The potential of green gas in the Dutch transport sector

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Abstract: In theory, green gas has the potential to become an attractive alternative for fossil fuels so as to contribute to the transport sector becoming more sustainable and environment-friendly. However, the large-scale implementation of green gas is hampered by many uncertainties. In this paper these uncertainties are assessed through on a series of SWOT analyses based on a study of the existing literature and inputs from stakeholders. The results of the SWOT analyses show that there are good prospects for the implementation of green gas in the longer run. The amount of green gas needed to replace the current fuel use of cars driving on diesel or petrol is huge, but it can be produced in an economically feasible way. For several specific markets,

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notably private cars, buses and trucks, it is found that green gas produced from landfill gas is profitable at least for private cars and may lead to relatively lower costs for the other two uses.

Keywords: green gas; sustainable transport; SWOT analysis.

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1 Aims and scope

The availability of natural resources – including fossil fuel – has been a *sine qua non* for economic development since ancient times. Scarcity of such resources has not only formed an impediment to economic progress, but has also had implications for human settlement patterns, migration decisions, technology development and transport.

The awareness of the global scarcity of resources has already a long history – with many anecdotal and ad hoc experiences in the past centuries –, but a real mental shift started in the early 1970s. A first phase in this new development – sometimes called the '*new scarcity*'– began with the publication of the 'Report to the Club of Rome' (see Meadows et al., 1972), in which an integrated picture of population growth, pollution, energy, raw materials and economic growth was sketched. It was argued that the limits to growth would mean a serious threat to the future of our planet.

The next phase started in 1987 with the publication of the so-called Brundtland Report, produced by the World Commission on Environment and Development (1987). In this study, the notion of '*sustainable development*' was advocated as a new, global policy paradigm, in which also international economic disparities – including poverty in developing countries – were explicitly addressed.

A third stage emerged in the beginning of the new century, when the threats of global *climate change* became broadly shared, not only in the developed world, but also in the developing world. International treaties on climate policy were adopted, CO_2 policies were agreed upon, but the ultimate success still remains disputable. The emission of CO_2 caused by transport is, for instance, still increasing due to the increase of the number of cars worldwide (Bithas and Nijkamp, 1997; Geerlings et al., 2012).

In the meantime, it is increasingly recognised that there are many actors involved at different governance levels, each with different interests and agendas. This limits the implementation of a global initiative and, consequently, there is a need for effective *decentralised climate policy initiatives* as well, that aim to provide operational handles on a more down-to-earth basis. Examples can be found inter alia in climate-neutral city and climate-neutral transport initiatives (see, for instance, United Nations Economic Commission for Europe, 2011). Clearly, such initiatives cannot be implemented overnight and require a long gestation period.

The present paper aims to sketch out the potential of a new energy initiative in the Dutch transport sector, which can be considered as a decentralised initiative, called 'green gas'. Green gas is a type of bio-fuel that is based on recycling and fermentation of biologically degradable materials, which after chemical upgrading can be added to the natural gas net. In theory, it is economically feasible, environmentally benign and sustainable and energy-efficient. Most current bio-fuels are not very cost-effective, so that – without government subsidies – there are only limited incentives for more sustainable energy alternatives (Nijkamp et al., 1998). Green gas has the potential to become an interesting substitute for the more expensive bio-ethanol and bio-diesel sources and may be a promising energy source that meets global sustainability targets.

Clearly, other alternatives such as electric vehicles have to be considered in this context as well. In any case, it is clear that in a bio-based economy, domestic bio-degradable waste may offer interesting opportunities for more climate-neutral energy initiatives in the transport sector.

This paper will map out the potential of implementing green gas in the transport sector in the following way:

- In Section 2 an overview of the possibilities and bottlenecks in developing and using green gas in the transport sector, taking the Netherlands as a frame of reference, is given, based on a literature overview.
- To assess the possible contribution of green gas to sustainable transport in the Netherlands, the advantages and disadvantages of green gas will systematically be described in Section 3 by means of a conceptual model.
- This model will serve as the basis for the set of exploratory empirically oriented SWOT analyses in Section 4.
- The following Section 5, offers a synthesis of the SWOT analyses.
- Finally, in Section 6 a provisional trade-off analysis is presented, with a view to the specification of the ingredients of a social cost-benefit analysis for evaluating the socio-economic and energy potential of green gas in the Netherlands.

