Gas for Climate

Job creation by scaling up renewable gas in Europe

Prepared for:

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EXECUTIVE SUMMARY

The smart combination of renewable gases and electricity is essential in achieving the decarbonisation of the EU energy system. Decarbonisation will strengthen employment throughout the EU economy, bringing additional employment opportunities. These opportunities will shift to more local and high skilled jobs in both the energy sector and through the overall energy technology supply chain. Scaling up renewable gases—as presented in the "optimised gas" scenario of the recent Gas for Climate study[1]—is estimated to create 600,000–850,000 additional direct jobs and 1.1–1.5 million indirect jobs by 2050.[2,3]

The energy transition and decarbonisation of the EU energy system will impact employment. Some jobs may disappear, such as jobs related to coal mining or to operating fossil fuel power plants. However, new employment opportunities will emerge, such as those related to the production and supply of renewable energy.

The March 2019 Gas for Climate study showed that renewable gas has a valuable role to play in the decarbonisation of the EU energy system. This report explores the possible employment effects of an EU-wide scale-up of renewable gas. It focuses on the employment effect from the supply of biomethane through anaerobic digestion and thermal gasification, and the supply of hydrogen by electrolysis using renewable electricity. Each of the renewable gases has its own distinct production pathway with specific employment effects.

The deployment of renewable gases as presented in the Gas for Climate "optimised gas" scenario brings new job opportunities in various sectors of the EU economy by 2050. The results of the analysis suggest the following potential direct employment opportunities in key economic sectors:

- 150,000–225,000 direct jobs in renewable electricity generation for hydrogen production and another 50,000–75,000 direct jobs in the energy sector
- 100,000–150,000 direct jobs in agriculture and forestry (among others) to provide the feedstock to biomethane production facilities
- 200,000–300,000 industrial direct jobs related to the development and operations of digesters, thermal gasification plants, and electrolysers

Next to that, deployment of renewable gases brings new jobs in the construction sectors, technical and non-technical services, and operations and maintenance sectors.

Production of biomethane through anaerobic digestion is primarily small scale and decentralised, based on biomass from sequential cropping, manure, and agricultural residues. Biomethane production through anaerobic digestion leads to increasing employment in rural economies because of the required efforts for biomass collection and biomethane production in agriculture. R&D efforts are required as well. In the "optimised gas" scenario in its Gas for Climate study, Navigant[4] estimates that the production of 660 TWh/year of biomethane through anaerobic digestion comes with 200,000–275,000 direct jobs and another 300,000–400,000 indirect jobs by 2050.

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[1] Navigant, 2019. *Gas for Climate. The optimal role for gas in a net-zero emissions energy system*. Available at: https://www.gasforclimate2050.eu.

[2] Direct jobs are the additional jobs expected based on increased activity in the various sectors along the value chain associated with developing (related to CAPEX) and operating (related to OPEX) renewable gas production, as well as associated to the feedstock and electricity needed to produce renewable gases (fuel expenditure). Indirect jobs are the additional jobs expected based on increased activity for the suppliers of each sector of the value chain (as defined for direct jobs) who also need to purchase goods and services and hiring workers to meet demand, and this in turn leads to a chain reaction with demand to their own suppliers, etc.

[3] Ranges reported throughout the report are rounded to the nearest 50,000. Because of rounding, the sum of individual numbers might not exactly add up to the total numbers reported.

[4] Navigant Consulting, Inc., n/k/a Guidehouse Inc. (Navigant). On October 11, 2019, Guidehouse LLP completed its previously announced acquisition of Navigant Consulting Inc. In the months ahead, we will be working to integrate the Guidehouse and Navigant businesses. In furtherance of that effort, we recently renamed Navigant Consulting Inc. as Guidehouse Inc.

In contrast, biomethane production from woody biomass through thermal gasification takes place at a much larger scale and is more centralised. It leads to employment benefits in forestry for biomass collection, and in industry for the development, construction, and operation of thermal gasification plants. Because of the required technical developments in thermal gasification, R&D efforts are required. In the “optimised gas” scenario in its Gas for Climate study, Navigant estimates that the production of 350 TWh/year of biomethane through thermal gasification comes with 100,000–150,000 direct jobs and another 150,000–200,000 indirect jobs by 2050.

The recent Gas for Climate study sketches a hydrogen scale-up pathway up to 2060. In the short term, increased quantities of blue hydrogen (produced from natural gas in combination with carbon capture and storage [CCS]) are expected, primarily to replace grey hydrogen in existing hydrogen applications. This transition requires the retrofit of existing steam methane reforming plants with CCS units, resulting in new employment opportunities because of R&D and technical implementation. In parallel to the growth of blue hydrogen production capacity, we expect large-scale demonstration projects for green hydrogen (hydrogen produced from renewable electricity in electrolysers). After 2030, an increasing market share of green hydrogen is expected, eventually replacing existing blue hydrogen capacity. In 2050 all hydrogen could be renewable, although it is likely that a fully renewable gas supply can only be reached around 2060.

