 2014). The government is promoting the development of a gas hub, which will encompass, gas trading, infrastructure and storage.

Following measures and policy instruments have to be seen in the bigger picture of above mentioned policy goals. A level playing field and stable investment climate where innovation is encouraged are also important (Argos, 2014). It is good to keep in mind that bio LNG is not a goal on itself but a means to achieve objectives mentioned above.

Dutch greenhouse gas policies have to be seen in global or a European context. In addition to EU policies there are some targets set by the national government. Dutch targets are that at least 14% of all energy to be generated from renewable sources by 2020, and 16% in 2023.In addition to global and European regulations there are some local regulations on emissions. There are currently 13 cities where older polluting trucks are prohibited in so called environmental zones (milieuzones) (ECM, 2014). Only Euro IV trucks, newer than October 2005 are allowed to enter the environmental zones of the cities.

Fuel mix blending FQD

The Netherlands has its own interpretation of the European FQD in the case of biogas in transport, where the EU prescribe a system where the green gas physically has to be used in transport to count in the FQD. The Netherlands has introduced a system of certificates, where the gas infrastructure can be used to transport and store green gas.

In the virtual green gas chain, green gas is injected in the grid by a biogas producer, on another location natural gas is extracted from the grid that can be "green washed" by certificates. Vertogas is appointed to facilitate the market for green gas certificates in the Netherlands.

The Dutch system is based on mass balances if a green gas producer feeds in a certain amount in the grid and a green gas consumer extracts the same amount and buys the certificates, the consumer claim to use green gas. The actual gas molecules may be grey. According to the EU regulations only 0,25% of the grid is green gas. So 0,25% times the total extracted gas used for transport is green and can count for the FQD.

Stimulation of sustainable energy production SDE+

The Stimulering Duurzame Energieproductie (SDE+) is an operating grant commissioned by the ministry of economic affairs. SDE can financially compensate producers of renewable energy to overcome the unprofitable component between the cost price of renewable energy production and the price of fossil energy. The amount depends on the technology used and is fixed for a number of years (RVO, 2014). The grant is targeted at companies, nonprofit organizations and institutions. SDE is available for:

- renewable electricity
- renewable gas
- renewable heat or a combination of renewable heat and electricity (CHP)

In 2015 some categories are added, it is also possible to receive SDE+ for co-firing biomass in coal fired power plants, wind energy on weirs and the replacement of wind turbines. SDE can compensate the difference between the production cost of renewable energy and fossil energy, over a period of 5, 12 or 15 years. The feed in tariff of the SDE grant depends on fossil fuel prices and the amount of energy produced. There is a budget ceiling.

SDE is set up in different phases, in phase one projects with the smallest unprofitable top can apply for a grant and in later phases more expensive technologies may apply for a grant. Currently we are in phase three of 2015 till the first of June. Each phase has a maximum base amount that increases from 0,023 €/kWh in phase one to 0,15 €/kWh in phase nine. In 2012 the SDE scheme was also available for the production of green gas used in transport, but from January 2013 biogas that was produced with SDE could no longer count for HBE's / biotickets (GGNL, 2014).

According to several experts in the field the SDE+ is an attractive subsidy to lower the risk of investment, the price for HBE's / biotickets is more fluctuating.

Bio tickets / HBE cost effectiveness

In order to satisfy the European fuel quality directive, the Netherlands has introduced a system where a minimum amount of renewable road transport fuels should be used. All suppliers of road transport fuel should blend a minimum amount of biofuel to their diesel or gasoline or to supply green gas or bio LNG to fulfill the regulations. There are parties that supply extra biofuels, this surplus can be sold to another party in the form of a "Hernieuwbare Brandstof Eenheid" (HBE) or former bioticket. These HBE's can be sold to parties that supply not enough biofuel to fulfill the regulations. The system of administrative transactions is called the HBE market. The idea is that the sector finds cost effective ways to produce enough biofuels. The system is based on mass balances.

The Dutch government aims to encourage the development of advanced biofuels. In the HBE system double counting of advanced biofuels is introduced, if the feedstock to produce biofuel cannot be used higher in the value pyramid. Examples are sewage water treatment, garden (GFT) waste or digestion of manure.

The price of HBE's can fluctuate as can be seen in Figure 10.

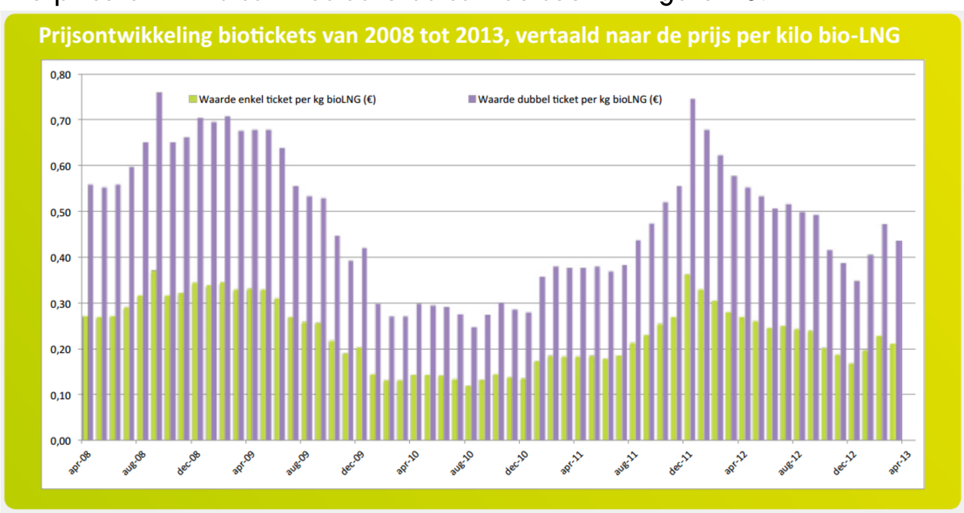

FIGURE 10 PRICE OF BIOTICKETS (PAAP, R. 2014)

If the origin of the biomass used to produce biogas is of the second generation and certified with NTA8080 double counting of biotickets is allowed.

Fuel taxes

Fuel taxes are important cost factors in transport and steering instruments for the national government. Dutch fuel taxes belong to the highest in the world. The excise duty on LNG is the same as on LPG Figure 11.

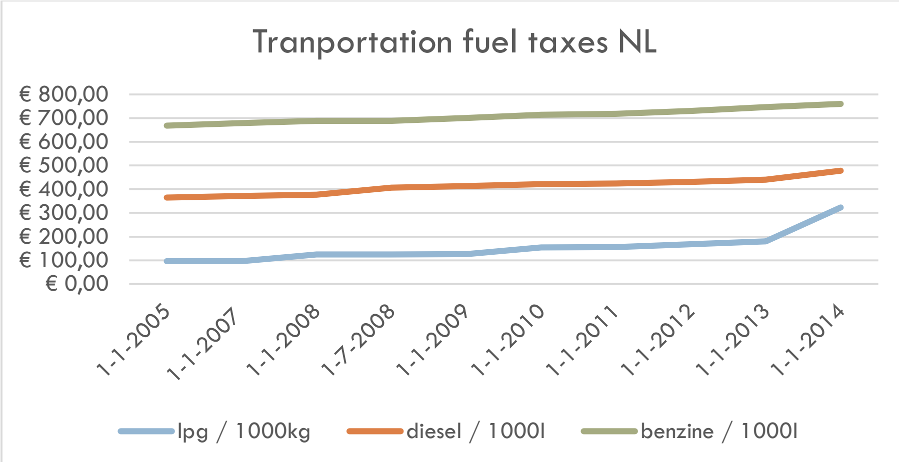

FIGURE 11 EXCISE DUTY

REFUND SCHEME LIQUEFIED NATURAL GAS / METHANE / BIOGAS

To encourage the use of LNG as a transport fuel the fuel tax increase of January 2014 is partly compensated by a refund scheme. This is a temporarily settlement. For every 1000kg of LNG there is a tax reduction of €125 till 2018.

Commissie Corbey

The Corbey Commission was established by the Secretary of State of Infrastructure and the Environment and aims to give advice to sustain agriculture, energy and chemistry in the development of a bio based economy (CDB, 2014). The bio based economy plays an important role in the drive to decrease carbon emissions, in the development of a knowledge economy and in the efficient use of resources.

The commission published their advice on the acceleration of the introduction of advanced biofuels in September 2013: "The best stimulus for development of technologies and a market for advanced biofuels is a blending target which is set out for the long-term. Objectives should therefore be agreed to on a European level for the reduction of greenhouse gas emissions for the period after 2020. Sub-objectives should be called in for advanced biofuels. For the period from now until 2020, it is important that the Netherlands sets a realistic compulsory sub-objective (0.5%) for advanced biofuels. This objective can be increased after 2020. As an alternative to this measure, a fiscal policy could be introduced which charges less tax on better biofuels. However, this policy does not offer any guarantees, all the more so because the volumes of advanced biofuels are too insignificant for the time being" (CDB, 2014). After 2020 the system of HBE's is uncertain and dependent on European agreements.

Noise reduction

Since 1998 there is in the Netherlands a standard for noise emission during loading and unloading in retail trade and craft businesses. The limits are set out in the 'Retail Trade and Craft Businesses Environmental Management Decree issued by government on October 1998, under article 8.40 of the Environmental Management Act (PIEK, 2014). Vehicles and equipment operating under 60dB (A) can receive a PIEK certificate which is suitable to use in the nighttime deliveries without causing noise disturbance.

Virtual Green Gas

There is currently a certificate system of Vertogas where it is possible to virtually extract green gas from the grid, while the actual molecules originate for 99,75% from fossil natural gas. A certificate system is not developed for bio LNG production. According to ECN a part of the future bio LNG production will be realized through certificates (Interview Marc Londo – ECN).

Smaller incentives to stimulate LNG

Subsidies to encourage biogas production (SDE+) and fuel taxes are measures to steer demand. Regulations about HBE's and virtually green bio LNG complement current Dutch policies. There are smaller measures to stimulate projects in energy innovation and sustainability.

- Energie Investerings Aftrek (EIA) Milieu Investerings Aftrek (MIA)
- Willekeurige Aftrek Milieu Investeringen VAMIL

There are some fiscal schemes to stimulate investments in environmentally friendly products or company resources. The fiscal advantage is that it is possible to amortize the investment on a self-selected point in time.

- Demonstratie Energie innovatie (DEI)

The DEI subsidy originates from the SER Energy Agreement and supports innovative pilot projects in the energy sector.

- Greendeals

One of the provisions in the SER agreement are Tax breaks for local clean energy initiatives. Clean sustainable projects that are hard to realize can be supported by a green deal. The idea is to remove barriers and couple green energy with economic growth.

- Netherlands Technical Agreement 8080 (NTA8080) (NTA8081)

NTA8080 is the international standard of sustainability criteria for solid, liquid and gaseous biomass. This voluntary agreement is set up by a broad stakeholder panel representing market players, government and civil society organizations, under the supervision of NEN (NEN, 2014). It is only allowed to double count HBE's (biotickets) if the biomass used to produce biogas is certified. This measure is implemented to encourage the use of waste instead of for instance maize to produce biogas.

- TKI Gas

Top consortia Knowledge and Innovation (TKI) Gas is one of the 7 themes in the top sector energy. In the TKI gas, there are 6 main themes one being green gas and another one small scale LNG. It is possible to get an allowance under the TKI between 25ct and 60ct for every invested euro for research and development of LNG.

- Local truck subsidies

Some local governments support the introduction of LNG trucks with a purchase subsidy, in the province Overijsel for instance there is a maximum of €10.000 per truck (Overijsel, 2014)

European Policy

The EU aims to get 20% of its energy from renewable sources by 2020. Renewables include wind, solar, hydro-electric and tidal power as well as geothermal energy and biomass. More renewable energy will enable the EU to cut greenhouse emissions and make it less dependent on imported energy. Boosting the renewables industry will encourage technological innovation and employment in Europe (EC Energy, 2014). The EU promotes a single market for electricity and gas.

The climate and energy package is a set of binding legislation which aims to ensure the European Union meets its ambitious climate and energy targets for 2020 also known as the "20-20-20" targets.

- A 20 % reduction in EU greenhouse gas emissions from 1990 levels;
- Raising the share of EU energy consumption produced from renewable resources to 20%;
- A 20 % percent improvement in the EU's energy efficiency.

Renewable Energy Directive

The general objective of the Renewable Energy Directive (RED) is to "achieve a 20 % share of energy from renewable sources in the Community's gross final consumption of energy and a 10 % share of energy from renewable sources in each Member State's transport energy consumption by 2020". (EU 2009/28/EC). This European goal is translated into national policy: national renewable energy action plans. In the Netherlands the goal is to realize 14% RES by 2020 (NREAP, 2010).

Article 21/2 of the directives states: "For the purposes of demonstrating compliance with national renewable energy obligations placed on operators and the target for the use of energy from renewable sources in all forms of transport referred to in Article 3(4), the contribution made by biofuels produced from wastes, residues, non-food cellulosic material, and ligno-cellulosic material shall be considered to be twice that made by other biofuels" (EU 2009/28/EC).

Article 16 "Member States shall ensure that the charging of transmission and distribution tariffs does not discriminate against gas from renewable energy sources"

Fuel Quality Directive

The Fuel Quality Directive (FQD) aims at "ensuring a single market for fuel for road transport and non-road mobile machinery and ensuring respect for minimum levels of environmental protection from use of this fuel" (EU 2009/30/EC).

European Emission standards

New trucks must meet the limits of exhaust emissions in the EU member states. The standards are increasingly stringent defined by European Union directives. The legislation currently in force for heavy-duty vehicles is directive 2005/55/EC and 2005/78/EC. From 31 December 2013 Euro 6 emission levels are mandatory for new sold trucks. The limits are based on engine output in g/kWh and presented in Table 2.

Pollutant	Gram per kW/h
CO	1,5
HC	0,13
NOx	0,4
PM	0,01

TABLE 2 EURO-6 EMISSION STANDARD

In Figure 12 the graphical presentation of the stricter emissions standards in time is represented. The difference between and Euro 1 and Euro 6 trucks are in terms of PM emissions 97% and in terms of NOx emissions 95%.

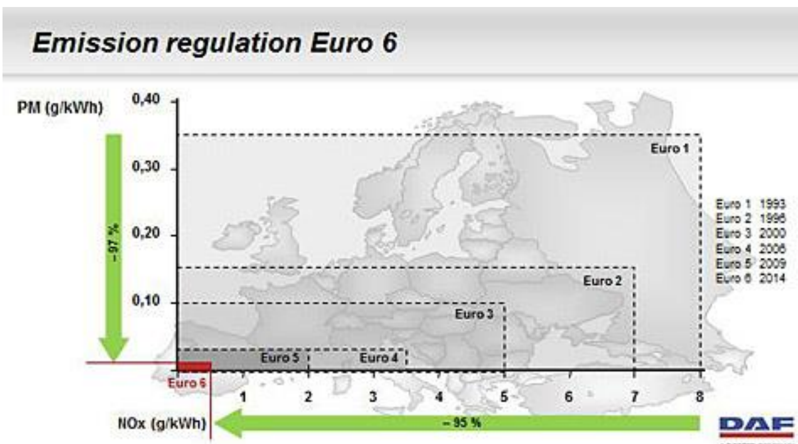

FIGURE 12 EURO EMISSION STANDARDS IN TIME

European Emission Trading System (EU ETS)

The EU ETS is a cap and trade system for reducing industrial greenhouse gas emissions cost-effectively. Currently the system is in its third phase, and compared to 1990 levels GHG emissions must be cut by 20% in 2020 and 80% in 2050. The price of emitting a ton of CO2 is currently between the 6 and 7 euro (EEX, 2014). Aircraft operators are included in the ETS but road transport is not. "One of the largest and still growing CO_2-emitting sector, the transport sector, and particularly road transport, has not yet been included in the EU ETS" {Heinrichs, 2014 #33}.

Other smaller European initiatives that influence bio LNG

The RED, FQD, emission standards and the ETS are the big European measures that influence the introduction of bio LNG. There are also smaller measures to stimulate for instance infrastructure investments and developments in sustainable fuels.

- Clean power for transport package
- Ten-T

- LNG Blue Corridors
- Innovation and technology: Horizon 2020
- Indirect land use change (ILUC)
- Interreg

Involved actors

For a good understanding of the system the involved actors and their role is described in this section. The actors are divided in four groups; consumers, fuel market, government and the society.