2 Green gas in the transport sector: a perspective

Natural gas is an important energy resource in the Netherlands and is used inter alia for electricity production, household use, transport (compressed natural gas, liquefied natural gas) and the chemical industry. Natural gas can be obtained from non-renewable, fossil sources (e.g., gas fields) and renewable, non-fossil sources (e.g., biogas, green gas). We will focus here on the latter sources, extracted from biologically degradable material. Biogas is the result of fermentation of organic material from various sources. Green gas may have similar properties as conventional natural gas from gas fields, except for a lower methane content (55–65% methane). Green gas is essentially a complementary form of biogas that needs to be modified in terms of methane (an upgrade to 88% methane) and nitrogen so as to make it compatible with the chemical composition of other natural gas supplied to the users. Green gas is becoming an alternative form of energy supply in various countries in Europe, including the Netherlands.

With a current share of no more than 0.1% in the total energy production in the Netherlands, the contribution of green gas to the total energy supply is relatively very small. But, as we will see below, green gas has a great supply potential, as it is able to use biodegradable waste and abundant agro-based sources. It may, in principle, contribute to sustainable environmental objectives and help to reduce the scarcity of fossil fuels. In this context, the EU Renewable Energy Directive (European Commission, 2009) is a relevant policy document. The Netherlands has agreed that, in 2020, 14% of the energy resources used should be renewable. Fuel producers are, therefore, currently forced to mix their fuels with a certain percentage of biofuels. The 14% target would imply for the transport sector that in the year 2020 at least 10% of all transport fuels would have to originate from renewable sources. This requirement could strengthen the future position of green gas in the Dutch energy supply system (see also Ecorys, 2012). This is based on the assumption that the supply of resources for green gas is sufficient.

What are the advantages in theory of green gas? Green gas could have significant ecological advantages through the use of bio-degradable materials, it could mitigate the scarcity of future energy resources and it may carry economic advantages (e.g., in terms of employment, cost-efficiency, reduced dependency on alternative energy sources and stimulation of knowledge-intensive innovative production technologies) (van Hemert et al., 2013).

In order to compare properly the emissions produced by alternative fuels, one should make a distinction between tank-to-wheel emissions and well-to-wheel emissions. The tank-to-wheel figures refer to emissions due to the use of the car, whereas the well-to-wheel approach also takes into account emissions caused in the process of producing the fuel. Green gas has very low emissions in the well-to-wheel calculations, because emissions in the production process are negligible. Indeed, the CO_2 in biomass has been sequestered from the atmosphere in forming the biomass.

Hence, green gas offers promising perspectives for the transport sector. It is a relatively clean energy source with a – for the time being – substantial growth potential. From a transport-environmental perspective, green gas has relatively favourable CO_2 and small particles emissions, much more favourable than diesel as car fuel. It is thus clear that green gas could offer a significant contribution towards the achievement of sustainable transport goals. Some experts estimate that an effective use of all available green gas in the Netherlands is sufficient for at least 400.000 cars. But even with a more modest future perspective, green gas is an attractive alternative for some 100.000–200.000 cars and hence way provide a significant contribution – of about a 20% substitution of diesel cars – to the 14% sustainable (i.e. renewable) energy target of the Netherlands. But such a large-scale implementation of green gas in the transport sector assumes effective organisational, technological and financial-economic conditions (see also PWC, 2012).

Two alternative studies assessing the environmental benefits of green gas have recently been performed in the Netherlands. Ecorys (2012, p.45) argues that in the Netherlands a reduction of CO_2 emissions in the transport sector is usually valued at 60 euro per tonne CO_2. It also calculates that an amount of green gas cars replacing cars driving on diesel is feasible. Then the Ecorys report calculates that in this case the net benefit (from a social cost-benefit analysis) amounts to 20–35 million euro per year. CE Delft (2010, chapter 5) reports on a rather detailed study regarding the environmental benefits of amongst others, green gas.[1] It deals with several specific markets, such as private cars, buses and trucks. On the one hand the study calculates how much higher the cost per kilometre is compared to diesel, while, on the other hand the savings in terms of CO_2 emissions are calculated. Then one can calculate how much it costs to reduce CO_2 for different biofuels. It is found that green gas produced from landfill gas gives a negative cost, because in this case net emissions become negative when it comes to private cars and provide a low cost for the other three uses. With co-digestion the picture is less favourable in this study. However, Groeneveld (2013) has pointed out recently new technological developments (thermo-pressure hydrolysis). She shows that with a moderate increase of fuel prices, also co-digestion might be profitable in the longer run.

