THE INTERNATIONAL COUNCIL ON CLEAN TRANSPORTATION

The potential for low-carbon renewable methane in heating, power, and transport in the Netherlands

Authors: Nikita Pavlenko, Chelsea Baldino, Stephanie Searle
Date: March 2019
Keywords: Biofuels, GHG Emissions, Low-Carbon Fuels, Renewable Energy Directive (EU)

Introduction and policy background

This study presents the production potential for renewable methane in the Netherlands in 2050, drawing upon the European Union-wide methodology and assessment developed by Baldino et al. (2018). The Netherlands is in the process of developing its domestic energy and gas infrastructure policies necessary to comply with both the recast Renewable Energy Directive (RED II) and its Paris Agreement commitments. This study is intended to provide an independent estimate of the renewable methane production potential in the country and the cost of greenhouse gas (GHG) reductions through increased renewable methane deployment through 2050.

Currently, natural gas is the primary source of energy in the Netherlands for power generation and heating, despite declining domestic production. In 2015, renewable methane only provided roughly 1% of the 33 billion cubic meters of gas consumed in the country (Scarlat et al., 2018). As part of its Paris Commitments to reduce its emissions by at least 80% below 1990 levels, the Netherlands intends to reduce its natural gas consumption to zero by 2050 (Netherlands Ministry of Economic Affairs, 2017). The Netherlands has updated its Gas Act to facilitate the development of new building construction without links to the natural gas grid, along with building retrofits to create gas-free districts that rely on alternative heating systems.

Increasing renewable methane production that utilizes existing gas infrastructure could also help achieve the goal of phasing out natural gas in the Netherlands. The Netherlands has a mix of short- and long-term policies and goals that create a strong push for natural gas market decarbonization and the increased use of alternative fuels. The country has set a short-term target to increase its renewable energy consumption to 16% of total energy by 2023. Renewable energy deployment in the heat and power sector is primarily supported through the Stimulation of Sustainable Energy Production (SDE+), a feed-in tariff that covers a portion of the difference between the wholesale cost of electricity and the cost of production for individual renewable energy projects over a 15-year period. This incentive covers some renewable methane projects. Beyond 2020, the SDE+ will also compensate producers based on avoided carbon dioxide (CO_2) in addition to supplied energy, providing a greater relative benefit to lower-carbon renewable energy producers (Wiebes 2018). This change could potentially increase support for very-low carbon renewable methane pathways.

For the Netherlands to phase out natural gas by 2050, it is necessary for policymakers to understand the extent to which renewable methane can replace natural gas over this timeframe. This study assesses the long-term renewable methane potential and production costs in the Netherlands. In addition, the potential contribution of renewable methane to the Netherlands' electricity, heating, and transport sectors is assessed, identifying the extent to which it can contribute to the country's policy targets. The study also estimates the greenhouse gas (GHG) reduction potential from renewable methane and puts this opportunity in perspective with the Netherlands' Paris Agreement commitments.

Acknowledgments: This work was generously supported by the European Climate Foundation. The authors would like to thank Adam Christensen for data inputs.

Assessment methodology

This study estimates the total theoretical production potential for renewable methane production in the Netherlands in 2050 across a variety of feedstocks and fuel conversion technologies. The methodology used in this paper is the same as in Baldino et al. (2018b), which assessed renewable methane production potential for the European Union. The estimated renewable methane production potential includes current renewable methane production of 250 million cubic meters in the Netherlands, which is approximately 13.5 TJ of energy annually (Scarlat et al., 2018).

Three renewable methane conversion pathways are assessed, including anaerobic digestion, gasification of wastes followed by methanation, and power-to-gas, in which electricity is used to create syngas which is then converted to methane. Only renewable methane produced from sustainable, low-carbon feedstocks that provide substantial GHG savings compared to natural gas is assessed. Baldino et al. (2018a) provides greater clarity on the reasoning behind the selection of feedstocks for this assessment. Table 1 lists the technology pathways assumed for each type of sustainable feedstock in this study, as well as the assumed GHG intensity and references for each pathway.