Transporters, trucks owners and drivers make the decision to buy a truck and how to fuel the truck. In this research the transporters can be seen as the consumers to buy trucks and fuel.

Oil and gas companies are involved in the developments in LNG, Shell and GDF Suez have announced investments in filling stations infrastructures. Rolande LNG is involved in trading LNG and pioneering in bio LNG production. These companies form the fuel market for (bio) LNG. Bio LNG liquefaction technology providers are GTS involved in Schoteroog and Wijster and Osomo. Biomass suppliers & Farmers are the energy sources for bio LNG production. Gas Transport Services (GTS) a subsidiary of Gasunie is TSO and responsible for the transport and storage of natural gas and green gas. The Gas act states that Gasunie is not allowed to produce biogas. Vertogas also a subsidiary company of Gasunie is responsible for certification system of green gas in the Netherlands.

Several governmental organizations are involved in policy towards bio LNG, the Ministry of Economic affairs (EZ) is responsible for SDE+ subsidies. The Netherlands Enterprise Agency (Rijksdienst voor ondernemend Nederland, RVO) is part of EZ and responsible for SDE+ and “Truck van de Toekomst” subsidies. The Ministry of Infrastructure and Environment (I&M) is responsible for the environmental effects of transport. Their goal is to minimize emissions in road transport. The Ministry of Finance is responsible for fuel taxation and for budget balancing. Local governments can implement for instance environmental zones.

The society is an actor as well, the whole society is facing the external effects of transport. The NGO’s involved in SER agreement mainly focus on the external effects and have effect on the public opinion towards new developments in energy infrastructures.

Conclusions current policies and involved actors

This chapter gives answers to the following sub-questions:

- Which actors are involved and what are their interests?
- What is the current national and European policy (status quo) towards bio LNG?
- What are possible and feasible policy alternatives?

Mainly four groups of actors are identified, consumers, producers, the government and the society. The truckers make the decisions to drive a (bio) LNG truck or diesel truck. The fuel market or producers determine whether to invest in bio LNG production. The government involved with several bodies imposes measures to steer demand and cope with external effects. The external effects intervene on the welfare of the society.

On a national level subsidies and fuel taxes are used as measures to steer demand. Regulations about blending requirements and virtual greening of biogas are currently used. The system of HBE's is a stimulus for bio LNG production but the prices are unstable. After 2020 it is not clear yet if the system of HBE's will still exist.

On a European level mainly three important regulations influence the business case for bio LNG. The RED about the share of renewable energy, the FQD about blending requirements for biofuels and the European Emission standards.

Based on the national and European regulatory context four stimulus measures are identified that could be used to stimulate a transition to bio LNG:

- Fuel tax increase or decrease
- Regulations on minimal amount bio LNG blending in LNG for transport
- Subsidize mitigated CO2 emissions in transport
- Virtually green bio LNG through certificates

In the next chapter the identified measures are combined to policy alternatives.

4. CBA MODEL

The next step in answering the research questions is to build the CBA model. In the previous chapter the context and possible policy measures are illustrated, in this chapter the policy alternatives are designed and the effects are being calculated by the CBA model. The first step is to define the reference case or business as usual case. A CBA calculates the difference (Δ) between the reference and alternatives. Table 3 shows the share of LNG and bio LNG trucks in the different policy alternatives, this chapter elaborates on the design of the alternatives. There are no transport models available to forecast number of diesel, LNG and bio LNG trucks for this research. The total transport demand is the same for the different alternatives, the shares are partly based on literature and partly chosen by the researcher.

ALTERNATIVES	**SHARE** GAS TRUCKS IN %	**SHARE** BIO LNG IN %
BAU	0	0
GAS	50	20
FQD	25	32,5
DIESEL TAX	50	50
CO2 TAX REDUCTION	12,5	35

TABLE 3 SHARES OF GAS AND BIO LNG FOR DIFFERENT ALTERNATIVES

Business as usual

To calculate the change (Δ) of effects of measures a reference is needed. In this reference or business as usual (BAU) scenario no profound changes of policy towards road transport are assumed. It is important that the BAU or base case is not only a status quo. Alternatives are compared with the reference. A “do nothing” scenario will probably result in a more negative sum of social cost and benefits then is assumable.

The BAU case is based on forecasts about transport demand in the Netherlands. Biofuel blending is incorporated in the model as well as the stepwise changing obligations from 6.25% in 2015 to 10% in 2020 in analogy with the European Fuel Quality Directive (Directive 2009/30/EC).

The emission factors of trucks are changing over time, technological development drives efficiency gains. On the other hand well to wheel (WTW) effects of oil production are increasing, because of the availability of oil fields. The aggregated data of CE Delft, TNO and ECN are used as input for the BAU scenario, their WTW predictions are based on the JEC Well to Wheel analysis of the Joint Research Center of the European Commission (JEC, 2014) and adjusted for the Dutch situation.

The BAU alternative also includes projections of the total transport demand for heavy trucks, based on the “Referentieraming 2012” and the “Nationale energy verkenning 2014” (RR, 2012 & NEV, 2014). The transport demand is also compared to the projections of CE Delft used in the SER energy agreement. The total transport demand is not influenced by the proposed policy measures. External factors can affect transport demand e.g. gross domestic product and oil price. After the CBA is build a scenario analysis is conducted to examine the reliability and robustness of the results.

In the base case the complete heavy road transport demand is fulfilled with diesel trucks. In the NEV 2014 the PBL indicates that cars and light vans can make a switch to alternative fuels, for heavy road transport the switch to gas or electricity is not mentioned. NEV forecasts growing CO2 emissions for trucks.

The number of trucks times their average mileage of truck combination is an input variable which is leading. The total average mileage of the years 2002-2013 is represented in Figure 13, this includes average mileage in the Netherlands as well as outside the Netherlands of Dutch registered trucks. The CBS has more recent numbers and Figure 14 shows that the RR 2012 is slightly high.

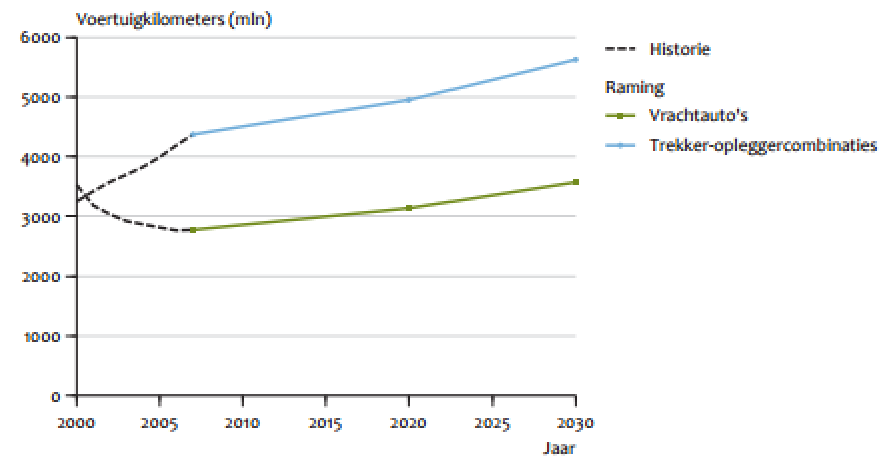

FIGURE 13 TRUCKS * MILEAGE RR PBL 2012

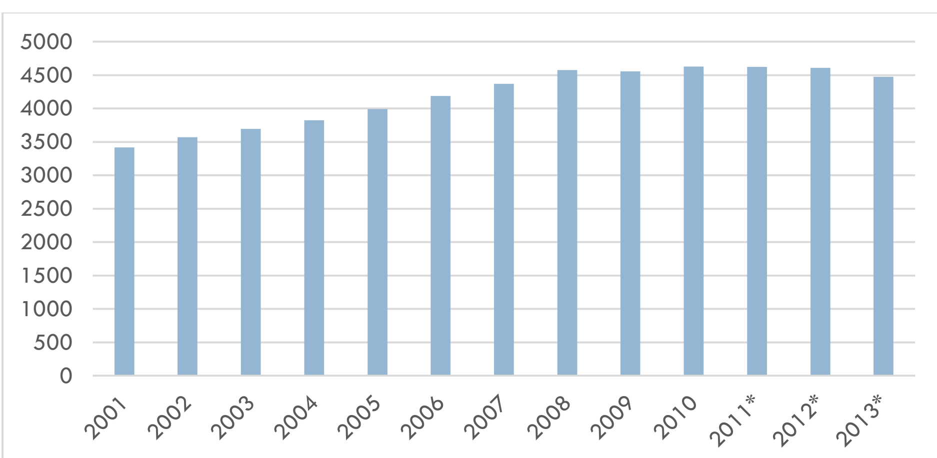

FIGURE 14 NUMBER OF TRUCK (TREKKER) KILOMETERS IN THE NETHERLANDS (CBS, 2015)

In this model the mileage is kept constant while the number of trucks is responsible for the increase in transport demand. The transport demand is based on the RR 2012, NEV 2014 and CBS data. Table 4 shows the growing total transport demand for Trucks in the Netherlands and their average mileage used as input for this research.

	2015	2020	2030	2050
TRUCKS	85000	100000	110000	120000
MILEAGE	46000	46000	46000	46000

TABLE 4 TOTAL TRANSPORT DEMAND IN TRUCKS AND MILEAGE PER YEAR

The policies that are carried out are:

- No subsidizing of bio LNG production
- Higher LNG tax because of expiring refund scheme
- No virtual greening of bio LNG
- Stable diesel tax

If the reference is set, different policy alternatives are designed based on current policies and compared with this BAU scenario. If a policy option scores better, the social utility is higher for that alternative. Four policy alternatives to stimulate bio LNG will be evaluated.

If diesel prices will rise the vehicle kilometers will be influenced. The price elasticity is price elasticity of vehicle kilometers is estimated -0.13 in relation to fuel prices (PBL, 2010). Price elasticity is estimated lower than the price elasticity of passenger cars, freight needs to be transported to for instance supply shops. Transporters can recharger higher fuel costs to their customers. For the sake of overview and simplicity the price elasticity of diesel is assumed 0 in this research.

Gas Alternative

The reference is set and alternative policies need to be designed. The effectiveness of policy measures is uncertain, actors are acting not completely rational. If for instance the total cost of ownership (TCO) of LNG trucks becomes a fraction lower than a diesel truck, it cannot be assumed that the whole sector makes a shift to LNG. To design a plausible alternative with associated number of trucks per fuel type, the view of the sector is used. As part of the elaboration of the SER energy agreement a team of different organizations have developed their view on gas as an alternative fuel in transport.

The document “Wegvervoer duurzaam gasvormig" is used as an input for the Gas alternative. Several organizations including gas experts and governmental organizations have formulated a view on the future role of gas in transport. There is not only an outlook for future (bio) LNG trucks but also a combination of policy measures to reach these numbers. In “Appendix Input data CBA” the indicators are presented. In Table 5 the predictions for (bio) LNG Trucks are presented based on the projections of the “Deelrapport Wegvervoer duurzaam gasvormig” directed by the SER.

YEAR	NUMBER LNG TRUCKS	LNG FILLING STATIONS	% BIO LNG
2020	6.500	36	10
2025	14.000	70	15

2030	21.500	110	20
2050	60.000	200	20

TABLE 5 GAS ALTERNATIVE PREDICTIONS

The maximum potential for heavy duty long haul trucks to switch to LNG is 50% according to Verbeek et. al. (Verbeek, 2014). The table gives possible realistic growth path rates of LNG and bio LNG in heavy road transport. Figure 15 shows the growth rates graphically.

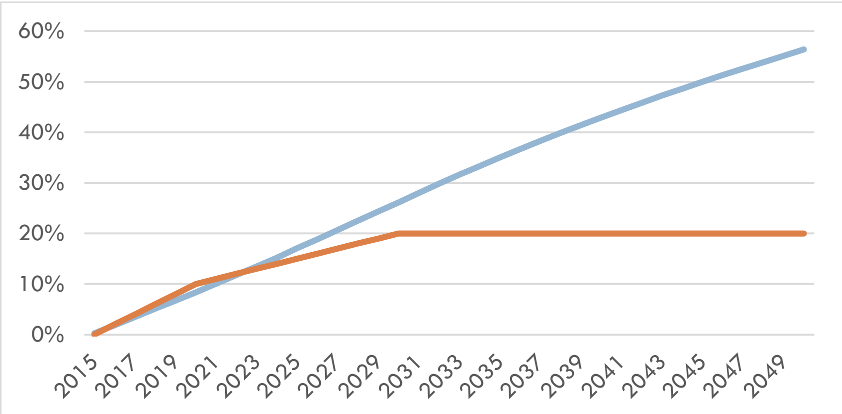

FIGURE 15 GAS ALTERNATIVE GROWTH PATH BLUE = GAS TRUCKS, RED = BIO LNG (SER, 2014)

The growth rates and measures to get there are based on literature and can be found in Appendix Input data CBA. The most important policy measures to reach the numbers from Table 5 are:

- Subsidize unprofitable margin of bio LNG production
- Stable low (bio) LNG tax for 10 years
- Allow virtual greening of bio LNG, but protect share of green gas grid injection

The policy "introduction" cost for the measures are small and not taken into account. The actual subsidies are incorporated in the CBA model. Continuation of supplemented measures is assumed, these measures are smaller incentives to stimulate bio LNG and not further taken into account in this research:

- Green deal zero emissions city logistics
- Lobby for stricter European CO2 emission standards
- Truck of the future 2.0
- Innovation programs TKI small scale LNG & safety
- Continuation and extension MIA/VAMIL

These last measures are small incentives to stimulate bio LNG

The costs of these measures need to be estimated in the CBA, on the other hand more LNG and bio LNG trucks result in lower emissions. Among other factors these costs and benefits are weighted against each other in the CBA. The total transport demand, number of trucks times mileage is not dependent on the use of gas versus diesel.

FQD alternative

To explore the policy options three other alternative are included in the analysis. The Gas alternative gives a growth path of gas trucks and associated policies. The fuel quality directive FQD alternative is based on European regulations on biofuel blending. In Europe the follow up of the FQD after 2020 is uncertain (NGVA, 2014). In the years 2015 -2020 the blending obligations are rising stepwise from 6,25% to 10%. In this alternative the blending obligation for bio LNG is increased with 0,75% point a year, to 32,5% in 2050.

The idea behind this alternative is that the market is self-responsible for financing the share of bio LNG. The government regulates the minimal amount of renewable gas, and leaves the implementation to the sector. The self-responsibility, without subsidizing the bio LNG production will lead to higher LNG prices. Experts in the National bio LNG workgroup expect a lower LNG penetration because of these higher prizes. The numbers presented in Table 6 are based on the assumption that the regulation makes LNG more expensive which results in a 50% lower LNG penetration than in the Gas alternative.

YEAR	NUMBER LNG TRUCKS	LNG FILLING STATIONS	% BIO LNG
2020	3.250	18	10,00
2025	7.000	35	13,75
2030	10.750	55	17,50
2050	30.000	100	32,50

TABLE 6 FQD ALTERNATIVE

The most important policy measures to reach the number from Table 6 FQD alternative are:

- Stepwise growth of blending obligation bio LNG
- Stable low (bio) LNG tax for 10 years
- Partly virtual greening bio LNG, but protect share of green gas grid injection

Assumption for this alternative:

- 50% lower LNG penetration than Gas alternative due to higher LNG prices

Diesel tax increase Alternative

Excise duties for transportation fuels are historically increasing as can be seen in Figure 11. This alternative assumes an increase in diesel tax. The refund scheme for LNG tax will expire after 2018. The higher taxes on fossil fuels will result in a better business case for bio LNG. The extra diesel tax revenues for the government can be used to subsidize the unprofitable gap of bio LNG production. The measures result in the following numbers presented in Table 7:

YEAR	NUMBER LNG TRUCKS	LNG FILLING STATIONS	% BIO LNG
2020	6.500	36	10
2025	14.000	70	20
2030	21.500	110	30

2050	60.000	200	50

TABLE 7 DIESEL EXISE ALTERNATIVE

The most important policy measures to reach the numbers from Table 7 are:

- Increase diesel fuel tax with €0,10
- Higher LNG tax because of expiring refund scheme
- Subsidize unprofitable gap of bio LNG production
- Partly virtual greening bio LNG, but protect share of green gas grid injection

Assumption for this alternative:

- The gap between gas and diesel will grow due to higher diesel tax, this makes the business case for (bio) LNG better. Subsidizing the unprofitable gap between LNG and bio LNG will lead to a high bio LNG penetration 50% in 2050.