Over time, employment benefits of hydrogen deployment shift from jobs related to R&D towards jobs related to the construction and operation of green hydrogen production plants and the required infrastructure for hydrogen. Employment benefits will mainly occur in the construction and industry sectors, for the construction of the plant, the production of the necessary equipment, and the operation of the plant. In the “optimised gas” scenario in its Gas for Climate study, Navigant estimates that the production of 1,710 TWh/year of hydrogen through electrolysis comes with 300,000–450,000 direct jobs and another 650,000–900,000 indirect jobs by 2050.

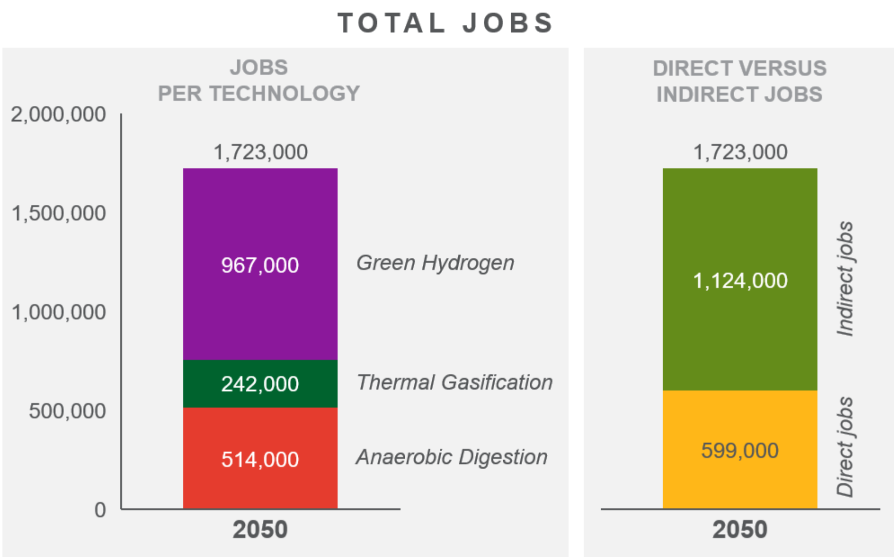

Figure 1. Jobs per technology (left) and direct vs. indirect (right)[5]

[5] The graph is based on the lower bound values. The ranges in the report are based on sensitivity analyses on the averages wages in different sectors (for the lower bound value the average wage in Germany, France, and Italy are assumed instead of the average wage in Europe, to reflect potential higher wages resulting in lower employment effects) and a higher import share for materials across the value chains (for the lower bound value a 20% import share is assumed, resulting in lower employment effects). Jobs reported in figures are rounded to the nearest 1,000. Because of rounding, the sum of individual numbers might not exactly add up to the total numbers reported.

The Gas for Climate study published in March 2019 showed that biomethane and hydrogen transported through (mainly existing) gas infrastructure have a valuable role in achieving climate neutrality by mid-century. The deployment of renewable gases brings new jobs throughout the EU economy, and job creation must be considered when assessing the future role for renewable gas. Investments in renewable energy creates opportunities for new local and high skilled jobs. Job creation can help foster societal support for deep decarbonisation. The development of renewable gas production technologies in Europe enables the export of knowledge and technologies, boosting employment even further.

1. INTRODUCTION

A significant increase in renewable energy production is needed to fully decarbonise the EU energy system by 2050. Increasing renewable energy production will create and already is creating employment opportunities across supply chains. In its annual employment overview, IRENA indicates that the renewable energy sector was employing at least 11 million people worldwide, directly and indirectly, at the end of 2018.[6] Since IRENA's first assessment in 2012, renewable energy employment numbers have grown by almost 50%. During 2018, the biggest employers were the solar PV, bioenergy, wind power, and hydropower industries. These employment developments are influenced by a wide range of economic, technical, and policy factors and are subject to geographic production shifts, corporate strategies, and changes in the supply chain.