Renewable methane supplied for heating and transportation is assumed to be first injected into the grid. It is also assumed that renewable methane used for electricity generation is combusted on-site at the renewable methane production facility and that the electricity generated is carried through the electricity grid. In Baldino et al. (2018), this route was found to be to be more economical than injecting renewable methane into the grid for use in existing gas power plants because establishing a connection to the electricity grid has significantly lower costs than connecting to the gas grid. Therefore, for this assessment of costs and GHG reductions, renewable methane used in the heating and transport sectors is compared with the average cost of gas supplied through the Netherlands' natural gas grid. In contrast, electricity generated from renewable methane is compared with the costs and emissions from grid-average electricity in the Netherlands. The corresponding GHG intensities of fossil gas and grid-average electricity are listed in Table 1.

The total technical production potential is compared to the estimated natural gas demand in the Netherlands in 2050, as well as the overall energy demand within the electricity and transport sectors projected in the 2016 EU Reference Scenario (European Commission,2016a). Estimates for heat energy demand are the sum of 2050 residential and industrial heating demand projections from the EU Heat Roadmap (Nijs, Castello, & Gonzalez 2017).

This analysis excludes cover crops as a potential source for renewable methane production due to data gaps on the current use of cover and catch crops, also known as sequential crops, intermediate crops, green manure, winter crops, and intercrops, in the Netherlands. Although cover crops are excluded from the primary analysis, the discussion below includes an approximate estimate of the potential that anaerobic digestion of cover crops could contribute in Netherlands in 2050, based on current trends. The same methodology used in Baldino et al. (2018b) is used in this assessment for the Netherlands.

Results

Figure 1 illustrates the total technical production potential and the production potential that could be cost viable at varying policy incentive levels for renewable methane in the Netherlands in 2050, depending on end-use sector. We find that no renewable methane production in the Netherlands would be cost competitive with fossil gas without policy

Table 1: Low-carbon renewable methane feedstocks, technology pathways, and lifecycle GHG intensities.

Feedstock	Technology pathway	GHG intensity	Reference
Livestock manure	Anaerobic digestion	-264 gCO_2e/MJ (-9.45 $kgCO_2e/ m^3$)	CARB (2015), average LCA value for dairy cows
Sewage sludge		19 gCO_2e/MJ (0.68 $kgCO_2e/ m^3$)	CARB (2015), average
Municipal and industrial solid waste	Gasification and methanation	-26 gCO_2e/MJ (-0.93 $kgCO_2e/ m^3$)	Wang (2017)
Renewable solar power-to-gas in 2050	Electrolysis and methanation (power-to-gas)	12 gCO_2e/MJ (0.42 $kgCO_2e/ m^3$)	Christensen & Petrenko (2017)
Netherlands electricity production, grid average in 2050		107.1 gCO_2e/MJ of delivered electricity	European Commission (2016a); Moomaw, (2011)
Natural gas		72 gCO_2e/MJ (2.58 $kgCO_2e/ m^3$)	Giuntoli, Agostini, Edwards, Marelli (2015)