CO2 tax reduction alternative

This alternative is built for a future where the focus is on CO2 emissions. A policy is designed where the mitigated CO2-equivalents will be subsidized by the government to decrease CO2 emissions and slow down the greenhouse gas effect. To determine the gain of bio LNG versus diesel the average mitigated CO2-eq are being calculated and multiplied with the shadow price of €78.

YEAR	NUMBER LNG TRUCKS	LNG FILLING STATIONS	% BIO LNG
2020	1.625	9	5
2025	3.500	18	10
2030	5.375	28	15
2050	15.000	50	35

TABLE 8 CO2 EMISSION ALTERNATIVE

- Extra tax reduction bio LNG for mitigated CO2 emissions (8ct)
- Stable low bio LNG tax for 10 years
- Environmental city zone: Extension Green deal zero emission city logistics to regulation
- Virtual greening of bio LNG production, but protect share of green gas grid injection

Assumptions for this alternative:

- Low tax for bio LNG only will result in lower LNG penetration, assumption is 25% of Gas alternative
- 10 years low tax levels and extra tax reduction of 8ct results in a better business case for bio LNG, the gap between LNG and bio LNG still exist so a moderate bio LNG penetration of 35%.

Scenario's

Variables that fall outsides the model, but do influence the results of the CBA are among others: economic development, oil price, technological development, climate change, environmental involvement and availability of biomass. It is not possible to show one exact picture of the future, policies have to cope with uncertain prospects. A robust policy scores well in different future scenarios. In this research a best and worst case scenario are designed to test the outcomes of the CBA. Variables that are adjusted are:

- Transport demand
- Diesel price
- Importance of external factors (shadow prices)
- Discount rate

Effects of policy measures

In a social cost benefit analysis it is important to identify all relevant effects of policy alternatives on the system. The outcome of the analysis is an overview of different measures with their monetized effects. If significant effects are not taken into account measures cannot be compared fairly. In analogy with the report "External costs of infrastructure and traffic" of CE Delft and VU Amsterdam the effects are grouped in different categories (CE Delft ea. 2014). Figure 16 shows four groups of effects; direct costs, GHG emissions, Air pollution and other external cost.

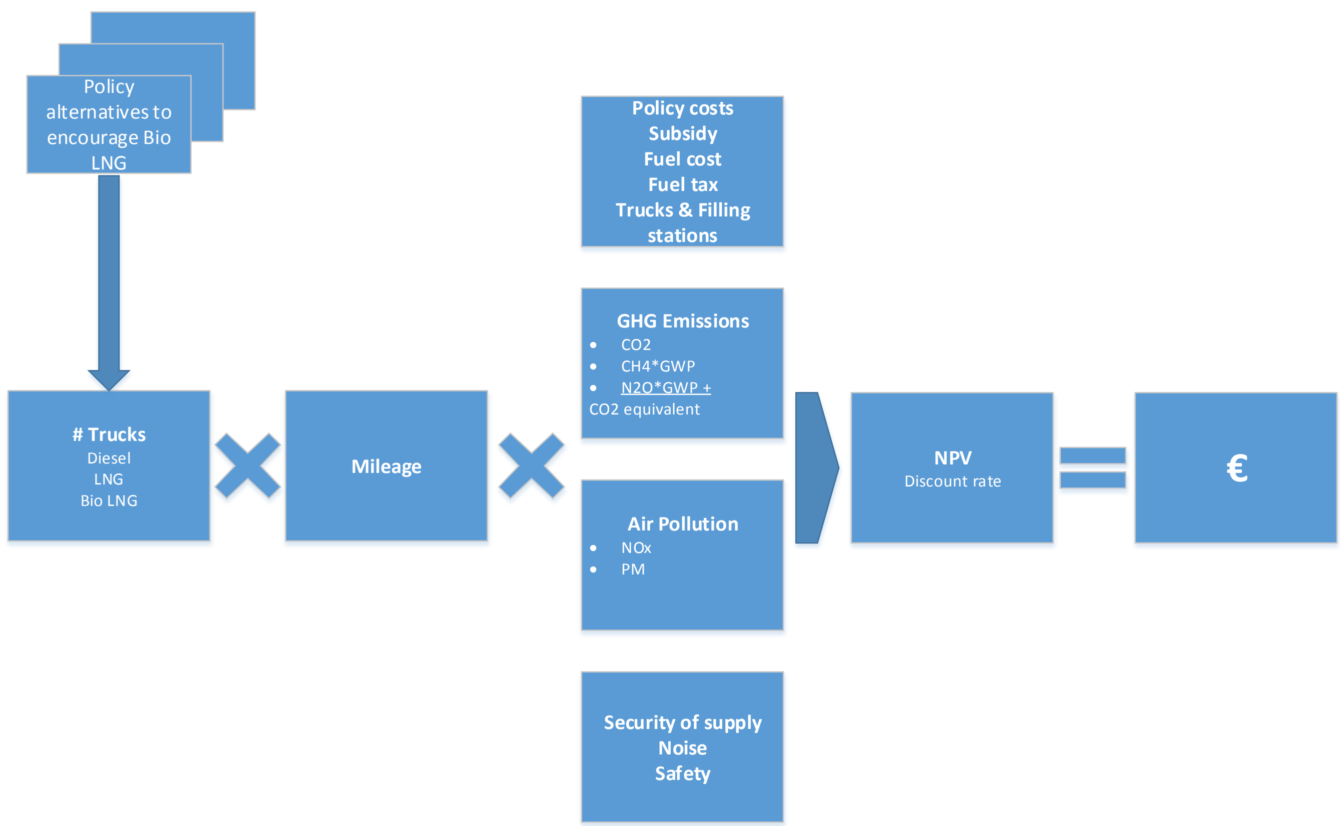

FIGURE 16 HOW THE CBA IS BUILD AND EFFECTS ARE CALCULATED

The number of trucks for different fuel types is a leading variable in this CBA, the different policy measures intervene on number of trucks. Trucks multiplied by mileage is the result of total transport demand. The total transport mileage can be multiplied by the fuel efficiency and emission factors to come to the emission in kilograms per year. The fuel efficiency of trucks is given in Table 9, these numbers are based on TNO data and validated by an interview with R. Verbeek (Appendix Interview Ruud Verbeek - TNO). The efficiency of diesel engines is already reaching its theoretical maximum, while gas engines can be further developed, according to R. Verbeek a gain of 10% is possible. In the initial calculation the extra technological development gain is not taken into account.

MJ/KM	2020	2030
DIESEL	11,24	11,16
LNG	11,24	11,16

TABLE 9 FUEL EFFICIENCY OF TRUCKS

In the simplified model the measures intervene on the number of trucks, an investment subsidy for gas trucks will be translated in a higher number of LNG trucks at the expense of diesel. Subsidizing bio LNG production will lead to lower bio LNG prices and more bio LNG trucks. In this way a translation is made from measures via number of trucks to effects.

Policy Costs & Subsidy

The introduction of measures to stimulate bio LNG always brings policy costs. Resources are needed to change and maintain regulations. Some measures can be relatively easy introduced at low costs e.g. changing the fuel tax, while other measures are costly for instance subsidizing the unprofitable gap of Bio LNG production. Two groups of policy costs have been identified:

Changing regulations come at low costs:

- The introduction of a bio LNG blending quota (FQD)
- Allow virtual greening of bio LNG with certificates
- Increase or decrease fuel tax levels (actual government revenue excluded)

Note that the production of bio LNG competes with other biogas distribution channels. In this thesis the assumption is made that if there is a solid business case for bio LNG production this will lead on the long run to extra biogas production capacity, in the reflection this issue will be addressed further.

Subsidies

- Subsidize unprofitable gap bio LNG production

Fuel costs and Fuel Tax

Future fuel prices are uncertain but are important factors in the calculation of total utility. The World Energy Outlook 2014 assumes a growing gap of gas and diesel prices as can be seen in Figure 17.

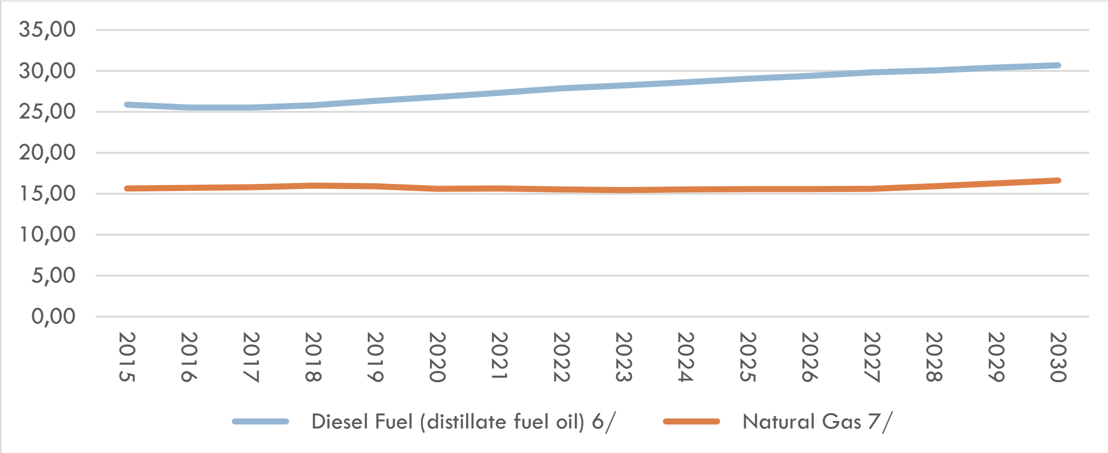

FIGURE 17 WEO 2014 GAP & OIL GAS 2015-2030 IN US $

The model input raw fuel prices exclusive taxes are based on ECN forecasts, based on the NEV 2014 and World Energy Outlook 2013 and adjusted for the Dutch situation (NEV, 2014 & WEO, 2013)

	2010	2020	2030
DIESEL	17,00	24,70	27,30
LNG	14,60	15,90	16,60
LNG	23,11	23,11	26,41

TABLE 10 FUEL PRICES EXCL TAXES IN €/GJ

Especially the low LNG price and the high oil price upward of 2020 are determinative for the results of the CBA. The bio LNG price in these figures is based on the SDE base rate. "Depending on the feedstock type production of green gas is in the range of 9,4 to 29,3 €/GJ, the lower end referring to the wastewater treatment plants and the higher end to manure mono digestion (Interview Marc Londo – ECN)".

According to René Laks transport companies can receive a high volume discount on the diesel price of up to 12,5 euro cents (Interview René Laks – Groen Gas Nederland). The sales of LNG or bio LNG is not in high volumes yet, so there are no or smaller discounts. The volume discount is not taken into account in this research.

Trucks & Filling Stations

The initial upfront investment of LNG trucks are higher than diesel trucks. In this research the difference is set to €20.000 in line with TNO, ECN and CE Delft. According to the importers of Scania and Iveco the difference is currently between €25.000 and €35.000 but likely to decline if more gas trucks are being sold (LNG Platform, 2015). According to PWC the economical lifespan of a truck is between 5 to 8 years (PWC, 2013). LNG24 currently estimates the investment for a LNG filling stations around €1 million, PWC estimates the investment on €600.000 (PWC, 2013). The first filling stations will probably be more expensive than later ones, in this research the estimate of PWC is used with the note that the lifecycle is 15 years.

Greenhouse gas emissions

The characteristics of diesel combustion engines are different than gas engines. The cleaner combustion of gas and particularly biogas is one of the motives to stimulate the transition from diesel. To be able to compare the greenhouse gas (GHG) emission of a diesel truck with an LNG and bio LNG Truck. Three components are identified from literature and relevant in this case; carbon dioxide (CO2), nitrous oxide (N2O) and methane (CH4) (CE Delft, 2014). To monetize the effects, CH4 and N2O emissions are converted in CO2-equivalents through the global warming potential.

GLOBAL WARMING POTENTIAL

The global warming potential (GWP) is a relative measure to calculate the amount of heat trapped by a gas in the atmosphere. The number represents the heat trapped by a gas in comparison to the amount of heat trapped by a similar mass of CO2. So the GWP is a metric for weighting the climate impact of emissions of different greenhouse gases.

IPCC Fifth assessment report 2013	Lifetime (years)	GWP time horizon 20	GWP time horizon 100
Carbon dioxide CO2		1	1
Methane CH4	12.4	86	34
Nitrous oxide N_2O	121.0	268	298

TABLE 11 GWP OF GHG

The different well to tank (WTT) and tank to wheel (TTW) emissions of trucks on different fossil fuels can be found in literature. The WTT emission factors (CO2, CH4) of bio LNG production in the Netherlands is not well established. The biogas production mix in 2020 and later are uncertain. TNO CE Delft and ECN are working on a document with aggregated data on CO2-equivalents. The current status of the document is "internal", due to a lack of specific WTT emission information the data of TNO CE Delft and ECN is used. Table 12 shows the shows the emission factors.

LNG trucks emit 85% CO2-equivalent w.r.t. diesel in 2030 and 86% in 2050. The aggregated data contains assumptions about the biogas production mix between 2015 -2050. The WTW CO2-equivalents emission factors for bio LNG are predicted to become negative in 2030 and 2050. To understand the negative WTW effects, it is important to understand how the data is build up, see Figure 18 WTW emissions calculation.

FIGURE 18 WTW EMISSIONS CALCULATION

CO2	2010	2020	2030	2050
DIESEL	999,57	1008,03	1015,32	1046,89
LNG	846,09	856,89	868,66	908,13
BIO LNG	156,52	148,90	-108,29	-70,89

TABLE 12 WTW CO2-EQ EFFECTS OF TRUCKS ON DIFFERENT FUEL TYPES IN G/KM (TNO, 2015)

LNG trucks emit 85% CO2-equivalent w.r.t. diesel in 2030 and 86% in 2050. The aggregated data contains assumptions about the biogas production mix between 2015 -2050. The WTW CO2-equivalents emission factors for bio LNG are predicted to become negative in 2030 and 2050. To understand the negative WTW effects, it is important to understand how the data is build up, see Figure 18.

The reason the WTW effects are negative is that the WTT finished fuel emissions of bio LNG are negative (Table 12). The assumption is that in 2030 and 2050 a part of the biogas is produced with manure digestion. The mitigated methane emissions are imputed in the WTT emission factors. ECN is responsible for these predictions and the numbers are investigated further, an interview is conducted with M. Londo of ECN to get more insight in the assumptions behind the numbers (Appendix Interview Marc Londo – ECN).

It becomes clear that biogas production from manure mono digestion has great potential to mitigate methane emissions. The GWP100 of methane is 34 according to the latest IPCC report, so mitigating one ton of methane results in 34 tons of mitigated CO2-equivalents. If the time horizon is set to 20 years the effect even doubles. The JEC uses the GWP's of the fourth IPCC assessment report. The Joint Research Center of the European Commission has published a WTW analysis wherein the WTT emissions of compressed biogas are investigated for different production routes (JEC, 2014). The second and third bar in the graph below represent the production of biogas from liquid manure. The JEC study is also used by ECN to deduce the specific Netherlands emission factors. Note that the negative WTW CO2-equivalent emissions of biogas are the "result of intensive cattle breeding rather than an intrinsic quality of biogas." (JEC, 2011).

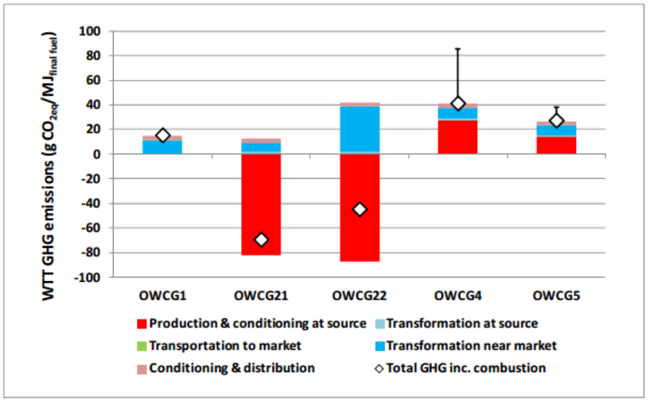

FIGURE 19 WTT EMISSIONS OF CBG

SHADOW PRICES

Total truck mileage multiplied by efficiency and GHG emission factors are added in the CBA to a combined number of CO2-equivalents. To monetize the emission of CO2-equivalents a CO2 price is needed.