Seen from the supply side, green gas has the potential of making a significant contribution to the share of renewable energy in the Netherlands. However, the market demand for green gas is currently not large enough to let the sector grow into a mature industry. Hence, up-scaling the demand for green gas seems to be in order for a further stimulation of the production of green gas. This can be done, for instance, by subsidising vehicles that are equipped for green gas. The production of green gas in the Netherlands is currently supported by the so-called SDE + policy scheme, which aims to stimulate the production of sustainable energy. That implies that in the transport sector the price of green gas is compared with predominantly alternative fossil energy carriers, where high taxes are levied. In the energy sector, a competitive deployment of green gas seems difficult to realise in the short run, because of the low production costs and the specific taxes on 'grey' alternatives. In case the external cost of these alternatives would be internalised by means of a carbon tax or the abolition of subsidies, green gas would get a fair chance.

In the Netherlands, the government seems reluctant to invest in green gas in the transport sector, although until recently it has invested in the infrastructure (gas stations). Uncertainties regarding the feasibility of implementing green gas as described above seem to complicate the government's choice for financial support of green gas in the transport sector. To determine the economic feasibility of green gas, not only an overview of the main competitors, but also an exploration of the social, political and technical feasibility is required. We therefore claim that a comprehensive Social Cost - Benefit Analysis (SCBA) can contribute to a better understanding of the advantages and disadvantages of an energy transition with green gas.

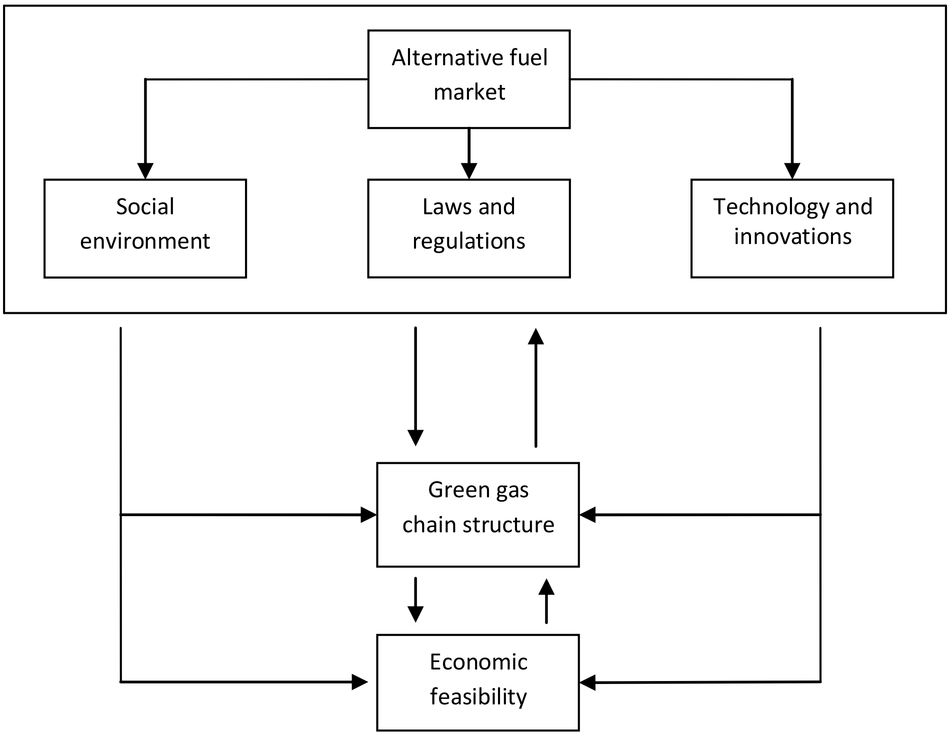
3 A conceptual model

3.1 Introduction

To deliver the building blocks for an SCBA we have chosen to use an interdisciplinary paradigm on transport innovations (see Figure 1), because the elements of such a paradigm are useful and manageable to analyse the possibilities of designing a SCBA. We will explain the choice of the various elements of the conceptual model briefly.