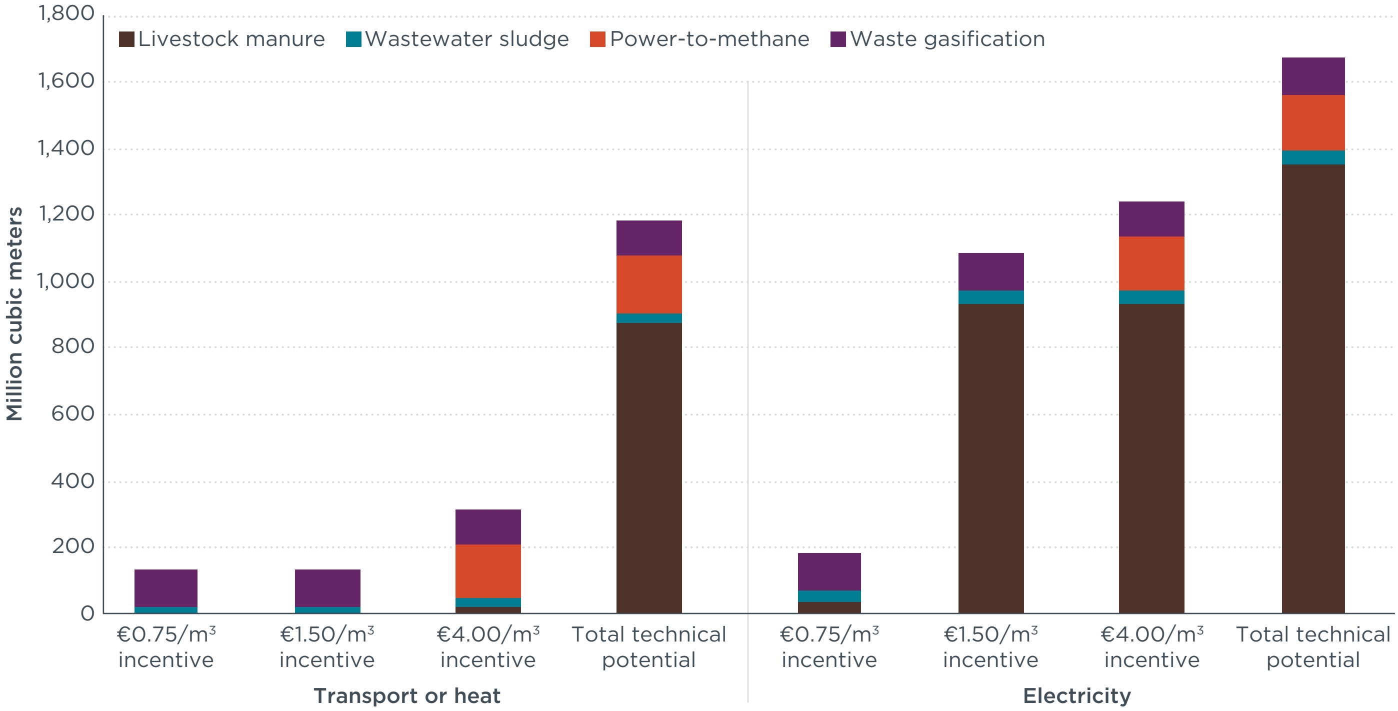

Figure 1: Total technical production potential and economically viable production potential of renewable methane delivered for transport or heating, or power, with varying levels of policy incentive (constant 2018 €) in 2050; for comparison, the current average EU natural gas price is €0.20/m³.

support. At each incentive level, the quantity of cost-viable renewable methane production potential increases, until the total technical production potential is reached on the right-hand side of the diagram. The chart shows that the overall technical production potential for renewable methane is approximately 1.2 billion cubic meters for transport or heating, or approximately 1.7 billion cubic meters for electricity. The difference is due to efficiency losses incurred when upgrading and compressing raw biogas from anaerobic digestion into renewable methane that can be injected into the gas grid. In both cases, livestock manure renewable methane accounts for over 80% of the total renewable methane production potential in the Netherlands, while waste gasification, renewable power-to-methane, and wastewater sludge each account for less than 10% of the total.

Figure 1 also illustrates a substantial gap in the amount of renewable methane that can cost effectively be produced for electricity generation and the amount that can be injected it into the grid for use in heating and transportation at each policy incentive level. Notably, at the €1.50/m³ subsidy level, which is roughly equivalent to a transport fuel subsidy of €1.50 per liter, the amount of renewable methane available to generate electricity is more than eight times the amount of renewable methane that the same subsidy level could incentivize for injection into the natural gas grid. This is because the cost of supplying renewable methane to the transport or heating sectors is generally higher than for electricity production. Delivering renewable methane from livestock manure to the gas grid can be cost-prohibitive due to the expense of developing pipeline infrastructure to connect widely dispersed dairy farms to the natural gas grid. Therefore, this route is only cost-viable for the largest farms. In contrast, on-site combustion for electricity not only eliminates the need for new pipeline interconnections, but also removes the requirement for onsite upgrading and compression of raw biogas into renewable methane for grid injection.