The effects of GHG are diverse; agricultural loss, sea level rise, health issues, damage of buildings and infrastructure, impact on biodiversity and ecosystems (CE Delft, 2014). The actual value of mitigating a ton of CO2 is difficult to determine. There is no actual value for CO2 and because of the external effects, the willingness to pay for lower GHG emissions differs. Due to a lack of market prices, shadow prices are used to determine the social costs of GHG emissions.

	LOW	MIDDLE	HIGH
CO2	44	78	155

TABLE 13 SHADOW PRICE CO2 IN € (CE DELFT, 2014)

Air Pollution

Greenhouse gas emissions affect the temperature in the atmosphere, the next group of effects relate to air pollution. Air pollution cause negative effects on human health, agriculture, ecosystems, biodiversity and buildings and infrastructure. In the literature review and during interviews two key elements are identified to compare the different fuel engines. Nitrogen oxides (NOx) and particulate matter (PM). Sulfur dioxide (SO2) is not included in this research, in shipping this is still an important source of air pollution, while in road transport Ultra-low-Sulfur diesel (ULSD) has become the norm since the EURO-IV standard in 2005.

The same approach is used as in Air Pollution. Determine the total vehicle kilometers and multiply with the emission factors per fuel type. Shadow prices of CE Delft are used to calculate the social cost of the pollutants. Table 14 and Table 15 represent the WTW emission factors of gas and diesel trucks. Note that the difference in pollution of particulate matter between gas and diesel is smaller than expected. The small difference relates to new EURO-VI diesel trucks. According to TNO the difference between EURO-VI gas and diesel trucks is small, while the differences between old and new trucks can be significant (Appendix Interview Ruud Verbeek - TNO). The NOx shadow price for road transport is €10600 per ton (CE Delft, 2014)

	2030	2050
DIESEL	0,740	0,743
(BIO) LNG	0,555	0,557

TABLE 14 WTW NOX EMISSION FACTORS IN G/KM

	2030	2050
DIESEL	0,081	0,081
(BIO) LNG	0,077	0,078

TABLE 15 WTW PM10 EMISSON FACTORS IN G/KM

In heavy populated areas the social costs of PM emissions are higher than in remote areas. To calculate a mean price per truck kilometer the average price is multiplied with the shares of the road types. 75% of the truck mileage is highway. The calculation led to a shadow price of €75794 per ton.

External effects

SECURITY OF SUPPLY

If the government in the Netherlands decides to implement measures to encourage the use of bio LNG, this will result in a lower oil dependency. Locally produced biofuels increase the self-sufficiency of the Dutch economy. There are different ways to score the energy security of a country e.g.; Shannon-Wiener index, net energy import ratio and oil consumption by capita {Shakya, 2011 #41}. In this research a sort of mileage price is needed for the different fuel types. Diesel is the dominant and only fuel and substituting diesel with an alternative fuel will lead to diversification. The approach is to set a premium on diesel to monetize the cost of a possible oil crisis. Alternative fuels will also be affected in case of an oil crisis but to a lower extend.

The assumption is

- Once every four years an oil crisis occurs with a duration of one month and a price increase of 20% for diesel, 10% for LNG and 5% for bio LNG.

The CPB conducted a CBA on the substitution of oil by biomass to increase energy security in 2004, one of their findings was: "subsidizing the use of biomass appears to be a highly expensive policy measure. Replacing crude oil by biomass as input increases production costs strongly" (CPB, 2004). In this research the avoidance of CO2 emissions is not taken into account. The security of supply effect is expected to be low, but present.

NOISE COSTS

Noise emissions from traffic pose an environmental problem of growing importance (RICARDO-AEA, 2014). CE Delft states that noise is very costly to society and should be taken as seriously as other forms of pollution, as it is similarly damaging to human health. In the Netherlands new Iveco Trucks are Piek certified which means they can operate below certain noise levels. There are indications that gas trucks produce less noise than diesel trucks, measures that stimulate the transition to gas trucks can have impact on noise levels. LNG24 claims that a LNG truck produces 50% less noise. A working paper of the IEA states that the differences are smaller, stationary advantage of 1 dB, while in motion the levels are the same. The gearbox and brakes of a diesel versus LNG truck do not differ, while the gas engine can be 8dB more quite than the diesel engine. In this analysis a noise reduction of 30% is assumed based on a case study of Albert Heijn (LNG platform, 2014). A reduction of 3 dB is like doubling the distance from the noise or reducing traffic volume by 50%. In the costs per kilometer two elements are incorporated, nuisance costs and health costs. The baseline of noise costs is based on a CE study and can be found in Table 16.

	€/1000 V KM
DIESEL	28
(BIO) LNG	19.6

TABLE 16 NOISE COSTS PER 1000 TRUCK KM

Note that noise reductions can lead to opportunities for city logistics to deliver earlier and later. Rush hours can be avoided because of a broader time window, this is not taken into account in this research.

SAFETY

The risks of a system where a part of the diesel trucks are replaced by gas trucks imposes other risks to the society. Actual data on accidents with gas trucks does not exist yet. The LNG sector argues that the safety track record of present global LNG industry is good. The LNG Platform has signed a LNG safety deal with the ministry of I&M, to build knowledge on LNG safety (LNG Platform, 2015). The fuel characteristics of diesel, LNG and LPG are displayed in Table 17.

	DIESEL	**LNG**	**LPG**
AUTO IGNITION TEMPERATURE	360	620	365
LOWER – HIGHER EXPLOSIVE LIMIT	0.6-6.5%	5.9-16%	1.8-10%
RELATIVE DENSITY	0.825	0.64	1.56
	Water = 1	Air = 1	Air = 1

TABLE 17 FUEL CHARACTERISTICS CONCERNING SAFETY (LNG PLATFORM, 2015)

CE Delft has published the external cost of accidents in Dutch road transport, the safety costs of 1000 vehicle kilometers are given in Table 18. Data on gas trucks is not available, LNG and LPG have other characteristics, but to make an assumption of the safety costs of a LNG truck, the difference of diesel and LPG is being used. The “bulk” safety costs are related to the fuel type. The extra costs of LNG are not only related to intrinsic safety of the fuel, but also to infrastructure and fueling stations.

VEHICLE	SECTOR INTERNAL €/1000KM	SOCIETAL EXTERNAL €/1000KM
CAR DIESEL	41	3
CAR LPG	42	3
TRUCK DIESEL	74	3
TRUCK (BIO) LNG	76	3

TABLE 18 SAFETY COSTS PER VEHICLE KILOMETER, ASSUMPTION ON BIO LNG (CE DELFT, 2014)

Indirect effects

Effects that are indirect and not taken into account are:

- Employment
- Knowledge innovation economy

Conclusions CBA model

This chapter gives answers to the following sub-questions:

- What are possible and feasible policy alternatives?
- How can CBA be used to valuate policy alternatives towards bio LNG?

From the chapter current policies four measures are identified which are used to build four alternative policies upon. The projected number of trucks are derived from literature. The four contemplated policy alternatives are compared to a reference alternative to calculate the effects of the alternatives. In this calculation the input variables are based on literature and shadow prices are used to valuate external effects. In this section it becomes clear that there is an information asymmetry between input data. In literature several sources of TTW effects of trucks can be found, but what the safety effects of (bio) LNG trucks is based on assumptions. The uncertainty of different input variables is also asymmetric, for instance the high shadow prices of emitting a ton of CO2 is 3,5 times higher than the low shadow price.

5. RESULTS

The model has been build up as described in the previous chapter, the SCBA shows the effects relative to the BAU alternative as can be seen in Table 19.

Alternative	*Net Present Value*
BAU (reference)	0
Gas	1,4
FQD	0,8
Diesel tax	1,5
CO2 tax reduction	0,4

TABLE 19 WELFARE EFFECT OF ALTERNATIVES 2015-2050 IN BLN €

Interesting to see that the BAU alternative scores worst. The high costs for the BAU alternative are mainly determined by fuel costs and GHG effects. The World Energy Outlook 2014 fuel prices are used as input. In the forecasts the gap between oil and gas derivatives is growing. The volume discount on fuel prices are not taken into account and can make the BAU alternative "cheaper".

The alternatives score better than the BAU reference. In the macroeconomic effect taxes and subsidies are excluded. The effects on the governmental revenues (tax income – subsidies) is represented in Table 20.

Alternative	*Governmental revenue (taxes minus subsidies)*
BAU (reference)	0
Gas	-1,4
FQD	-0,6
Diesel tax	0,6
CO2 tax reduction	-0,3

TABLE 20 GOVERNMENTAL REVENUES OF THE ALTERNATIVES 2015-2050 IN BLN €

In this table the effects for the Dutch government are represented, all alternatives except Diesel tax increase lead to lower governmental revenue. The Gas policy alternative will cost the Dutch government €1,4 billion in the period 2015-2050. The Diesel tax increase will lead to more revenues for the government, approximately €0,6 billion in the same period.

The effects can be grouped to see what the effects will be for a group of actors. For instance the effects of measures on government revenue. Fuel taxes are important income for the government, policy options that have a negative impact on governmental revenue could potential lead to problems in state budgets. Figure 20 shows the distribution of effects. The effects for the "fuel market" are not significant, this can be explained by the way the CBA model is built, the input variable fuel price is inclusive profit margin for fuel producers.

FIGURE 20 DISTRIBUTION OF EFFECTS FOR DIFFERENT ACTOR GROUPS

From a governmental point of view the "Diesel tax" alternative seems interesting, but this alternative will increase costs for transporters. The by the sector proposed "Gas" alternative brings the least tax revenues for the government. This is mainly caused by a high number of LNG trucks and lower LNG tax than diesel tax. The transport sector faces the lowest costs in the Gas alternative. In the tables below the costs of the alternatives are presented.

Gas	mln kg	Mln €	disc €
Policy costs		0	0
Subsidize bio LNG production gap		954	270
Fuel		-6493	-1905
Fuel tax		-3474	-1085
Truck cost		3555	1187
Filling stations		284	104

Greenhouse gas emissions	CO2-equivalents	-12466	-972	-541
Air pollutants	NOx	-9	-91	
	PM	0	-11	-58
SOS			-50	-28
Noise			-387	-217
Safety			92	52
Total				-2222

TABLE 21 CBA OF GAS ALTERNATIVE 2015-2050

FQD		mln kg	Mln €	disc €
Policy costs			0	0
Subsidize bio LNG production gap			0	0
Fuel			-3373	-1043
Fuel tax			-1894	-620
Truck cost			1884	661
Filling stations			157	60
				0
Greenhouse gas emissions	CO2-equivalents	-7933	-619	-340
Air pollutants	NOx	-5	-49	
	PM	0	-6	-32
SOS			-27	-15
Noise			-210	-120
Safety			50	29
Total				-15

TABLE 22CBA OF FQD ALTERNATIVE 2015-2050

Diesel tax		mln kg	Mln €	disc €
Policy costs			0	0
Subsidize bio LNG production gap			1709	425
Fuel			-2364	-707
Fuel tax			2672	1594
Truck cost			1671	526
Filling stations			128	44
Greenhouse gas emissions	CO2-equivalents	-19244	-882	-455
Air pollutants	NOx	-9	-41	
	PM	0	-5	-26
SOS			-23	-13
Noise			-177	-97

Safety		42	23
Total			270

TABLE 23 CBA OF DIESEL TAX ALTERNATIVE 2015-2050

CO2 tax reduction		mln kg	€	disc €
Policy costs			0	0
Subsidize bio LNG production gap			0	0
Fuel costs			-1560	-469
Fuel tax			-853	-261
Truck cost			890	298
Filling stations			73	28
Greenhouse gas emissions	CO2-equivalents	-3700	-289	-155
Air pollutants	NOx	-2	-23	
	PM	0	-3	-15
SOS			-12	-7
Noise			-97	-54
Safety			23	13
Total				-622

TABLE 24CBA OF CO2 TAX REDUCTION ALTERNATIVE 2015-2050

The tables show that all alternatives score better on external effects, except safety, the CO2 effects are significant, but tax and fuel cost are more determining the outcomes. The graphical representation of absolute values of the effects of the alternatives give more information (Figure 21). Note that according to truck costs only the extra investment for a gas truck is taken into account.

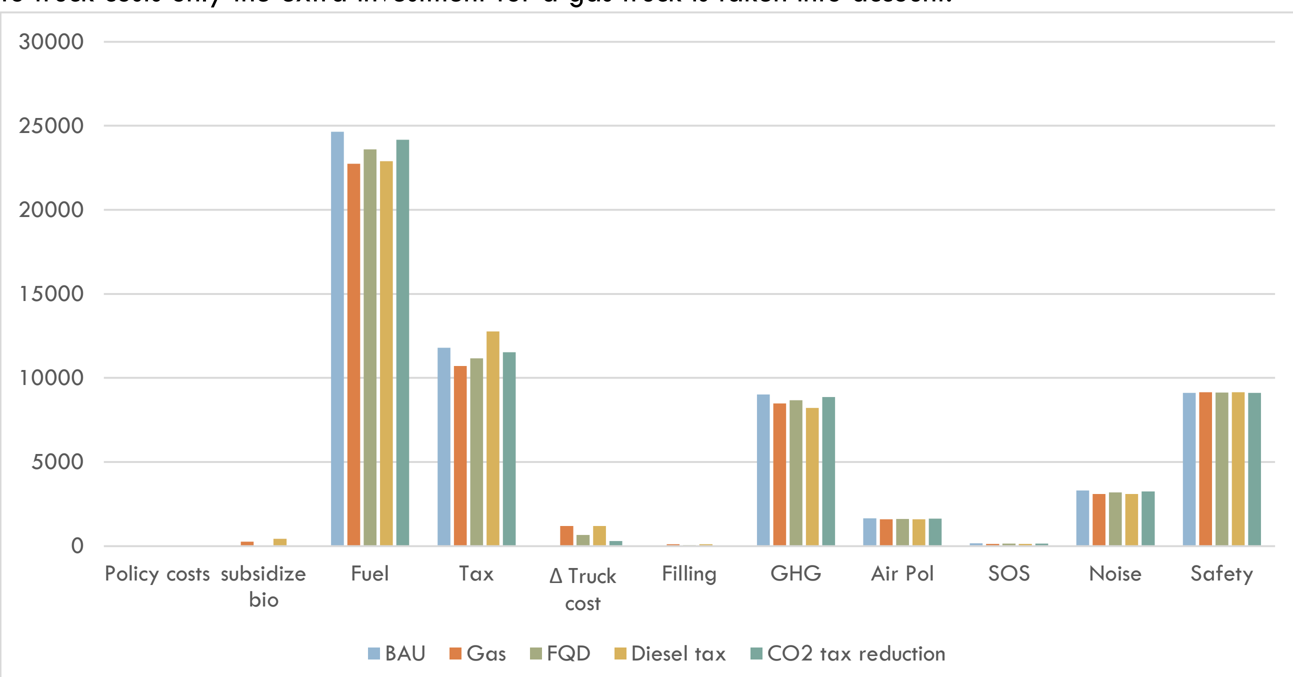

FIGURE 21 CBA DISCOUNTED EFFECTS OF ALTERNATIVES 2015-2050 IN MLN €

From Figure 21 it becomes clear that the fuel costs have a big impact on total effects, tax and greenhouse gas effects are also significant. The effects on air pollution, security of supply, noise and safety do not differ significant between the alternatives. Safety costs of trucks are quite high, these costs are mainly linked to traffic accidents.

Greenhouse gas emission impose significant effects on society as can be seen in Figure 21, in the figure below the absolute emissions of CO2-equivalents are showed in million tons. Figure 22 shows the increase of CO2-equivalent emissions till 2020 because of growing number of trucks, after 2027 the growing number of LNG and more particular bio LNG trucks compensates the growing transport demand. The bio LNG trucks have a small negative WTW CO2-equivalent emission.