It is important not only to determine the economic feasibility of green gas, but also its social, political and technical feasibility. This section presents a qualitative exploration of the various elements of the production process of green gas and an overview of the main competitors. This analysis is supported by a growing scientific literature on transport innovations and the role of policy (Feitelson and Salomon, 2004). The core message of the literature is that transport innovations will only be adopted by the market, if the innovation is economically, socially, politically and technically feasible. Williamson (1993, 1998) provides a simplified framework for distinguishing different analysis elements compared to the more elaborated framework of Feitelson and Salomon (2004). By identifying four consecutive layers, he identifies different categories of institutions that govern economic behaviour. This 'layered' approach is presented in Figure 1. The model was developed by Williamson for the analysis of complex governance systems and to understand their dynamics. This conceptual model forms also the basic structure of the analysis of the current green gas system. Each of the determinants identified by Williamson will be further specified for the assessment of the SWOT analysis of green gas in Section 4.

Figure 1 Layered interdisciplinary paradigm



Source: Williamson (1993, 1998)

3.2 Green gas chain structure

The optimal manner in which– and the location where – green gas can be sold depends on the available biomass and local opportunities for production and distribution. In identifying routes to opportunities for outlets of green gas, a broad look should be cast at the whole green gas chain, including the biomass market, biogas production (gasification/ fermentation) and upgrading of raw biogas to green gas as well.

The choice regarding the biomass mix in the Netherlands in the short term has partly already been made. The SDE + 2011[2] contained mainly requests for fermentation projects, where fruit, vegetables and garden residuals and sewage sludge are used as raw material. This policy is driven by the relatively low cost of such projects compared to pure manure and co-digestion of manure. The use of manure is nevertheless still essential for the production of biogas, as it is widely available due to overproduction in the agricultural sector and there is no short-term alternative technology available to deal with manure.

Currently, the three main production routes of biogas are: (a) direct recovery from landfill (waste), also described as ‘passive methanation’; (b) sewage treatment and (c) digestion plants that transform manure, energy crops (1st generation biofuels), waste from the food industry and household waste into biogas. Fermentation is a well-established technology. In Europe, for instance, biogas is mainly produced in large-scale fermenters.

The investment cost of a biogas plant is mainly dependent on the size and material mix. Both are also dependent on local conditions, such as the distance between the existing energy infrastructure and the availability of raw materials and the technological concept (own use versus large-scale sale of heat or grid injection). Indeed, with a large concentration of suppliers of manure and proximity of demand, profitability of the investments is enhanced.

3.3 Alternative fuel market

According to a recent Ecorys study (2012) containing details on the application of green gas in traffic and transport, green gas competes in road transport especially with fuels such as diesel, petrol, LPG and electric vehicles. Driving on hydrogen can, since recently, be added to the list (see Table 1).

The Ecorys study presents a comprehensive comparison of green gas with other fuels. It shows that the use of green gas can indeed lead to lower external effects of transport. Measured by Well-To-Wheel (WTW), green gas cars and trucks/buses emit less CO_2 per kilometre than the newest cars on petrol, diesel, LPG and natural gas. The emerging newest technologies are seen by experts as competitors of green gas. Under the influence of EU policies, conventional cars have to be more environmentally friendly (less CO_2 emissions per kilometre). According to various sources, including the Dutch Environmental Assessment Agency, a 20% improvement towards 2020 is feasible at not too high costs (PBL, 2012). However, this claim requires further investigation. So, at the moment, the 'competitors' of green gas are better, but green gas is clearly ahead in lower CO_2 emissions per kilometre. In terms of air pollution (in particular with respect to emissions of NOx and PM_{10}), green gas does well compared to the latest competing technologies. However, this will most likely be a small gain in a SCBA, as this does not seem to be a political issue at the moment.