The cheapest sources of renewable methane are likely to be the gasification of municipal and industrial wastes and the anaerobic digestion of wastewater sludge. Both sewage sludge and gasification yield renewable methane that is cost-viable at under €0.75/m³; however, both sources are severely constrained by feedstock availability. For example, while renewable gas production from the anaerobic digestion of sewage sludge is the cheapest source of renewable methane in this analysis, only about 27 million m³ would be available in 2050. Likewise, the gasification and methanation of wastes is also constrained by the lack of feedstock. As Searle and Malins (2015) estimate that there is no sustainably available agricultural or forestry residues available in the Netherlands, only a small amount of municipal and industrial waste is available for gasification, yielding just over 100 million m³ of renewable methane.

The total production potential for power-to-gas in the Netherlands is only 159million m³ in 2050. This is due to low wind and solar power generation potential in the Netherlands compared to other parts of the world and because it will likely take a longer time to fully scale up the power-to-gas industry. Even at a high incentive level of €4/m³, we find that this pathway is not able to cost-effectively generate a substantial amount of renewable methane.

The incentive levels shown in Figure 1 are relatively expensive compared to the level of support provided by the existing SDE+ program. For example, in 2018 the SDE+ awarded the highest biomass fermentation subsidy to mono fermentation of manure for gas, at approximately €0.076/kWh after accounting for the base electricity price (Netherlands Enterprise Agency, 2018).[1] This equates to only around €0.23 per m³ of renewable methane, far less than the necessary incentive level to make renewable methane cost viable for all but the largest dairy farms.

Figure 2 illustrates the quantity of GHG reductions that can be achieved through the deployment of additional renewable methane in the Netherlands in 2050 at the €1.50/m³ incentive level and at full technical production potential. On the left-hand side, the chart shows the GHG reductions achieved from displacing natural gas used in transportation or heating, whereas the right-hand side illustrates the GHG reductions from displacing grid-average electricity in the power sector. As with the total technical production potential estimates discussed above, there is greater potential for carbon reductions through the deployment of renewable methane to the power sector than in the transport or heating sectors, especially when considering the difference in cost. Overall, there is enough technical production potential to generate 14.9 million tonnes of GHG reductions from deploying renewable methane to the electricity sector, compared to only 11.4 million tonnes when used in the transport or heating sectors. Furthermore, at an incentive level of €1.50/m³, renewable methane would generate roughly 20 times the quantity of GHG reductions in the electricity sector than in transport and heating.

Figure 2 also illustrates the contribution of different feedstocks to the total GHG reductions achievable from renewable methane in the Netherlands. The bulk of the GHG reductions achievable in either sector comes from livestock manure, which is not only abundant, but has an extremely low carbon intensity due to the avoided release of methane emissions to the atmosphere, which would otherwise be produced from untreated manure (as shown in Table 1).

Even at its total technical production potential, the amount of renewable biogas that could be produced in the Netherlands from sustainably available feedstocks would only displace a relatively small share of the country's energy needs. Figure 3 contextualizes the 2050 technical production potential of renewable methane in the Netherlands, comparing it to the projected natural gas demand in the same year. The overall technical production potential for renewable methane in the Netherlands falls far short of meeting projected 2050 gas demand predicted by the EU's Energy Roadmap, with only approximately 3-7% penetration being viable, depending on end-use sector. The EU Energy Roadmap may not take into account the Netherlands' goals for phasing out natural gas consumption, and so if the Netherlands reduces overall gas use, renewable methane