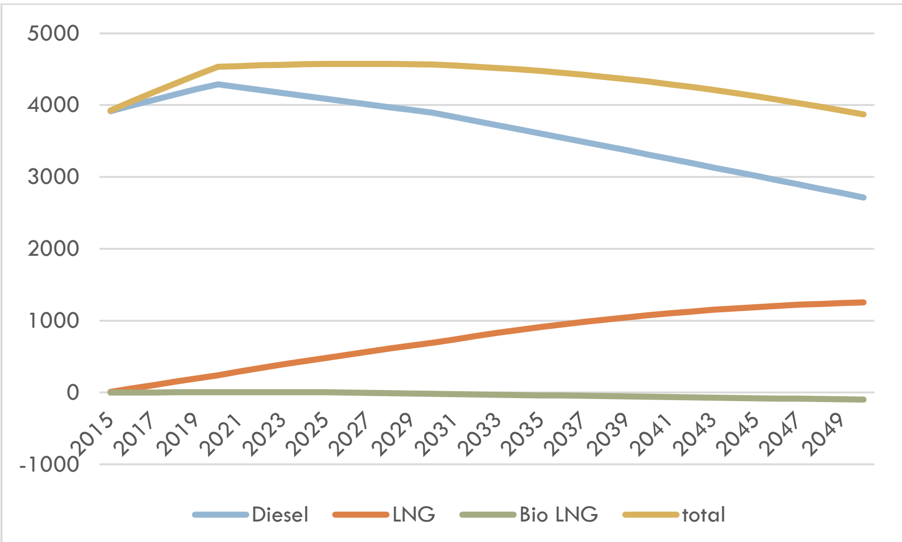

FIGURE 22 CO2-EQUIVALENT IN MLN TONS FOR DIESEL TAX ALTERNATIVE

Sensitivity analysis

A sensitivity analysis helps to understand how input variables influence outputs in the CBA model. The robustness of the outcomes is researched further. The uncertainties of the input data can be translated in a bandwidth of the final results. The focus of the sensitivity analysis will be on effects that are significant, and on effects where in the literature review or interviews high uncertainties exist. In a sensitivity analysis the variables are changed while other variables are kept constant.

Reality check

According to the Greengas forum in the Netherlands the maximum potential for bio LNG production is listed below (RHG, 2014). These values are compared to the alternative with the highest bio LNG penetration, the “Diesel Tax” alternative. Table 25 shows that only a part of the total maximum potential is used.

	2020	2030
MAX POTENTIAL BIOGAS PRODUCTION (MLN NM3)	1237	3738
MAX PERCENTAGE BIOGAS TO BIO LNG (%)	17%	35%
MAX POTENTIAL BIO LNG (PJ)	4.23	26.29
BIO LNG USE IN DIESEL TAX ALTERNATIVE (PJ)	0.22	2.16

TABLE 25 MAXIMUM POTENTIAL OF BIO LNG PRODUCTION IN NL ACCORDING TO GROENGAS FORUM

To check whether the growth rates show a normal pattern the number of trucks in the gas alternative is presented below. The number of gas trucks will grow to 2020 because of the growing transport demand, after 2020 the number of diesel trucks will decline in this alternative.

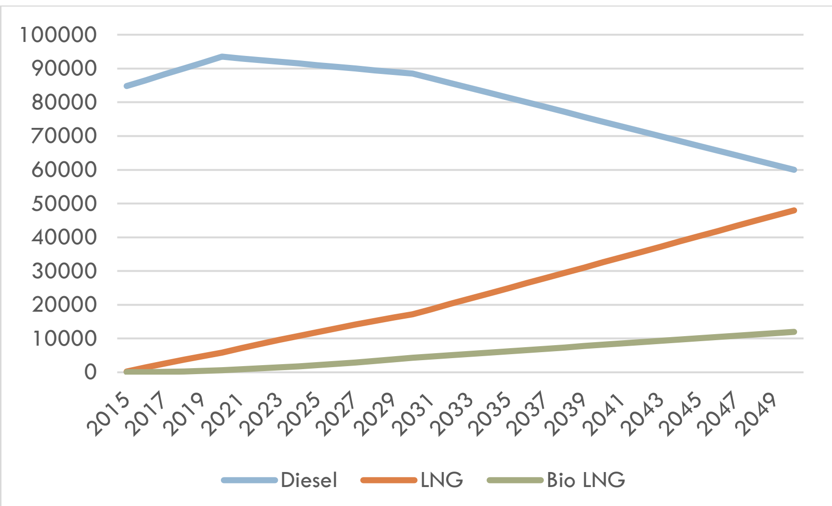

FIGURE 23 NUMBER OF TRUCKS IN THE GAS ALTERNATIVE

The number of filling stations based on the number of gas trucks presented by the sector (Appendix Input data CBA). The alternatives with the highest share of gas trucks (Gas & Diesel tax) have the most filling stations.

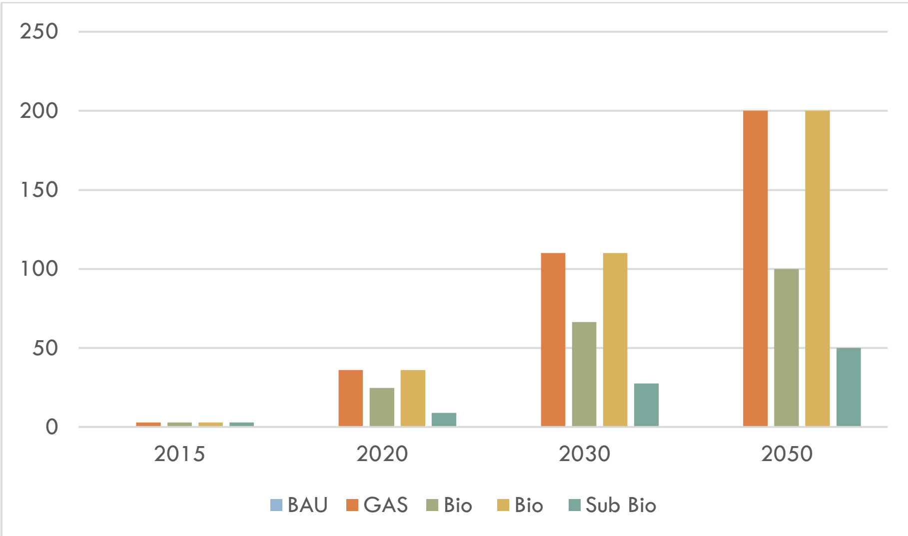

FIGURE 24 NUMBER OF FILLING STATIONS FOR DIFFERENT ALTERNATIVES 2015-2050

The model shows short payback times, Figure 25. These numbers are checked with importers of Iveco and Scania trucks. The importers note that payback times of 3 years are currently realistic, but under specific conditions:

- Mileage more than 100.000 kilometer per year
- No detour filling stations

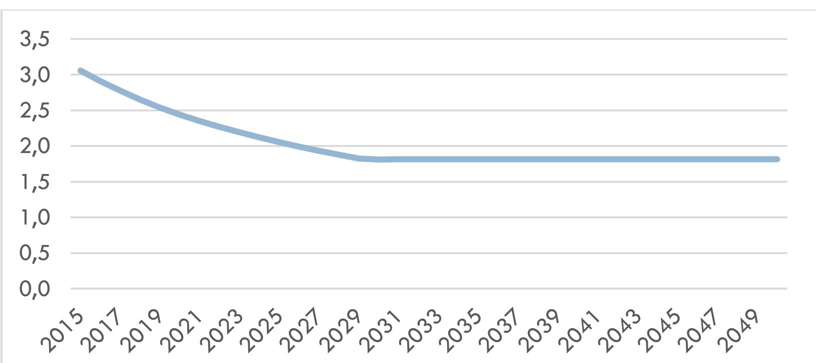

FIGURE 25 PAYBACK TIME OF A LNG TRUCK IN GAS ALTERNATIVE

In the sensitivity analysis the extra investment for gas trucks will be further investigated. The model uses a generalized mileage of 46000 kilometers a year and no diesel volume discount. Also note that there are more drivers to not buy a gas truck, e.g. lack of filling stations, residual value and engine power.

Some results of the CBA are shown in the section above, the results are calculated on the basis of several input variables. Input data is as much as possible based on objective sources of national and international valued sources. Forecasts come with uncertainty, to test the dependence of the outcomes of the CBA to changes in input data a sensitivity analysis is conducted. The results of the CBA show which effects have the biggest impact, this gives already an indication which factors are responsible for the outcomes as presented in the previous chapter.

Determining factors:

- Total truck mileage
- Fuel prices
- CO2-equvalent prices
- Discount rate

Uncertain input data:

- SOS
- Noise
- Safety
- Truck costs

MILEAGE +20%

The result of more 20% kilometers a year per truck is not shocking, the effects are calculated in effect per truck kilometer, so most effects increase with 20%, except truck costs. The diesel tax alternative scores lower because of relatively higher taxes. BAU alternative is still slightly more expensive.

MILEAGE -20%

No significant changes in the outcomes, the payback time for gas trucks increases. The outcome distribution of the alternatives does not change due to a lower mileage.

DIESEL PRICE +20%

The total costs of all alternatives grow, the share of diesel trucks in each alternative is 50% or more, so an increase in diesel prices results in higher costs. The effect fuel cost becomes more dominant. The differences between the alternatives are increasing with higher diesel prices. If the effects are added up the CO2 tax reduction alternative becomes relatively more expensive and scores second worse after the BAU alternative.

DIESEL -20%

The dominance of the fuel price effect decreases. The diesel tax alternative becomes relatively expensive if total costs are concerned. The BAU alternative score second worse. If government revenue is not taken into account the diesel tax alternative scores best, taxes. Overall the diesel price is one of the most determinant factors. The payback time of gas trucks goes up from 3.1 years to 4.6 years in 2015. Determining is the projected gap between diesel and LNG prices Figure 26 represents the SCBA fuel price input, mind that the energy content of diesel is 35,9MJ/l and LNG is 48,6MJ/kg.

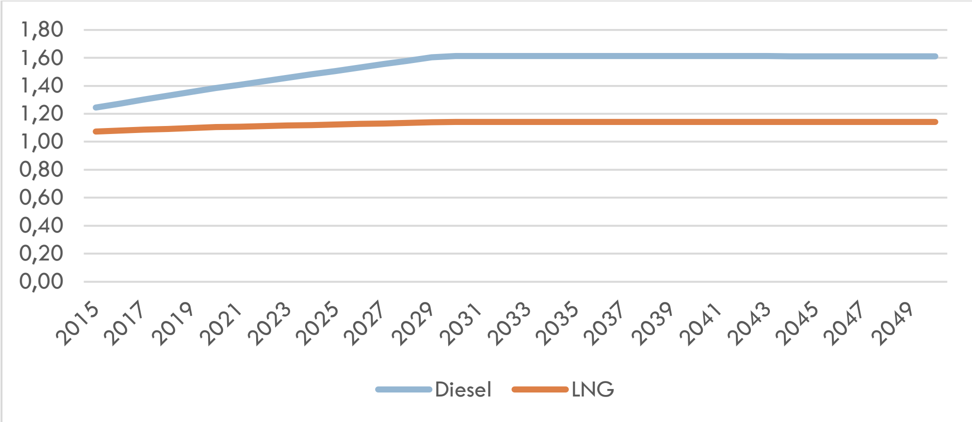

FIGURE 26 GAP DIESEL - LNG PRICES TAXES INCLUDED USED AS SCBA INPUT IN €/L AND €/KG

BIO LNG PRICE +25%

The price of bio LNG is one of the uncertain input variables, the pump price is increased with 20% to see if the outcomes change. Figure 27 shows the result of the price increase of 25% for bio LNG, note that excluding government revenues and subsidies the BAU alternative is still the most expensive in terms of costs. The gas and diesel tax alternative score good. The distribution of the alternatives has not changed, the total price of the alternatives where bio LNG is used are only slightly higher 46689 to 46399 mln euro. An increase of the bio LNG price of 25% results in an increase of 0.6% of the total costs of the diesel tax alternative. In this alternative 25% of the trucks is finally replaced by bio LNG in 2050, the discount rate of 5.5% marginalizes the effects.

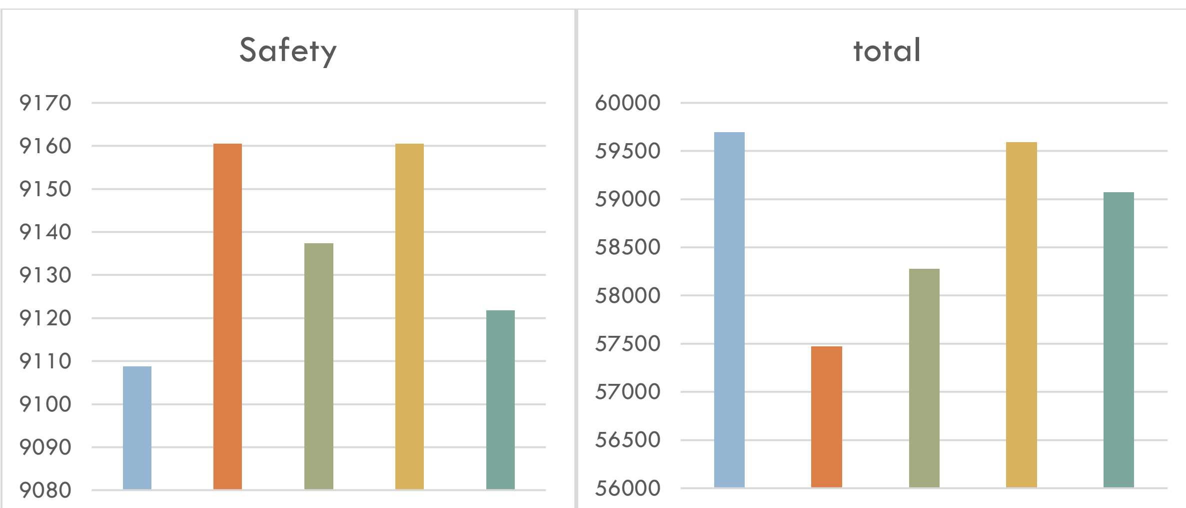

FIGURE 27 LEFT: EFFECTS MINUS SUBSIDIES AND TAXES. RIGHT: GOVERMENTAL REVENUE 2015-2050 IN MLN €

REPLACE SHADOW CO2 PRICE OF €78 WITH ETS PRICE OF €7,50.

Surprisingly the effects of the CO2 price decrease of more than 90% does not result in a complete other outcome. The differences between the alternatives becomes smaller, but still the BAU alternative has the highest costs if taxes and subsidies are excluded. The gas alternative scores better than the diesel tax alternative in case of low CO2 prices. Figure 28 shows the effects.