Table 1 CO_2 emissions of a middle class car/type of fuel

	Green gas	*Fossil natural gas*	*Petrol*	*Diesel*	*LPG*	*Electric*	*Plug-in hybrid*	*Hybrid*
Tank-to-wheel	120–145	120–145	150–180	130–160	110–150	0	100–165	120–180
Well-to-wheel	30–55	130–175	180–210	160–190	155–185	75–90	110–170	115–180

Source: Ecorys (2012)

3.4 External environment

Currently, green gas is produced in 11 European countries and injected into the local gas networks in nine countries (Wellinger et al., 2012). In most countries, the volumes produced are still marginal. Several EU countries have national (quality) standards for injecting green gas. There are initiatives at the EU level to harmonise injection of new gases into the existing gas grid. Fraunhofer UMSICHT, a German energy technological institute, has estimated that upgrading costs between 1.4 and 2.3 cents per kWh (van Foreest, 2012). Scale effects can also be created by central improvements, i.e. connecting decentralised different biogas producers to one upgrading installation.

The upgrading to green gas and injection into the gas grid increases the market potential of biogas. Traditional gas users such as power plants, industry and households get access to renewable gas, albeit mixed with conventional gas in the net. Costs for injection are estimated between 0.1 and 0.3 cents per kilowatt hour (van Foreest, 2012). Green gas injection into the gas grid is increasing, in particular in Germany, the Netherlands and Sweden. In these countries, technical regulations are developed in order to facilitate injection and to ensure a constant gas quality in the network.

Providing the infrastructure (stations) is one of the main challenges for the growth of the demand for green gas in traffic and transport. Existing gas stations may be used to facilitate the application of green gas in the transport sector. For this, the proximity to a biogas production site is required. The stations can also purchase licenses to sell compressed natural gas as compressed green gas. This will need to be facilitated by a regulatory framework that supports a functioning certification system with sufficient impact on the market.

3.5 Regulatory systems

The Renewable Energy Directive (European Commission, 2009) states that in 2020 the share of renewable energy sources in gross final consumption of energy in the Netherlands should be 14%. For the transport sector, this more specifically means that by 2020 at least 10% of all transport fuels (petrol, diesel, biofuels and electricity) must come from renewable sources. In 2009, natural gas consumption in the Netherlands amounted to 48.8 billion cubic meters, implying that the Netherlands needs to produce more than 6.8 billion cubic meters of renewable gas in order to achieve the 14% target for the share of renewable energy sources. At present, only 0,318 billion cubic meters of biogas (gas equivalent) is produced or 0.65% of the total gas consumption (Von Eije, 2012), but the bulk should be reached through a mix whereby also the contribution of solar and wind energy will be taken into account. The bulk of this gas is burned directly in a Combined Heat and Power plant (CHP). Currently, only 0,037 billion cubic meters is upgraded to natural gas quality (i.e. green gas) or 0.076% of the total gas consumption. It is clear that at current production levels renewable gas will not provide a proportional or sizeable contribution to the achievement of the 14% target.

A transformation from a small subsidised sector, as it is at the moment, into a mature, large-scale industry is only possible, if there is sufficient demand for renewable gas. Biogas is usually produced in rural areas due to the greater availability of biomass. The gas can be burned, but in those areas it is often impossible to achieve sufficient demand for heat. Therefore, at present, a large part of the biogas is upgraded to green gas that can be injected into the national distribution network, where the demand is ensured. On the basis of environmental benefits, the construction of the infrastructure – a precondition for the use of green gas in the transport sector – has also been encouraged in recent years in the Netherlands. By doing so, the Netherlands would follow Sweden, where 26% of the biogas is upgraded to transport fuel (Petersson, 2010). It is the ambition of Sweden to have a fleet that is independent of fossil fuels in 2030. In the Netherlands, such a concrete ambition has not yet been agreed upon.

Although the volumes of injected green gas increase, subsidies are still needed to make green gas commercially viable in comparison with the reference fuel gas. In the Netherlands, the additional costs of biogas produced from landfills and wastewater are relatively small compared to a country like Germany (ECN, KEMA, 2011). This is mainly due to the high costs of raw material. The opportunity for growth seems to come mainly from co-fermentation, which uses expensive energy crops. To achieve serious market volumes and to meet at least 50% of the ambitious government targets in 2020 and 2030 in the Netherlands (also in Germany) substantial financial support from the government is required (van Foreest, 2012).