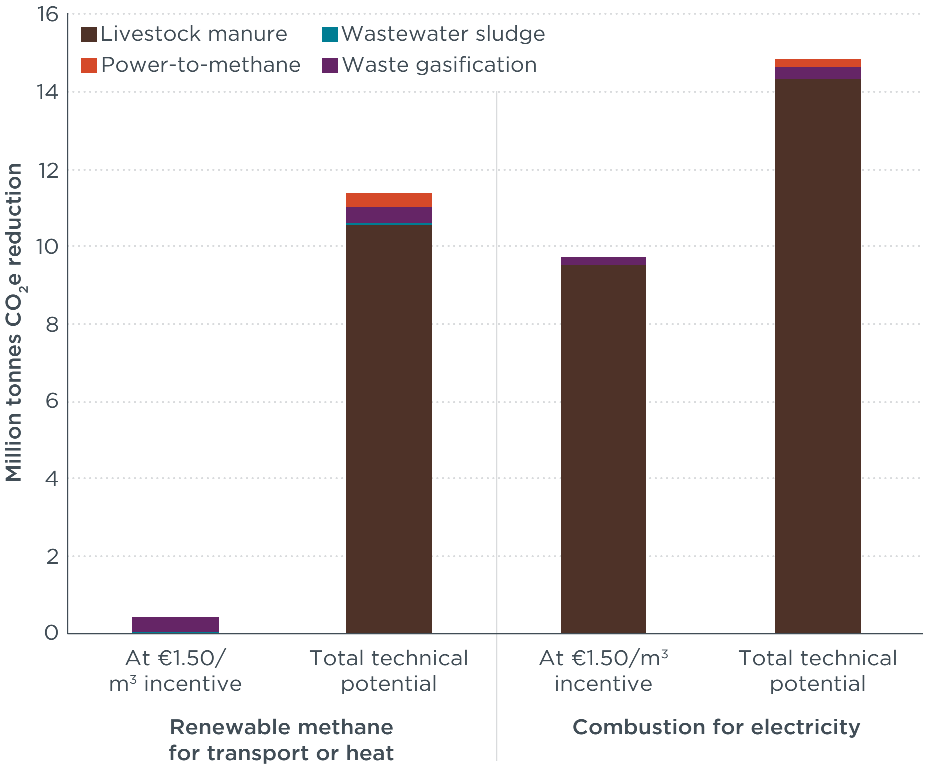

Figure 2: Greenhouse gas mitigation potential of renewable methane for transport or heating, or power in 2050 at an incentive level of €1.50/m³.

1 Depending on the structure of the system, different subsidy values can also be granted for renewable heat or combined heat and power

could potentially displace a larger relative share of that smaller gas demand in 2050. The figure also illustrates the potential contribution of renewable methane relative to the projected total energy demand in the transportation, heating, and electricity sectors in 2050. Energy demands for total gas and transport are shown in terms of pre-combusted fuel and in terms of post-combustion delivered energy for the heat and electricity sectors. We estimate that renewable gas could supply, at most, 5.0% of the Netherlands' total projected natural gas use. If diverted to only one end-use sector, it would provide at a maximum 8.0% of transportation energy demand, 3.8% of heat demand, or 3.5% of electricity demand. Factoring in costs, however, even with a fairly high incentive level of €1.50/m³, the volumes of renewable methane available to transportation and heating would plummet significantly—to only around 1% of demand in each sector. For the electricity sector, there would be a much smaller drop-off in cost-viable contributions to the total demand, as the bulk of renewable methane production potential would be available at that subsidy level.

Another potential source of biomass for renewable methane production is cover cropping. While cover cropping is relatively uncommon, some have speculated that in the future cover crops may provide a low-risk feedstock for anaerobic digestion if grown on existing farmland in between crop rotations. Based on the assumptions outlined in Baldino et al. (2018), we estimate that, at most, 4.4 million m³ of renewable methane per year could be available from cover cropping in 2050, which would not significantly change the estimate of the total volume of renewable methane production potential.