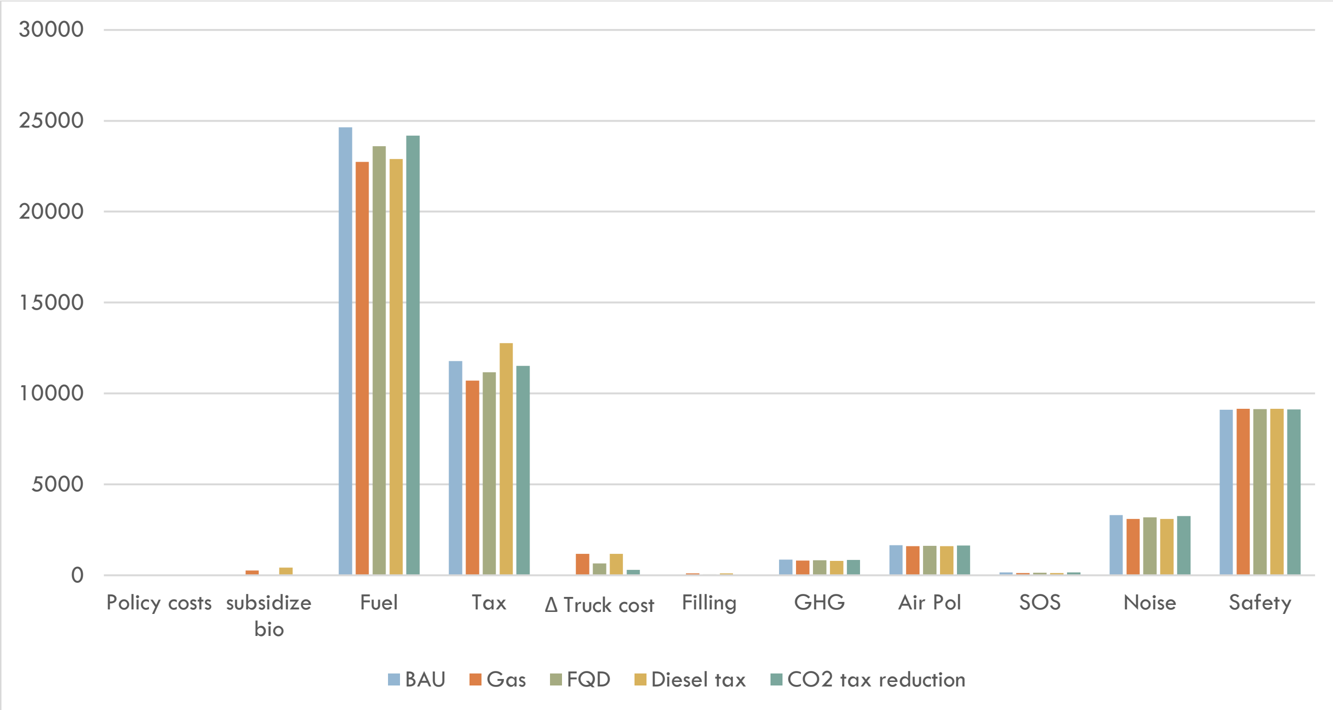

FIGURE 28 CO2-EQUIVALENT PRICE OF €7,50

DISCOUNT RATE

The difference between external effects and investments in trucks and fuels is increased to see what the effect is on the outcomes.

discount rates		Sensitivity analysis
CO2-eq	2,5%	1%
Air pollution	2,5%	1%
SOS	2,5%	1%
Noise	2,5%	1%
Fuel	5,5%	10%
Tax	5,5%	10%
Trucks	5,5%	10%
Filling station	5,5%	10%
Subsidies	5,5%	10%

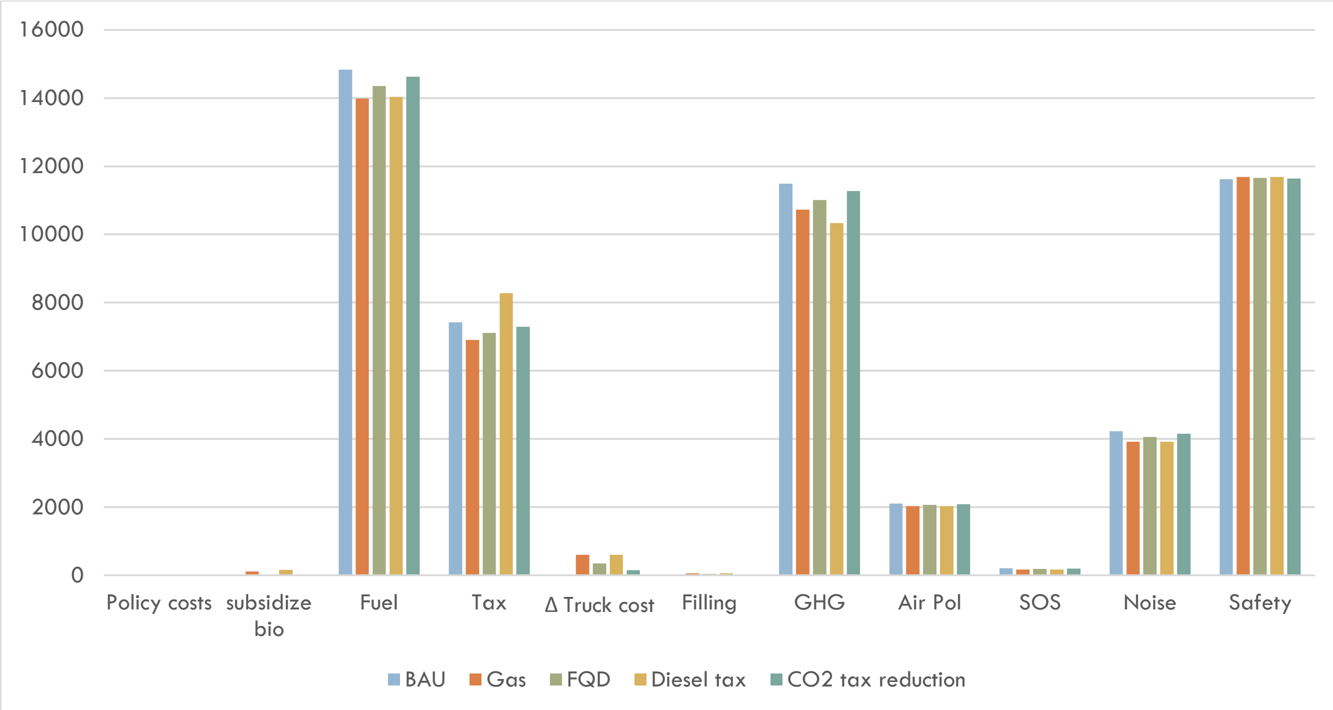

FIGURE 29 HIGH DISCOUNT RATE FOR DIRECT COST, LOW DISCOUNT RATE FOR EXTERNAL EFFECTS 2015-2050 IN MLN €

Figure 29 shows that external factors are becoming more important with low discount rates, still the BAU alternative is most expensive.

SECURITY OF SUPPLY COST +50%

The premium on diesel increases from 0.4% to 0,8%, this results in only small changes, diesel becomes slightly more expensive.

NOISE COSTS DIFFERENCE BETWEEN GAS AND DIESEL +/- 50%

If the difference in noise between gas and diesel trucks would be doubled from 30% to 60% the noise costs for the alternatives look like Figure 30. If the difference is halved to 15% the differences between the alternatives become smaller.

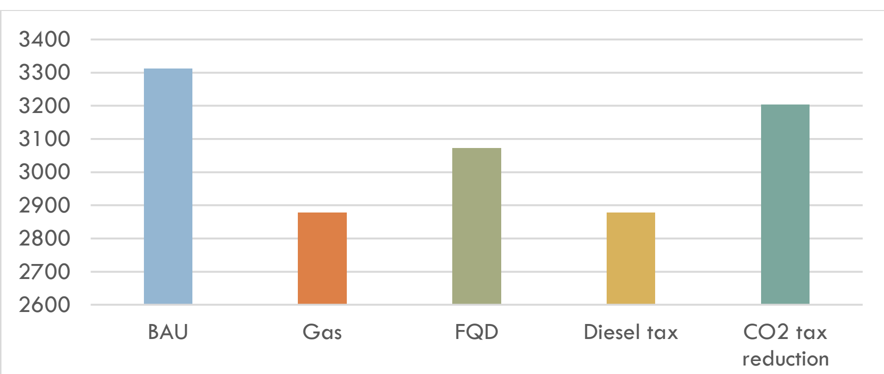

FIGURE 30 NOISE COSTS WHEN DIFFERENCE BETWEEN GAS AND DIESEL IS 60%

SAFETY COST DIFFERENCE BETWEEN GAS AND DIESEL +100%.

The safety costs of LNG trucks are unknown, in the CBA the difference between gas and diesel cars is used to predict the gas truck cost per kilometer. This prediction is uncertain so the sensitivity of the outcomes are tested with a significant input data change of 100%. Diesel trucks have €0.077 safety costs per kilometer, gas trucks 0.079, if the difference is being doubled it becomes €0.081 /km. This change does not influence the outcomes significantly. Figure 31 shows that the alternatives score close.

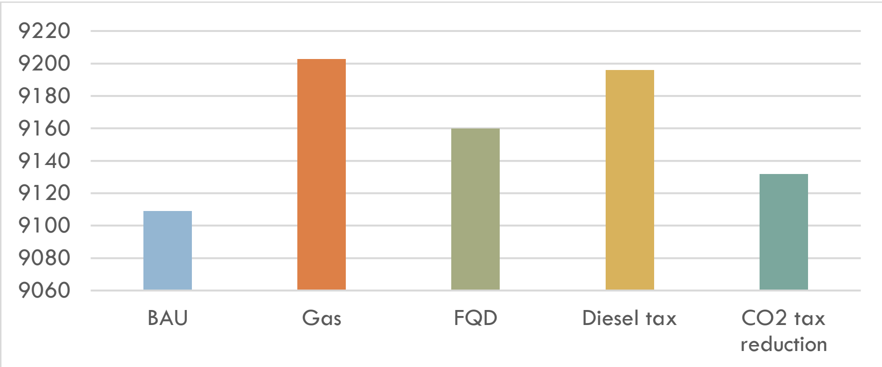

FIGURE 31 SAFETY COSTS 2015-2050 DISCOUNTED IN MLN €

INCREASE EXTRA COSTS TRUCKS BY 75% TO €35.000.

The last input variable that is going to be adjusted is extra truck cost. In the CBA a difference of €20.000 is used in the calculation. In the sector it becomes clear that currently the price difference for an LNG truck is higher; between €25.000 and €35.000. The higher value is used to test the sensitivity of the outcome. The alternatives score closer to each other, the distribution stays the same. The payback time goes up to 5,4 years, which is probably to long for transporters. In the model there is no feedback loop that high gas prices lead to less LNG trucks. The CBA is used to value effects, not to forecast the number of trucks.

Scenario analysis

In the sensitivity analysis single input variables are adjusted to see how they influence the outcomes of the CBA model. In reality the different input variables that fall outside the model also influence each other. If for instance the gross domestic product growth decreases because of lower global economic development, this impacts fuel prices and CO2 emissions. For that reason multiple input are changed in the scenario analysis.

The results as described in the chapter before are only true as the input variables are the same as forecasted. While uncertainties exist in the input variables the presented outcomes are not probable to happen. In the scenario analysis multiple inputs are adjusted to see what the outcomes will be in case of different futures.

It is not possible to perform a scenario analysis for all possible futures in the timeframe, in this research a worst case and best case scenario are being developed. In the scenario analysis the number of trucks is adjusted to the changing environment. The scenario analysis is used to explore the future, in two scenario's positive and negative input variables are combined to a worst and best case for bio LNG developments. The scenarios are based on the drivers and barriers for bio LNG and the interviews with experts.

Worst case

- Low transport demand and vehicle mileage
- Low gap between diesel and gas price
- Low shadow prices
- High bio LNG production price
- High gas truck costs
- Low discount rates on investments, high discount rates on external effects

The payback time of gas trucks is in the worst case scenario 8,4 years, the number of gas trucks is assumed to be 50% lower. Still there is a business case for trucks with a mileage of more than 100.000km a year. The low tax levels for LNG and bio LNG partly compensate the higher truck costs and higher fuel cost. The CBA of the worst case scenario is displayed below. Especially fuel costs, taxes and truck costs are determining factors. If all effects are added up, the BAU alternative scores best.

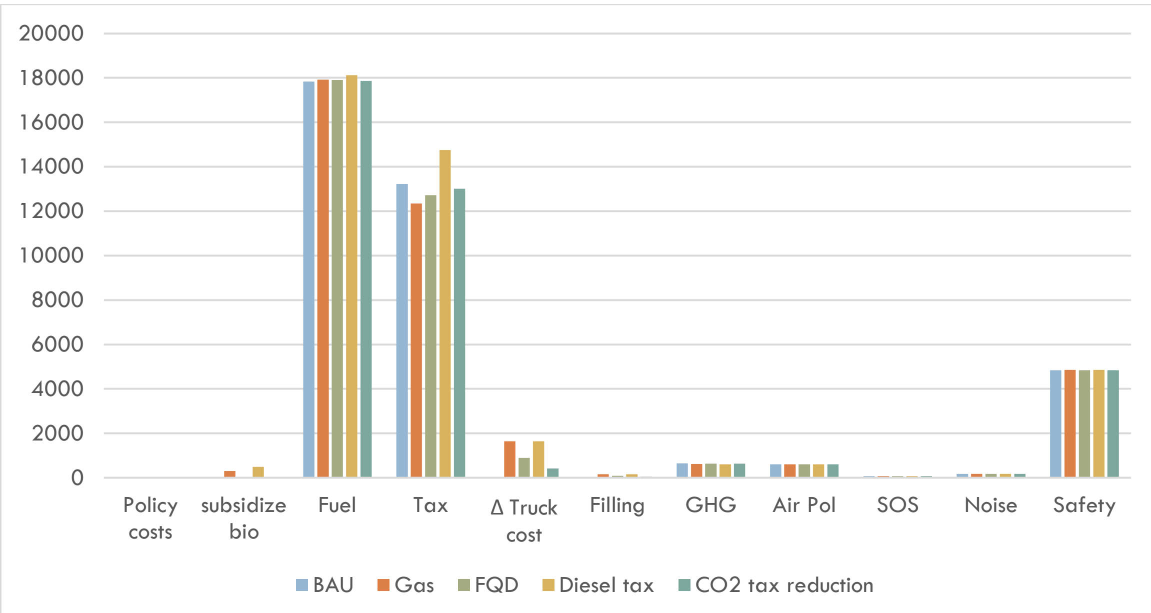

FIGURE 32 CBA WORST CASE SCENARIO

Best case

- High transport demand and vehicle mileage
- High gap between diesel and gas price
- High shadow prices
- Low bio LNG production prices
- Low gas truck costs
- High discount rates on investments, low discount rates on external effects

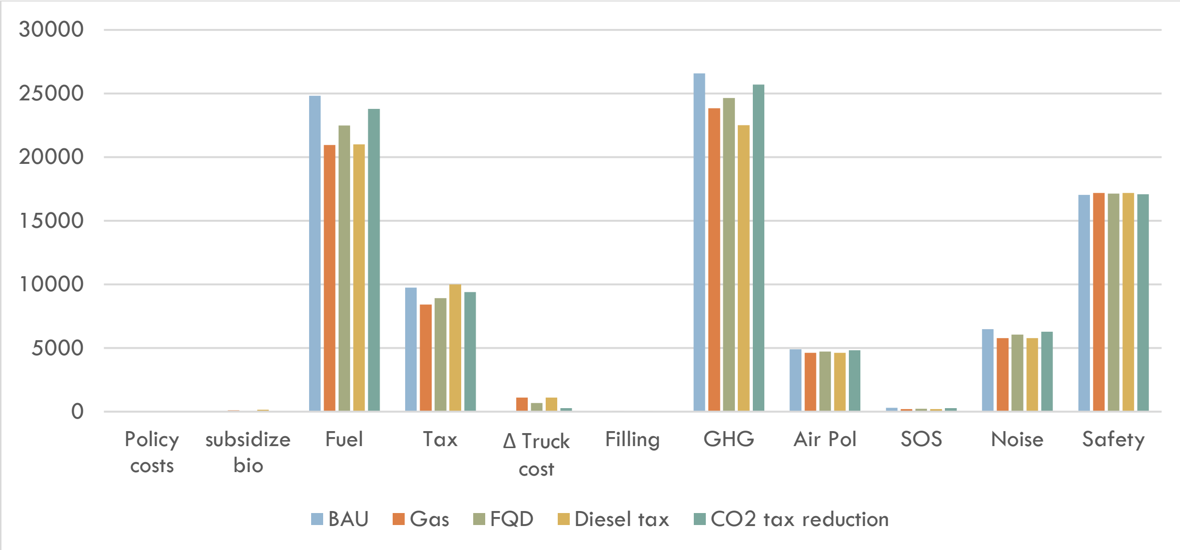

FIGURE 33 CBA BEST CASE SCENARIO

The high shadow prices and low discount rate on greenhouse gas emissions result in high cost as can be seen in Figure 33. In the “best” case scenario for bio LNG the external effects are far more determining the outcomes than in the worst case scenario. BAU alternative is way more expensive in the best case scenario.

Conclusions of results

This chapter aims to answer the following questions:

- What is the influence of different scenarios on the model outcomes?
- What are the social costs and benefits of different policy alternatives?

The model shows that all alternatives score better than the reference alternative, this means that the introduction of bio LNG imposes positive effects on the society. The distribution of effects is different between the alternatives. Transporters will profit the most in the Gas alternative, while the governmental revenues of the Diesel tax increase are the highest.

From the sensitivity analysis it becomes clear that changing a single input variable has small effect. The CBA is a combined model of different variables and effects and prices, the compound outcomes is quite robust. Fuel costs, truck costs, greenhouse gas emissions, taxes and subsidies are the determining factors. The CBA is being built to calculate the effects and does not forecast the number of trucks for the different fuels. The projected gap between the LNG and diesel price is high which makes the outcome robust.