The Dutch government has indicated its commitment to include the certification system of Vertogas (a daughter of Gasunie, the state-owned company that exploits the natural gas in the Netherlands) in the legal system in the Netherlands. At present, Vertogas facilitates trading of green gas through the system of certification and guarantees the origin of the gas for each certificate issued. This makes that the issue of green gas certificates is no longer a voluntary method, but a method that is well regulated and reliable. This method enables the development of a comprehensive, international trading system of green gas certificates across national borders. Besides, for the social awareness needed to become less dependent on fossil fuels, the Netherlands is also incumbent on the European Union.

3.6 Technology and innovations

Key techniques and innovations that can more specifically promote the wide application of green gas, according to the sources consulted (ECN, 2013), are particularly noticeable in the production process. If there is a successful introduction of gasification, an optimal use of the fermentation potential and sufficient opportunities for cross-border trade, then the volumes of green gas can reach a size of 10–20% of the national gas consumption. This can be a one to one replacement of natural gas in mature gas markets such as the UK, Germany and the Netherlands. In such a scenario, the traditional natural gas company would clearly lose a market volume. This loss will likely be added to the already declining demand as a result of further efficiency improvements in living and working environments and increasing penetration of renewable technologies in the energy sector. However, the decarbonisation of a substantial proportion of the gas can also enhance the credibility of long-term gas as a fuel in a low-carbon world, which means that the prospects are very promising.

4 The SWOT analysis

The strengths, weaknesses, opportunities and threats (SWOT) will be identified for the application of green gas in the transport system based on the analysis of its strategic positioning in the Dutch market, interviews with stakeholders (with different backgrounds varying from the private sector, the public sector and experts with a technical background) and document analysis. The SWOT analysis is organised around five determinants that play a role in the implementation and dissemination process, inspired by the insights on transport innovation provided by Feitelson and Salomon and structured by Williamson, as presented in Section 3:

- The green gas – Life Cycle Analysis (LCA) – chain structure.
- The alternative fuel market.
- External environment.
- Regulatory systems.
- Technology and innovations.

4.1 The green gas LCA – chain

A SWOT analysis for the green gas LCA chain in relation to the application in the transport sector has provided the following results.

Strengths	*Weaknesses*
• Different production routes possible and tested. • Fermentation is a widely used and proven technology with good energy efficiency. In Europe, biogas is mainly produced in large-scale fermenters, so there is a lot of experience already. • Low CO_2 emissions of green gas.	• Cost-effective production/operation still depends on financial support (subsidies, incentives, etc.) and regulations. • Green gas is currently produced in 11 European countries and injected in the net in nine countries, including the Netherlands. The availability of biomass in the Netherlands is relatively marginal (both absolute and relative) compared to other countries.
Opportunities	*Threats*
• Production of green gas is short-cycle and renewable, which guarantees a continuous availability of stock compared to existing fossil sources. • The existence of a gas network is essential for the distribution of green gas produced (production site ≠ users). This is a precondition for large-scale implementation in transport and injecting into the net. • Green gas chain may lead to an enhanced agricultural cluster. • Value of products: residues that remain after fermentation can be sold as organic fertiliser and soil improver. • Opportunity for a power-to-gas route, whereby the surplus of sun and wind energy can be converted to natural gas.	• Sufficient availability of raw materials for producing green gas? • Injection of green gas into the grid is increasing in Germany, the Netherlands and Sweden. At constant volumes therefore, the opportunity for use in transport is subject to competition. • Possible future fuels (and relatively new fuels such as shale gas) exhibit large uncertainties and refute the 'peak oil' forecast.

4.2 The alternative fuels market

The SWOT analysis for the alternative fuel market in relation to the application in the transport sector looks schematically as follows.

Strengths	*Weaknesses*
• Green gas can lead to lower external effects of transport. • Passenger cars, trucks and buses on green gas are cleaner (emit less CO_2 per kilometre well-to-wheel) than the latest passenger cars (on petrol, diesel, LPG and natural gas). Also in terms of air pollution green gas performs well (NOx and PM). • Green gas increases the independence of oil	• Green gas is currently not a dominant energy source. It is unclear whether the potential can be realised. • The financial resources for SDE are mainly directed to solar and wind projects and only to a quite limited part of green gas projects.
Opportunities	*Threats*
• The leading potential of green gas (well-to-wheel) compared to other fuels will definitely remain on the short term and medium term • Green gas in transport is in line with the political goal to strengthen natural gas (production).This strengthens also its economic position in the Netherlands.	• The 'competitors' of green gas perform better (as a result of EU policies), so that the advantage of green gas as clean fuel is narrowing. • Regulation is still based on tank-to-wheel and in this perspective green gas cars perform similar as competitors.