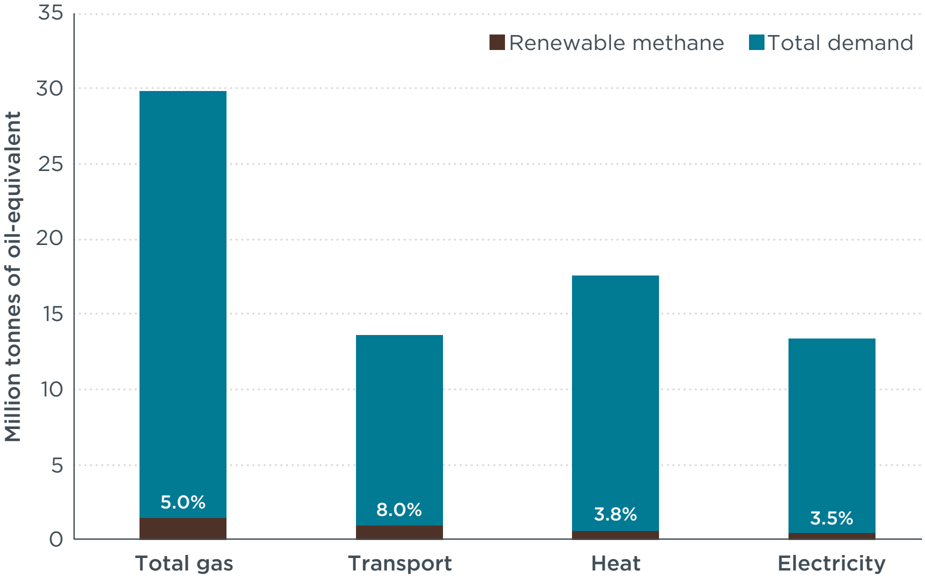

Figure 3: Maximum potential for sustainable renewable methane to displace total gas demand or total energy demand for transport, heating, or power in 2050.

Note: Total gas demand and transport shown as pre-combustion energy; heating and power shown as post-combustion energy.

Comparison to literature

Two other relevant studies have assessed the renewable methane production potential in the Netherlands. De Gemeynt (2018) estimates a total production potential of 3.6 billion m³ of renewable methane available in the Netherlands by 2030. Approximately 1 billion m² is estimated to come from the anaerobic digestion of animal manure, co-digestion with crops, and food & beverage industry waste. De Gemeynt (2018) estimates that the remaining 2.6 billion m³ of methane would come from the scale-up of gasification, primarily of woody waste and agricultural biomass, with minor contributions from power-to-gas.

CE Delft adjusted the assessment in De Gemeynt (2018), revising its estimate downward to better align with existing gas company projects. This study estimated that approximately 2 billion m³ of renewable methane could be available in the Netherlands by 2030, approximately one-third higher than our estimated technical production potential for 2050 (Leguit et al. 2018). Several different methodological choices explain the difference between CE Delft's results and ours. Notably, Leguit et al. (2018) estimate that the production costs for renewable methane range from €0.54-€0.90/m³ across production methods, with the potential to decrease to €0.24-€0.40/m³ as technology improves. While this estimate may reflect the production costs for gasification of municipal solid waste (MSW) and anaerobic digestion of sewage sludge, it may be overly optimistic for biogas production from livestock manure which would require additional spending for pipeline interconnections. Indeed, the study assumes that network operators may bear the cost of expanding the gas grid, rather than producers.

The make-up of the biomass gasified in both studies is relatively opaque, drawing upon estimates of total biomass energy potential in the Netherlands conducted by DNV-GL (Schulze et al. 2018). The authors estimate that there would be nearly 5 million tonne of oil equivalent (Mtoe) of biomass "freely-available" in the Netherlands by 2035, with a technical production potential of approximately 8.5 Mtoe.[2] This production potential includes waste wood (1 Mtoe), agricultural residues (1 Mtoe) and aquatic biomass (1.3 Mtoe). Of the 1 Mtoe of energy available from agricultural residues, DNV-GL includes 0.7 Mtoe (or around 850 million m^3) of animal manure, which aligns relatively closely with our estimate. This means that Leguit et al. (2018) and De Gemeynt (2018) double-count the renewable methane production potential from livestock manure, counting the same amount twice for use in anaerobic digestion and gasification.

The remaining 0.3 PJ of agricultural residues in the DNV-GL study come from "wet" crop residues that can be removed from fields without adverse effects. In contrast, Searle and Malins (2016) estimates that no additional forestry residues or agricultural residues can be sustainably harvested in the Netherlands without displacing these materials from other uses or adversely impacting soil carbon and fertility. Likewise, DNV-GL's states that the waste wood they consider available for renewable methane production is largely already used in the Netherlands, with 60% used for either fuel or secondary material manufacture and the remaining 40% exported. Aquatic biomass, the single largest contributor to the freely-available biomass production potential in 2030 in the DNV-GL study, remains a highly uncertain source of biomass due to high expense, lack of existing projects, and sustainability constraints (Baker et al. 2017). A modeling exercise commissioned by DG Research and Innovation suggests that in a reference scenario, only 41 million dry tonnes of algal biomass would be available throughout the entire European Union by 2050, at an average cost of €1,330 per tonne (Baker et al. 2017).[3]