The scenario analysis shows that the importance of the external effects are uncertain, the bandwidth of the shadow prices is high. It is remarkable that in the worst case scenario the fuel costs of the alternatives is only slightly higher than in the reference case (BAU). Bio LNG and especially LNG seems a no regret option. In the best case all alternatives score significantly better than in BAU.

6. CONCLUSIONS

Bio LNG can have potential in heavy road transport. There are multiple routes where biogas can be used; heating, electricity production, CHP, green gas grid injection and biogas can be used as a transport fuel. These routes are competing and the total amount of biogas production is limited. In the further future an extra source for biogas production could be power to gas.

Current policies concerning bio LNG are not harmonized, there exist subsidies for the production of biogas for grid injection or CHP but it is not possible to receive SDE+ if the biogas is used in transport. SDE+ subsidizes options other than bio LNG production, there is no level playing field. The system of HBE's, former biotickets are a stimulus for the production of bio LNG, for second generation biofuels a double counting exists. The price of HBE's is capricious and after 2020 it is uncertain if the HBE system will continue to exist. Investments in biogas production, upgrading capacity and liquefaction units are huge and upfront. If the government is not willing to stimulate bio LNG production the production will stay low.

During the interviews it became clear that the pivot point of biogas production seems to lay behind, this in contrast to wind and solar. If bio LNG production competes to green gas production, the 14% renewable energy share has to be compensated by other (more expensive) forms of renewable energy production. In this thesis the assumption is made that extra biogas production capacity is being built for future bio LNG production.

The fossil fuel prices are forecasted to increase, oil prices are predicted to increase faster than gas prices. The gap between the diesel and LNG is predicted to grow. The business case for gas in transport becomes better. Bio LNG pump prices are currently high but expected to stay rather stable, compared to fossil fuel prices. Still fossil LNG prices are predicted to be lower than bio LNG prices.

The government has different options to stimulate bio LNG. There are mainly two ways to stimulate the use of bio LNG; taxes & subsidies and by regulation. Four alternatives have been designed and the effects of these alternatives have been calculated. The most important effects where diesel and gas trucks differ are:

- Greenhouse gas emissions
- Air pollution
- Taxes and Subsidies
- Truck costs
- Filling station costs
- Security of supply
- Noise
- Safety

The first part of the research question can now be answered: *Which policies and regulations can be used to stimulate bio LNG?* The four alternative policies that are based on current policies and regulations on a national and European level are:

- Gas alternative, low taxes for LNG and partly subsidizing bio LNG production

- FQD alternative, regulates blending of bio LNG increase of 0.75% per year
- Increase diesel tax
- Extra tax reduction for mitigated CO2 emissions

A Social Cost Benefit Analysis is used to calculate the effects of the alternatives. The outcome is shown in the table below.

Alternative	*Macro-economic effect (taxes and subsidies excluded)*
BAU (reference)	0
Gas	1.4
FQD	0.8
Diesel tax	1.5
CO2 tax reduction	0.4

TABLE 26 EFFECTS OF DIFFERENT ALTERNATIVES TO STIMULATE BIO LNG 2015-2050 IN MLN €

From a macro economical perspective all alternatives score better that the BAU alternative. The benefits of the alternatives up weight the costs. One of the main conclusions is that the business as usual (BAU) alternative scores low, the cause is increasing diesel prices and emission of greenhouse gases and other pollutants. The magnitude of the outcomes is strongly related to the discount rate chosen. The sensitivity analysis shows that changing single input variables does not have major impacts on the outcomes of the model. LNG truck and especially bio LNG trucks can have lower CO2-equivalents emissions. The digestion of manure can even result in negative CO2-equivalent emissions, because of mitigated methane emissions.

The scenario analysis makes clear that the gap between diesel and LNG is one of the determining factors for the outcome of the model. The forecasted gap is quite high, so small changes in diesel or LNG prices do not directly lead to outcome shifts. The best and worst case scenario show complete other outcomes. The number of bio LNG trucks becomes significant in the longer further and the discount rate on investments makes that the bio LNG pump price does not significantly affect the outcomes.

The success of bio LNG is very dependent on the success of LNG. Only if there is a proportional share of gas trucks on the road the introduction of bio LNG can have significant effect. The effects of measures to stimulate bio LNG begin to have effect after 2020 as market shares increases. The investments are upfront and the effects come later. Discounting has a negative effects on projects with upfront investments because net present values of future effects are being decreased.

The last part of the main research question is: *What is the value of SCBA in providing more insight in the effects of these policies?* The value of SCBA in the exploration of the feasibility of a transition to an alternative fuel in this research is multiple. The SCBA increases the insight in the usefulness and feasibility of policy alternatives to stimulate bio LNG. This prevents policies that have a negative effect on the welfare to be developed. SCBA can result in a better understanding of the different effects of policy alternatives for policy makers. Decisions can be made on the basis of a better understanding of all the societal aspects of policy measures. The SCBA gives insight in the distribution and order of magnitude of different effects. The distribution shows where problems can occur when policy alternatives are implemented. SCBA enhances discussions in the early stage of exploring policy alternatives by providing objective and independent information.

In this research the method is not used as a go or no go decision tool, but more as an exploration tool to test the feasibility of a transition to bio LNG. This can lead to problems because the tool is used in an undeveloped area. The quality and bandwidth of input data is uncertain. Some variables are more certain than others, so there is a data asymmetry. Accumulation of assumptions and shortcuts can lead to biased results. The presentation of the outcomes is difficult, a generalized table only shows aggregated information and too much emphasis on the limitations of CBA will lead to a “toothless” instrument. In the exploration phase the SCBA is used as an information provider and not as a go, or no go decision tool.

Reflection

The SCBA is used to develop insight in the distribution of effects, monetization forces the researcher to make effects comparable. The process to calculate a price for all the single effects and add them up eventually makes the outcome unknown throughout the research project. Changing the input values results in other outcomes. Categorizing effects is necessary to create oversight of the subject. The CBA provides a basis to compare different policy options.

Policy alternatives are the result of politics and are path dependent, the proposed alternatives are designed to explore the policy options and their weaknesses and strengths. The outcome of this research is not to point out one ideal policy alternative. The translation of policy measures to input variables for the CBA model is weak.

The gas sector proposed a set of measures and forecasted the number of trucks in a document, this is used as one alternative policy. The other policies are derivatives of the Gas alternative based on interviews and assumptions of the researcher. The degrees of freedom and choices that have to be made to design alternatives can make the researcher feel subjective. This can negatively influence the timeframe of the research.

Certain forecasted data points in time are used to build the CBA, between the points a simple interpolation is used to find data inputs per year. The CBA is built with several uncertain variables, if the distribution of variables were known a Monte Carlo analysis could be used to investigate the risks further. This would also result in more insight about the uncertainty of the outcome. The bandwidth is now set by a best and worst case scenario, while in reality uncertainties can also cancel out each other. The contribution of CBA in common infrastructures will be surrounded by less assumptions, comparable projects may be realized elsewhere or scaled up or down.

The number of trucks used in the model for the different alternatives are fixed and not dependent on other input variables. This is done because there was no transport model available which provides insight in feedback on fuel prices and policies. The assumptions made to forecast number of vehicle kilometers are done by the researcher. If the subject is research more extensive price elasticity’s should be included in a transport model, it is now not clear when transporters are going to switch from diesel to LNG or bio LNG.

In this thesis WTW effects are used to compare alternatives, WTW effects contain the emissions of fuel production. On the other hand the demarcation is set to the Netherlands, the production of fossil fuels is mainly located outside the Netherlands. There is a tension between those assumptions.

After the CBA is being built in excel a lot of information can be extracted from the model. The presentation of results of a CBA is generalized data, the difference of the effects to the reference is presented. Results are aggregated and contain little information.

The model assumes a sort of exponential growth rates while in real life the world is changing more ad hoc. The discount rates are set for the whole period and are subjective, environmental effects can be easily valued lower with higher discount rates. The use of shadow prices is necessary to value external effects, but highly uncertain. The shadow prices can change in time, in this research the shadow prices are kept constant when for example fuel prices and vehicle efficiencies change in time.

The time horizon of 35 years is long, it is hard to make projections about the effects of alternative fuels in a context of so many uncertainties. The policies should be constantly adopted to changing environments, in this research a policy is set for 35 years which is not realistic. Policy measures should be adopted in time, if the gap between diesel and LNG is big enough you do not need any governmental stimulation anymore.

Valuing safety or valuing the environment is controversial. The monetization of "ecosystems services to humans" is not the same as intrinsic value of for instance different species. The valuation is also time and place dependent.

The ability to design a national policy to stimulate bio LNG and receive strategic benefits is uncertain. European policies to decrease emissions and air pollutants are becoming increasingly important and policies between member states are adapted to create one single market for (alternative) fuels.

Price of bio LNG production is volume dependent. If demand for biogas is high and volumes of bio LNG are growing this will result in higher prices despite the efficiency benefits of economies of scale.

In this thesis the transport volume is assumed to be a given, in reality the transport volume is dependent on several internal variables. The government can also introduce strict measures to decrease transport volumes. These measures can even result in lower social costs and more benefits. This thesis only focusses on one fuel, but there are more possibilities to reach the policy goals.

This research focus on Netherlands but the market is more international oriented, there should be possibilities to trade biomass and biogas. The prices of bio LNG production can drop if not only national virtually greening of bio LNG is allowed, but also international. If for instance German green gas certificates can be used to supply Bio LNG the price can potentially drop.

Competing distribution channels for biogas. Bio LNG production can cannibalize the injection of green gas in the grid. The extent of flexibility to switch to other distribution channels is not clear. In this research the assumption is made that for the production of bio LNG extra production capacity for biogas will be installed. The total potential for biogas production is being used to check if the amounts are realistic (Routekaart Hernieuwbaar Gas, 2014)

Further research

The combination of a CBA with a transport model will result is more accurate forecasts of the number of trucks. Better forecasts with a feedback loop of fuel prices on number of trucks will result in more accurate predictions of effects.

Another point that can strengthen the analysis is more insight in the price elasticity of diesel versus (bio) LNG trucks, the price elasticity of diesel trucks is low, but there are currently no real alternatives. The willingness to shift to (bio) LNG not known. A survey can be conducted on consumer preferences, to estimate market behavior.

In the demarcation the focus is set to heavy duty road transport because of the shorter lifespan and high potential. It could be interesting to extend the analysis with a CBA on shipping, the air pollution gains can be even better in shipping. Sulphur needs to be included in the analysis because heavy fuel oil Sulphur contents are significant.

In this thesis the production price of bio LNG is assumed to be fixed, while in reality the price is dependent on demand volume and biomass price. Also the relation between competing distribution channels for biogas is not clear.

The CO2-equivalent effects of biogas are determining factors in the CBA, there is discussion if the transport sector can incorporate the complete negative WTW effects, while the intensive cattle breeding is responsible for the manure surpluses.

LNG and bio LNG are new alternative fuels, the knowledge and experience about the fuel safety is not well established yet. In this thesis a comparison is made with LPG, but characteristics between the fuels are quite different. A better understanding of the safety costs for gas trucks can result in better comparisons between fuel types. The safety costs of local bio LNG production plants are also unknown.

In this research the fuel pump prices are used as an input, in these prices the infrastructure costs are incorporated. More insight in the composition of these fuel prices can strengthen the analysis.

Specify subgroups of trucks, in this research one big group is used, but the some trucks are only driving <25.000km while others drive >100.000. Because of the coldness of LNG and bio LNG it not suitable for vehicles that are not used for longer periods.

The focus of the thesis was on single fuel gas trucks, dual fuel trucks can achieve higher fuel efficiencies, incorporating dual fuel trucks will make the analysis more complex, but can make the analysis more accurate.

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8. APPENDIX

Interview Erwin de Valk - Waterschap Vallei en Veluwe

(Policy advisor water chain) 3-12-2014 14-15.30h

Introduction

Waterschap Vallei en Veluwe (V&V) is an independent governmental organization active in the third administrative level, some basic figures:

- FTE 406
- Sewage treatment plants (RWZI) 16
- Municipalities 37
- Inhabitants 1115254
- Water system management € 54 million
- Sewage treatment management € 75 million

Erwin explains what the societal involvement of V&V is and about their ambitions to become an energy neutral company in 2025. Erwin also explains the way V&V finance their projects through Nederlandse Waterschapsbank N.V. with low interest rates. V&V wants to be an example of societal involvement and is keen to safeguard its socially image and brand. The management considers energy production as a core value the last several years. Long term efficiency is important as well as trying to value waste as high as possible in the pyramid. There is budget available to invest in innovation. Where ROI in business is 3 to 4 years, projects in V&V can have ROI of 5 to 10 years. A digester is built to operate 30 years or longer, the investment decisions are different for market parties.

Vallei & Veluwe has just taken a new biogas motor in operation. In Harderwijk they are investigating a business case to produce 12,5 million Nm3 of extra biogas in combination with CO2 supplies to Calduran Kalkzandsteen B.V. The work of workgroup bio LNG is explained and some new sector developments are discussed. The ambitions in the "Energy Factory" are discussed.
The production costs of biogas of V&V are low and not subsidized. SDE on RWZI is low, so bioticket route can be more profitable. The business case is also determined with the costs to get rid of sewage sludge. It is cheaper to burn the sludge where it comes from the digester, because there is lower organic matter in it and it is easier to dehydrate sludge. Sewage plants have possibilities to co digest other waste streams to boost biogas production, not all waste stream are suitable, there are categories. The digestate is being burnt.
Erwin explains the strong agricultural lobby in the Netherlands that have influence on SDE regime. And also the influence of Shell on policies according to his view.

Erwin explains what the options for biogas are according to V&V for their sewage treatment plants.

- Biogas to keep own digesters on temperature
- Biogas in local grid for residential heating
- Biogas in CHP plant (currently used)
- Upgrade biogas to green gas and inject in grid
- Upgrade biogas to green gas and compress to CNG
- Upgrade to 99% methane and liquefy it to bio LNG

V&V is interested in bio LNG because:

- New stringent PEM emission regulations on CHP are coming in 2017.
- Makes lot of transport movements by trucks to transport sludge to Germany
- They can produce more biogas than they can use electricity used in their own process (

Drivers for the development of bio LNG

- Sustainable
- Self-sufficient energy
- Radius of LNG

Barriers

- Operational costs
- Fiscal schemes
- Permits
- Biomass prices

Societal benefits

- CO2
- Security of supply
- Sustainability
- Local production
- Closing the circles

Interesting EU schemes

- LIFE+
- Inners

Co digesters in NL have problems their where excesses with cheating parties which injected waste streams which were not suitable to co-digest.

Hierbij een overzicht van de productiecijfers binnen ons waterschap.

Daarbij staat nog niet het gegeven dat wij ca. 30.000GJ warmte leveren aan de woonwijk Zuidbroek in Apeldoorn. Deze warmte wordt geproduceerd door de WKK's op de zuivering van Apeldoorn.

Kostenbepaling ligt wat ingewikkelder. Wij kunnen wel becijferen wat iedere m3 biogas oplevert. Dat is weer verschillend per zuivering en afhankelijk van o.a. de rendement van de WKK, gaskwaliteit, de vraag of er warmte kan worden afgezet en of je meer dan het eigen verbruik produceert(en hoeveel meer).

Ik weet dat ECN en KEMA een kostprijs hebben bepaald voor het biogas van rwzi's. Deze is te vinden in de toelichting die is gegeven bij de jaarlijkse bepaling van de SDE.

Het bijzondere bij de waterschappen is het feit dat wij niet actief de markt op gaan om zuiveringsslib te verzamelen. Dit komt gewoon binnen. Daarnaast is het vergisten van slib ook gunstig voor de ontwatering en daarmee de afzetkosten. En je zet organische stof om, wat ook afzetkosten bespaard.

MWh	2010	2011	2012	2013
Amersfoort	3.812	3.731	4.161	4.000
Apeldoorn	4.546	4.717	7.430	7.000
Apeldoorn (SEA)	8.590	8.366	6.257	7.000
Ede	1.958	2.467	2.249	2.300
Elburg	1.887	1.614	2.397	2.400
Harderwijk	1.883	2.230	2.253	2.250
Nijkerk	897	942	941	950
Renkum	834	913	905	900
Soest	604	912	632	750
Terwolde	286	230	193	250
Veenendaal	1.135	1.062	1.446	1.300
totaal	26.431	27.184	28.864	29.100

Over CO2 kan ik al wel meedelen dat wij daar zeker mogelijkheden in zien. Echter dit is locatie specifiek. CO2 als koelmiddel kent volgens mij het grootste afzetgebied. Verder kan CO2 worden gebruikt bij bepaalde teelt in kassen.