4.3 External environment

The SWOT analysis of the external environment in relation to its application in transportation may be presented as follows.

Strengths	*Weaknesses*
• Application of green gas in transport is in line with sustainability thinking. • Green gas transport can contribute to urban air quality.	• Network of filling stations (gas) is currently underdeveloped. • Consumer confidence is insufficiently developed for this application. Based on the observations above, full scale application in transportation is currently not to be expected: market developments are uncertain and added value should be argued more convincingly.
Opportunities	*Threats*
• Network of filling stations (CNG and LNG) is under development. • Pro-active, well- organised lobby. • The major car manufacturers have gas vehicles: passenger cars and trucks. • Broader focus than on consumer vehicles only, in particular larger transport vehicles (garbage collection, buses, supplies) in urban areas with entrepreneurs as a customer. • Production and use of vehicles compared with semi-electrically driven cars is significant: 60,000 (green gas) compared to 18,000 (electric) at European level in 2012.	• Dynamics and unpredictability of decision making support/facilitation of green gas (in transport) at different levels (EU, national, regional) hinders consumer acceptability. • Conflicting social issues around resource management for green gas.

4.4 Regulatory systems

The SWOT analysis of laws and regulations in relation to the application in the transport domain can be presented schematically as follows.

Strengths	*Weaknesses*
• The Netherlands is at the forefront of green gas certification. Biogas is contained in three EU directives (Renewable Energy, Recycling and Useful Application and Deposit). • The system of a 'Bio-tickets' system developed for the application of green gas in transport is currently satisfactory to make the system work, but this is not a sustainable system.	• No single European system (yet) for green gas certification. • SDE system primarily stimulates digestion projects in relation to input into the net. To date, no stimulation measures are applied in the transport sector. • Many ad hoc changes in the subsidy system (i.e. from a political/policy perspective). To make green gas a success (in transport), continuity is desirable. • Tax regime for green gas in transport is not inviting to proceed with large-scale implementation (tank-to-wheel, taxation system for cars).
Opportunities	*Threats*
• Current leadership position can lead to economic empowerment of Netherlands	• No clear European funding due to lack of consensus among EU-countries on the implementation of green gas. • Unclear how EU policy will be set out in legislation. • Fiscal policy of the Dutch Ministry of Finance is inherently risk-averse (income should not fall). This creates a barrier for adjusting the tax regime for green gas.

4.5 Technology and innovations

The SWOT analysis for technology and innovation in relation to applications in transportation may be presented in the following way.

Strengths	*Weaknesses*
• 'Proven technology' (fermentation) • Green gas in line with technical developments of different modalities. Two thirds of the stations are in the hands of regional parties (and less by vested interests).	• An authoritative player who is strongly in favour of the production and application of green gas is lacking. Interests are fragmented. • Introduction of green gas is not in itself a system innovation. It requires a system change in fuel distribution and production of motors (drive systems). • Construction of distribution system is costly (local produce and direct delivery). • Vehicle production is currently rather limited compared to conventional techniques. • Technology and possibilities are known for a long time. The large-scale implementation of green gas is difficult.

Opportunities	*Threats*
• Cost of driving is halved compared to ten years ago (200,000 instead of 400,000 units). • Further introduction of alternative technologies (gasification) and mono-manure. • Meaningful interpretation of (temporary) fallow land. • Successful implementation can lead to the creation of additional employment (e.g., in agriculture or the knowledge sector).	• Penetration into a market dominated by vested interests. • In imaging: the introduction of green gas in transport also raises at least the issue of 'technology push'.