The assumption in Leguit et al. (2018) and De Gemeynt (2018) that the entire amount of available biomass could be gasified and converted to methane in 2030 is also likely overly optimistic. No commercial-scale gasification-methanation facilities exist today, and design, construction, and ramping-up of new facilities using this technology would likely take years. In our assessment, we find that very little renewable methane could be produced using gasification in the 2030 timeframe.

Conclusion

This analysis finds that total renewable methane production potential in the Netherlands is relatively limited and would meet less than 5% of the Netherlands' projected 2050 natural gas demand. At maximum production potential, renewable methane could displace existing fossil fuel consumption and generate between 10 and 15 million metric tonnes of CO_2e reduction, depending on end-use.

Our analysis demonstrates that it is much more cost-effective to use the majority of renewable methane production potential for on-site electricity generation rather than injecting it into the natural gas grid. Because more than 80% of the Netherlands' sustainably available renewable methane feedstocks come from livestock manure, the added cost of grid interconnections for distant farms would make grid injection cost-prohibitive without extremely high policy incentives. While sewage sludge anaerobic digestion and gasification of MSW are likely to be the cheapest sources of renewable methane, both will be highly limited by feedstock availability and together contribute only around 10% of the total technical production potential. Similarly, we expect renewable power-to-methane production potential to be limited in the Netherlands, even in the 2050 timeframe.

Overall, renewable methane can only make a modest contribution to the Netherlands' overall Paris Agreement ambitions and long-term plan to reduce reliance on natural gas. Although incentives should be made available to renewable methane producers utilizing sustainably available feedstocks with good GHG performance, the Netherlands will largely have to wean itself off its reliance on gas in order to completely phase out natural gas consumption by 2050.

2 The energy content here refers to the energetic value of the biomass prior to conversion into fuel or electricity

3 Assuming an energy value of 23.2 MJ per dry kg of algal biomass, this equates to approximately 900 PJ of energy for the entire EU-28.

References

Alliance Environnement. (2017). *On payments for agricultural practices beneficial for the climate and environment* [Final report]. Retrieved from the European Commission https://ec.europa.eu/agriculture/sites/ agriculture/files/ fullrep_en.pdf

Baldino, C., Pavlenko, N., Searle, S., & Christensen, A. (2018a). *The potential for low carbon renewable methane as a transport fuel in France, Italy, and Spain.* Retrieved from the International Council on Clean Transportation https://www.theicct.org/publications/ potential-renewable-methane-france-italy-spain

Baldino, C., Pavlenko, N., Searle, S., and Christensen, A. (2018b) *The potential for low-carbon renewable methane in heating, power, and transport in the European Union.* Retrieved from the International Council on Clean Transportation https://www.theicct.org/publications/ methane-heat-power-transport-eu

Baker, P., Olivier, C., Haffner, R., Heidecke, L., van Hussen, K., Meindert, L.... and Walker, M. (2017). *Research and Innovation Perspective of the Mid- and Long-Term Potential for Advanced Biofuels in Europe.* Retrieved from the Directorate-General for Research and Innovation, European Commission https://publications.europa.eu/en/publication-detail/-/ publication/448fdae2-00bc-11e8-b8f5-01aa75ed71a1

California Air Resources Board (CARB). (2015). *Low carbon fuel standard re-adoption: Natural gas carbon intensity and other CA-GREET model adjustments*. Presented at CARB Meeting, April 3rd, 2015. Retrieved from https://www. arb.ca.gov/fuels/ lcfs/lcfs_meetings/040315presentation.pdf

Christensen, A., & Petrenko, C. (2017). *CO2-based synthetic fuel: Assessment of potential European capacity and environmental performance*. Retrieved from the International Council on Clean Transportation https://www.theicct.org/sites/default/ files/publications/CO2-based-synthetic-fuel-EU-assessment_ ICCT-consultant-report_14112017_vF_2.pdf