Wij hebben gesprekken met een bedrijf die CO2 wil gebruiken als grondstof om er een bouwmateriaal van te maken.

Interview Carlijn Lahaye - Attero

Date: 11-12-2014 11u-14u

Attero focuses on the production of recovered raw materials and sustainable energy from waste. Attero is the biggest green gas producer in the Netherlands, 7,5 mln Nm3 in 2013 and rising 2 mln Nm3 a year. The plant is Wijster has an annual processing capacity of 800,000 tons. Attero has the goal to be CO2 neutral in 2015. Carlijn explains the different routes for the biogas and what the feedstock is for the production. Attero has realized the first Dutch biogas hub in Wijster, where different farms can connect to feed their biogas in. The gas hub combines landfill gas, biogas from GFT digesters and biogas from manure digesters. At the plant in Wijster the biogas is cleaned upgraded and fed into the grid or liquefied in cooperation with Rolande.

SDE+ subsidies are an important and stable income stream for Attero to fit the business case for green gas production from digestion. On landfill gas there is no SDE+. For bio LNG there is no SDE+ subsidy because the gas is used in transport.

Difficulties with Rolande because bio LNG production facility is not producing yet. Attero has a contract with Rolande where Rolande buys a part of the biogas but is not using the biogas now. The extra biogas upgrading capacity that would come available if the liquefaction unit is running, cannot be used currently.

Drivers for bio LNG:

- Valuate mitigated CO2
- Environmental concerns
- Biomass gasification (syngas)
- LNG developments
- CO2 as refrigerant

Barriers:

- Competition with other end users
- Biomass availability
- Diesel price drop
- CO2 price drop
- Developments of bio plastics / chemicals (higher value in cascading model)

Possible measures to stimulate a transition to bio LNG:

- Diesel tax increase
- Blending regulations, but mind that there is currently no bio LNG production in NL.
- Hedging bio tickets / HBE's
- Bio LNG certificates

Interview Jan Fransen - Natuur en Milieu

Expert Milieugegevens Team Mobiliteit 12-1-2015 14-16u

First a short introduction of to the topic and the background of the interviewee. Jan Fransen has studied Technical Physics in Delft and after his graduation he started working at N&M. He has had multiple function within the organization. He was also involved in the SER meetings but in the end N&M did not endorse the outcomes of the sessions. Jan explains the strength of the gas lobby in the Netherlands, were NGO's want to go electrical there is a strong push from the industry to focus on fossil fuels.

Jan explains the importance of wind energy in future energy systems and that he believes that electrification of road transport is the least bad option. Even heavy duty road transport can be electrified eventually by for instance catenary like trolleybuses. At the moment there is no bio LNG production and LNG is not better than diesel. There could be a lock in effect of gas.

There is another reasons why N&M does not support a transition to LNG or bio LNG for road transport. In the figures production slips of methane are not incorporated, in Qatar the slip of methane is probably lower than 2%, but in Russia the installations are old and poorly maintained and there is no data available about production leakages there. There are also uncertainties about shale gas and leakage of gas after hydraulic fracturing. Russia is the "motor" of the European blue corridors project.

The short term effect GWP20 of methane is higher than the short term effect of CO2, according to the IPCC the short term effect on the climate is 86 times higher than CO2.

The internal TNO figures about WTW CO2 emission of bLNG trucks are not accurate according to Jan, the negative values for bio LNG are based on co digestion of large quantities of manure. The mitigated CO2 equivalents are completely assigned to bio LNG while the agricultural sector has to deal with the emissions of manure. The agro sector in the Netherlands has also a strong lobby according to Jan. In biofuels there is an issue with food production, if you produce biofuels they should be of the second generation. In Germany there is a lot of maize cultivated for the production of biofuels, this is threatening the food production. According to Jan biofuels should only be produced from waste streams.

The scenarios of GroenGas about the digestion potential of in the Netherlands is not accurate, the co-digestion of manure, chicken manure in particular, is not a good option. The substrate is also getting more expensive, the forecasts are way too high according to Jan. N&M thinks that there is a biogas potential of about 20-25PJ in 2020.

There are different options to use the biogas, while the production is limited bio LNG should only be used where there are no other alternatives. N&M thinks that only in shipping and aviation biofuels like bio LNG should be used. In shipping the potential is the highest while you can replace heavy fuel oil. The import potential for the Netherlands is about 140PJ where only a fifth can be used for the production of bio LNG.

The current SDE system is functioning not well partly because the subsidy is not dependent on the quality of the energy source. It would be better to provide an investment subsidy as a revolving fund. In the system of biotickets it in important that biogas is physically traded not virtual, because there are risks of fraud.

In a cost benefit analysis it is important to use the right figures and give a holistic view of a change on the system. For instance a LNG truck can produce less noise than a diesel truck, but electric trucks are even more quite.

Jan finishes with a list of factors that are important to include in the CBA.

Greenhouse gas emissions:

CO2, N2O, CH4 and SO2, NOx

Air pollution:

NOx, PM10, PM2,5 and ultra-small particles

Noise

Security of supply

Energy use WTW, e.g. hydrogen truck uses 3 times more energy

Land use

Water use

Interview Ruud Verbeek - TNO

Senior Technical Consultant 19-2-2015 16u

Ruud Verbeek is expert on engine emission control technologies and was involved creating the datasheet used in this research. Main questions about the datasheet are:

- The negative CO2 emissions of bio LNG,
- The small difference of PM emissions of diesel and LNG trucks
- The CO2 emission factors are in CO2 equivalents?
- Are PM emissions a combination of PM10 and PM2,5, are ultra-small particles incorporated?

Ruud explains that in the WTW effects for bio LNG, mitigated methane emissions of manure storage tanks are incorporated. This is controversial, but the green lobby has used its influence to calculate with these values. TNO was not responsible for the emission factors of the energy carriers, there expertise is more the vehicle side. In the negative emission factors manure digestion or imports from the UK are incorporated. Ruud refers to the European Union Joint Research Center, JEC a EUCAR CONCAWE collaboration WTW analysis. NOx and PM emissions are presented in g/km, not in g/kw. About the difference in energy efficiency of diesel versus gas trucks he explains that the assumption is that gas trucks become 5% more efficient between 2015 and 2020.

Important drivers that can stimulate the use of bio LNG are:

- Lean and green sector developments
- CO2 legislation, monitoring truck emissions
- NL encouragement bio tickets & SDE
- EU directives FQD & RED

Barriers:

Lack of long term EU legislation

Interview René Laks – Groen Gas Nederland

Directeur Groen Gas Nederland 18-3-2015 14.30-16u.

We start with a model validation and look to different input variables and check if things are missing. René states that international Trucks drive more than 46000 kilometers a year, approximately 100.000km/y. He also points out that transport companies are not paying the consumer diesel price, they are not paying tax and receive a high volume discount of about 12 cents.

LNG and bio LNG are strongly connected, developments in bio LNG will come to a hold if the share of LNG is not increasing. The market driven demand for bio LNG is present at the moment and is an important driver for bio LNG.

Bio LNG scores well on emissions, CO2, PM10 and NOx. Sulphur is not really an issue, because the Sulphur is cleaned in the refinery.

A barrier could be the demand for bio LNG in shipping, in shipping there is no real alternative and the demand could raise bio LNG prices. IEA has made prediction for energy prices, this should be the basis for model calculations. It is important to include bio diesel in the BAU alternative. A technology development in gas engines is to be expected around 30%.

An interesting development is the expiration of European milk quota. Farmers are already investing in more milk production capacity and this will result in more manure. René thinks the tax on LNG is going to rise to diesel levels, or that it will be coupled to CO2 emissions.

An international bio ticket system which is CO2 oriented could be a driver for bio LNG. The transport companies are reluctant to invest because of the uncertainties in tax policy in the Netherlands. The payback time should be no longer than 3 - 3,5 years. The residual value of a gas truck is also uncertain.

Liquefaction is expensive and virtually greening LNG could be an option. It would be interesting to perform a study to the price elasticity of LNG, when will transporters switch to LNG and are they willing to pay a premium for bio LNG?

Interview Marc Londo – ECN

- Hoe kan het dat de “kosten grondstoffen” van CBG hoger geschat zijn dan die van LBG?

Hier is het de term ‘kosten grondstoffen’ die je waarschijnlijk op het verkeerde been zet. Het gaat hier om de kale prijzen aan de pomp, dus inclusief distributiekosten en marge voor de pomphouder maar exclusief belastingen. We zijn ervan uitgegaan dat CBG/LBG vooral via certificaten geleverd gaat worden, niet via separate levering. Voor het kostenverschil tussen CBG en LBG hebben we hetzelfde verschil aangehouden als voor CNG/LNG; en die gegevens zijn afkomstig uit een gasstudie van ruim een jaar terug: zie http://www.ecn.nl/docs/library/report/2013/o13038.pdf. Distributiekosten voor LNG zijn daarin geschat op 6 €/GJ, voor CNG op 10,8 €/GJ

- De kale diesel / LNG prijs voorspelling is die gebaseerd op de WEO-14?

Nee, alle prijzen van fossiele energiedragers in de studie zijn gebaseerd op de nationale energieverkenning 2014 (NEV2014), http://www.ecn.nl/docs/library/report/2014/o14036.pdf. Die baseert zich hoofdzakelijk op de WEO, maar gegeven de timing is dat de WEO-2013 geweest.

- Welke mix van biogas productie is aangenomen in 2020 en 2030?

Even overgenomen uit de interne verantwoording:

For 2014:

- The green gas production costs were derived from the 2014 SDE base rate. Depending on the feedstock type production of green gas is in the range of 9,4 to 29,3 €/GJ, the lower end referring to the wastewater treatment plants and the higher end to manure mono digestion. All feedstock digestion–that uses various types of residue flows, from the food and beverage industry or from biofuel production– is chosen as the reference as it has additional potential and has a mid-range cost level. Biomass manure co-digestion is excluded due to the uncertainties related the co-substrate price uncertainties, and the socio-economic and environmental impacts of increasing demand for some of the co-substrates like maize. Manure mono-digestion, although most relevant as a greenhouse gas mitigation option, has high costs as a green gas production option.

For 2020:

- We consider that in 2020 the reference green gas price will remain the same as in 2014. Costs of digestion options will not change significantly, and methane production through gasification (bio-SNG) is still too small to have impact on the market.

For 2030:

- Due to growth in green gas demand, we assume the potentials for digestion options become exhausted, and gasification will become the price-setting production technology. In the Routekaart Hernieuwbaar Gas, bio-SNG production costs are estimated to decrease from 24,8 €/GJ in 2020 to 20,2 €/GJ in 2030. This has been taken as the reference price for Bio-CNG in that year.

- Final advice base rates SDE+ 2014. S. Lensink (ECN). September 2013.ECN-E-13-051. http://www.ecn.nl/docs/library/report/2013/e13051.pdf

- Routekaart hernieuwbaar gas. Groen Gas Forum. Juni 2014. : http://groengas.nl/wp-content/uploads/2014/06/Routekaart1.pdf

Nationale Werkgroep bio LNG

Meeting 3 September 2014 15.30-17.00

Meeting 3 October 2014 9.30-11.00

Meeting 3 November 2014 14.00-16.00

Meeting 2 December 2014 15.00-16.30

Meeting 13 January 2015 10.00-12.00

Meeting 3 February 2015 10.00-12.00

Meeting 16 June 2015 10.00-13.00

European Biogas Association Conference

Attended lectures:

2. Clean power for transport: a European alternative fuels strategy. The role of natural gas and biogas
Antonio Tricas Aizpun, Policy offi cer, DG for Mobility and Transport – European Commission
3. Biogas/biomethane: EU legal framework and support possibilities under the Common Agricultural Policy
Andreas Gumbert, Policy Offi cer, DG for Agriculture and Rural Development – European Commission

1. The energy policy of the European Union, targets 2030
Andreas Pilzecker, Policy Offi cer, DG for Energy – European Commission
2. EBA's strategy to respond to the challenges facing the European biogas industry
Jan Stambasky, President of European Biogas Association
3. Moderated panel discussion with all today's speakers: How can biogas contribute to energy security?
Moderator: Harm Grobrügge, EBA Vice-President

Biomethane technical session
Chairman: Dr. Attila Kovács, EBA
Latest developments in biogas cleaning and upgrading technologies
Prof. Dr.-Ing. Frank Scholwin
Technical development of biomethane from gasifi cation and biogas with focus on Sweden
Dr. Anna-Karin Jannasch, Swedish Gas Technology Centre
Biomethane standardization
Erik Büthker, Charman of TC 408

Sustainable biogas
Chairman: David Collins, EBA
The role of modern biotechnology in future biomass processing *Theo Verleun, DSM Biogas*
Biogas industry as a part of sustainable farming
Dr. Stefano Bozzetto, European Biogas Association
Indirect Land Use Change (iLUC) and biogas industry
Horst Fehrenbach, Institut für Energie- und Umweltforschung Heidelberg

Biomethane production
Chairman: Erik Meers, Scientifi c Advisory Council
Solvent development for biogas scrubbers for CO2 removal
Marco Linders, TNO
Power-to-gas
Dr. Benoît Boulinguiez, MT-Energie GmbH
Biomethane in the Netherlands – current state and future outlook *Michael Sanders, Association of the Green Gas Producers VGGP*

Perspective of biogas in the Netherlands and surrounding regions
Chairman: David Collins, EBA
1. The importance of renewable energy resources in the long-term energy strategy of The Netherlands in general and the Energy Valley region in particular *Prof. Dr. André P. C. Faaij, Professor 'Energy System Analysis'*
2. Biomass gasifi cation overview *Ilkka Hannula, VTT Energy*
3. Biogas as a pillar and a bridge to a renewable energy system in North-West Europe
Gerard van Pijkeren, Vertogas

Biogas site visits

Waternet / AEB, Amsterdam October 2, 2014

This installation processes sludge from WWTP Amsterdam West (1.000.000 p.e.), sludge from WWTP Westpoort (500.000 p.e., by pipeline) and smaller WWTP's from the water board AGV (by truck). Design capacity sludge treatment is for 2.000.000 p.e.

GTS Schoteroog GPP®Plus4T, Haarlem October 2, 2014

The biogas for this upgrading facility is from the Schoteroog landfill and from the waste water treatment plant Haarlem Waarderpolder. The installation produces LBG (Liquefied Biogas) and green gas.

De Meerlanden, Rijsenhout October 2, 2014

This installation uses organic waste from households as substrate and has a biogas production of 10.000 m3 per day.

Appendix Input data CBA

ACTIEPLAN DUURZAME BRANDSTOFFENMIX DEELRAPPORT WEGVERVOER DUURZAAM GASVORMIG

Jaar	Aantal vrachtwagens LNG+CNG+LPG	Aantal LNG-tankstations (LPG en CNG zie eerdere hoofdstukken)
2020	6.500 trekkers LNG 850 bakwagens LNG 1.000 CNG trucks 1.000 dual-fuel CNG trucks 500 vuilniswagens CNG 1.200 dual-fuel LPG trucks	36
2025	14.000 trekkers LNG 1.200 bakwagens LNG 3.000 CNG trucks 3.000 dual-fuel CNG trucks 1.200 vuilniswagens CNG 3.200 dual-fuel LPG trucks	70
2030	21.500 trekkers LNG 1.400 bakwagens LNG 5.000 CNG trucks	110

	5.000 dual-fuel CNG trucks 2.000 vuilniswagens CNG 5.000 dual-fuel LPG trucks	
2050	60.000 trekkers LNG 2.000 bakwagens LNG 2.000 CNG trucks 2.000 dual-fuel CNG trucks 1.000 vuilniswagens CNG 2.000 dual-fuel LPG trucks	200

Jaar	Aandeel hernieuwbaar LPG	Aandeel hernieuwbaar CNG	Aandeel hernieuwbaar LNG
2020	11%	100%	10%
2025	15%	100%	15%
2030	20%	100%	20%
2050	20%	100%	20%

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