5 Environmental economics perspective: a synthesis

As mentioned above, one advantage of green gas over other fuels is that its generation and use result in considerable fewer emissions of CO_2 than in the case of other fuels for transport purposes. From a societal point of view, this advantage should be taken into account in determining the optimal mix of fuel. Consequently, it should lead to the implementation of policy instruments that induce the consumers to choose the preferred fuel mix. There are several ways to do so, but generally it is accepted that price instruments work effectively as well as efficiently. In practice, this would not mean subsidisation of green gas, but rather taxing alternatives according to the negative external effects they cause through CO_2 emissions. Three major problems then arise:

1 At a world scale, there is a large variety of estimates of the climate damage caused by a marginal emission of CO_2, which would represent the optimal CO_2 tax or price. One benchmark that could be taken as a point of departure is the current price of slightly more than 6 Euro per tonne for CO_2 permits at the EU ETS. However, given the large amount of emission permits grandfathered in the past, one could argue there is excess supply of permits and therefore the market price does not represent the appropriate price. Moreover, when this price would be applied to fossil fuels, green gas would hardly be competitive.

2 Fossil fuels for transport are already heavily taxed. One could argue that these taxes only serve the purpose of raising revenues, but one may wonder whether this is relevant in the present context. Most likely taxes on fossil fuels are already much higher than the marginal external cost they bring about. Hence, for this reason, it will be hard to advocate a higher taxation of fossil fuels for the sake of levelling the playing field for green gas.

3 Finally, even if a higher tax on fossil fuels would be warranted based on climate change considerations or environmental considerations in general, strong resistance is to be expected from several lobbying groups in society, that will invoke arguments dealing with international competitiveness of e.g., the transport sector. This would call for international coordination, which is most likely to be difficult to achieve, given the large differences that exist at present in e.g., the EU countries.

6 Conclusions

Transport has many positive characteristics, both for the individual user and for society as a whole. This partly explains why the transport sector, for more than a century now, has experienced an unprecedented growth. At the same time, transport has undesired side-effects. There are serious concerns related to emissions (at the regional, national and the global level), safety, health issues and resource management. Natural gas has the potential to address some of these concerns: it has the lowest CO_2, NOx and PM emissions compared to other fossil fuels. As far as the energy supply in the Netherlands is concerned, it is important to take natural gas into account. Biogas (biogas is defined as part of natural gas) has an additional advantage compared to natural gas, namely that the carbon dioxide released during combustion was already active in the atmosphere before. As a result, on balance, no extra CO_2 is emitted into the atmosphere. But of course, there are many hurdles to be envisaged and to be taken. This study includes a series of SWOT analyses that concentrate on the green gas – Life Cycle Analysis (LCA), the structure of the alternative fuel market, the social environment and the consumer acceptance, the legal and regulatory system and the technological characteristics and innovation elements. In particular, the financial viability, the technological challenges, the national and international energy market developments and the infrastructural supply show great possibilities and market potentials.

It is found, based on the SWOT analysis, that the green gas technology is a proven technology, it performs better than alternative fuels in terms of emissions, it decreases dependency on fossil fuels and it could improve the economic empowerment of the Netherlands. On the other hand, cost-effective production and distribution of green gas, increased competition from alternatives and unclear future policy support for green gas obstructs large-scale implementation. The findings of this SWOT exercise form the ingredients of a social cost-benefit analysis, which is synthesised in a dedicated section (Section 5) on the environmental-economic perspectives.

It is found that the inherent advantage of green gas over other fuels is that its generation and use result in considerable fewer emissions of CO_2 than in the case of other fuels for transport purposes. From a societal point of view, this advantage should be taken into account in determining the optimal mix of fuel.

Consequently, it should lead to the implementation of policy instruments that induce the consumers to choose the preferred fuel mix. There are several ways to do so, but generally it is accepted that price instruments work effectively as well as efficiently. In practice, this would not mean subsidisation of green gas, but rather taxing alternatives according to the negative external effects they cause through CO_2 emissions, as is the actual situation in Sweden at the moment.

As such, green gas has the characteristics and potentials to become a success, but the challenge is to handle existing organisational barriers. Green gas is by no way the technological fix for the challenges the transport sector is facing.

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Notes

1 It should be noted that the CE study abstracts from the present system of taxes and subsidies on fuels. This may be the correct way to pursue this study, but it may complicate the implementation of policies to 'set the prices right'.

2 SDE is a policy instrument of the Dutch government aiming at stimulating sustainable energy. It was initialised in 2008, and is yearly updated. For 2012-2014, these updates are denoted by SDE+2011-SDE+ 2014 (SDE+2014).