De Gemeynt. (2018). *Green Liaisons: Hernieuwbare moleculen naast duurzame elektronen.* Retrieved from Groengas Nederland https://groengas.nl/nieuws/rapport-green- liaisons-toont-belang-hernieuwbare-gassen-in-energie-en- grondstoffenhuishouding/

European Commission. (2016a) *EU reference scenario 2016: Energy, transport and GHG emissions, trends to 2050*. Retrieved from. https://ec.europa.eu/energy/sites/ener/files/ documents/20160713%20draft_publication_REF2016_v13.pdf

European Commission. (2016b). *Report from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions: Energy prices and costs in Europe*. Retrieved from https://eur-lex.europa.eu/legal-content/EN/ TXT/?uri=COM:2016:769:FIN

Giuntoli, J., Agostini, A., Edwards, R., & Marelli, L. (2015). *Solid and gaseous bioenergy pathways: Input values and GHG emissions* [Joint Research Centre Science and Policy Report]. Retrieved from the Institute for Energy and Transport https://ec.europa.eu/energy/sites/ener/files/ documents/Solid%20and%20gaseous%20bioenergy%20 pathways.pdf

Leguit, C., Kruit, K., and Rooijers, F. CE Delft. *Contouren en instrumenten voor een Routekaart Groengas 2020- 2050* [Contours and instruments for a Roadmap Green Gas 2020-2050]. Retrieved from CE Delft https://www.ce.nl/ publicaties/2197/contouren-en-instrumenten-voor-een- routekaart-groengas-2020-2050

Moomaw, W., Burgherr, P., Heath, G., Lenzen, M., Nyboer, J., & Verbruggen, A. (2011). *Annex II: Methodology. In IPCC: Special Report on Renewable Energy Sources and Climate Change Mitigation* (pp. 181-205). Retrieved from the Intergovernmental Panel on Climate Change https://www.ipcc.ch/report/ renewable-energy-sources-and-climate-change-mitigation/

Netherlands Enterprise Agency. (2018). *SDE+ Spring 2018.* Retrieved from https://english.rvo.nl/sites/default/ files/2018/02/Brochure-SDE-Spring-2018.pdf

Netherlands Ministry of Economic Affairs (2017). *Energy Agenda Towards a low-carbon energy supply.* Retrieved from https://www.government.nl/documents/reports/2017/03/01/ energy-agenda-towards-a-low-carbon-energy-supply

Nijs, W., Castello, P.R., Gonzalez, I.H. (2017). *Baseline scenario of the total energy system up to 2050*. Retrieved from Heat Roadmap Europe https://heatroadmap.eu/wp-content/ uploads/2018/11/HRE4_D5.2.pdf

Scarlat, N., Dallemand, J.-F., & Fahl, F. (2018). Biogas: Developments and perspectives in Europe. *Renewable Energy 129*(A). 457-472. doi: 10.1016/j.renene.2018.03.006

Schulze, P., Holstein, J., Vlap, H. (2018). *Biomassapotentieel in Nederland [Biomass Potential in the Netherlands]* (DNV-GL report). Retrieved from Gasunie https://www.gasunie.nl/uploads/ fckconnector/5105fcba-372b-4da0-b4b4-56fd9f9c1854

Searle, S., and Malins, C. (2015). Waste and residue availability for advanced biofuel production in EU Member States. *Biomass and Bioenergy, 89*. (2-10). doi:10.1016/j. biombioe.2016.01.008

Wang, M. (2017). GREET® Model. *The greenhouse gases, regulated emissions, and energy use in transportation model. GREET 1 Series (Fuel-Cycle Model).* Retrieved from the Center for Transportation Research, Energy Systems Division, Argonne National Laboratory https://greet.es.anl. gov/ greet_1_series

Wiebes, E. (2018). *Kamerbrief over verbreding van de SDE+[Letter to Parliament about Widening the SDE+].* Retrieved from Economische Zaken en Klimaat https://www. rijksoverheid.nl/documenten/kamerstukken/2018/11/26/ kamerbrief-over-verbreding-van-de-sde