The current state of employment in the EU biogas sector was analysed by IRENA[7] and EurObserv'ER.[8] They estimate that the number of direct and indirect jobs in the European Union was around 71,000 in 2017. Compared to 2016, the biogas job market contracted by 5%. This decline began in 2011 and was caused by many EU states' apprehensiveness to the use of energy crops. Consequently, investments in the biogas market have shrunk. Germany has the biggest share of labour force in biogas (48% of the total FTE related to biogas in the EU). However, growth is limited and many equipment manufacturers are now beginning to rely on export of their products because regulations do not allow for the feed-in of biogas of varying quality into the grid. The UK is in second place for biogas employment in the EU. However, both FTE and turnover dropped by 30% between 2016 and 2017. Even in Italy (where the biogas sector would appear to be more stable[8]) there has been a reduction in investments. This reduction is due to a drop in support programmes for the production of biogas for cogeneration and to challenges connected to restrictions in biomass feedstock types for biogas plants that are transformed to biomethane plants—even when part of the biogas is still used for electricity production. This led to the construction of extremely small biogas plants that can only be fed by manure, slurry, and residues; at the same time it prevents the transition from the current biogas production to biomethane. The reduction in investments has led to a drop in employment numbers.

Employment in the hydrogen industry is mainly related to the fossil-based hydrogen from existing steam methane reformers for industrial purposes. Today, the number of jobs related to blue hydrogen (hydrogen produced from natural gas in combination with carbon capture and storage [CCS]) and green hydrogen (hydrogen produced through electrolysis using renewable electricity) in the EU is close to zero.

The latest Gas for Climate study assessed a cost-optimal way to fully decarbonise the EU energy system by 2050.[9] Renewable and low carbon gas play an important role in Gas for Climate's "optimised gas" scenario, providing flexible electricity production, heating buildings in times of peak demand, producing high temperature industrial heat and feedstock, and fuelling heavy road transport and international shipping.

The "optimised gas" scenario assumes a significant increase in renewable electricity (wind, solar PV, and some hydropower) with an increase in renewable and low carbon gas. Supply of renewable and low carbon gases reaches 2,880 TWh in 2050.[10] The renewable methane considered in this scenario is predominantly biomethane produced through anaerobic digestion and thermal gasification. Hydrogen can be produced from renewable electricity (green hydrogen) and from natural gas

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[6] IRENA, 2019. *Renewable energy and jobs – Annual review 2019.* Available at: https://irena.org/publications/2019/Jun/Renewable-Energy-and-Jobs-Annual-Review-2019.

[7] IRENA, 2018. *Renewable energy and jobs – Annual review 2018*. Available at: https://www.irena.org/publications/2018/May/Renewable-Energy-and-Jobs-Annual-Review-2018.

[8] EurObserv'ER (2018). *The state of renewable energies in Europe edition 2018 - 18th EurObserv'ER Report*, page 42-49. Available at: https://www.eurobserv-er.org/category/all-annual-overview-barometers/.

[9] Navigant, 2019. *Gas for Climate. The optimal role for gas in a net-zero emissions energy system*. Available at: https://www.gasforclimate2050.eu.

[10] From which 660 TWh biomethane from anaerobic digestion, 350 TWh biomethane through thermal gasification, 1710 TWh hydrogen, and 160 TWh methane from power-to-methane. In this report we focus on biomethane and hydrogen production.

combined with CCS (blue hydrogen). Because hydrogen production will be increasingly based on renewable electricity to eventually achieve a fully renewable energy system in 2050, the employment analysis focuses on hydrogen from electrolysis.

This report describes the employment effects of the decarbonisation of the EU energy system through the increased production of renewable gases, as described in the Gas for Climate “optimised gas” scenario. It will focus on the renewable gas supply chains of anaerobic digestion, thermal gasification, and green hydrogen.

To assess the employment effects of renewable gas development in Europe, we performed a semi-quantitative analysis (Figure 2). In Chapter 2, we provide an overview of the production pathways of biomethane production through anaerobic digestion and thermal gasification, and green hydrogen production through electrolysis. In Chapter 3, we describe the expected EU employment impact of the deployment of renewable gas estimated using a spreadsheet-based input-output model developed by Navigant based on recognised literature sources.[11] The model derives estimates of employment linked to the “optimised gas” scenario from the Gas for Climate study based on investments in renewable gas across the different sectors of the economy in 2050. The methodology is described in more detail in Appendix A. In Chapter 4, we provide cross supply chain conclusions and recommendations.

Figure 2. To assess the employment effects of renewable gas development in Europe, we performed a semi-quantitative analysis

[11] Here are some recent examples of studies using the same approach:
https://www.plan.be/admin/uploaded/201702231020450.CBA_2017.pdf
http://www.ukerc.ac.uk/asset/0A611DB6-DCEA-4628-97FC16042EAD4F20/
https://climateactiontracker.org/documents/401/CAT_2018-11-27_ScalingUp_MethodologicalAnnex.pdf .
Also see this paper highlighting the various possible approaches to assess regional economic impact of renewable energy sources development: https://www.sciencedirect.com/science/article/pii/S1364032118303447

2. RENEWABLE GAS PRODUCTION PATHWAYS

The "optimised gas" scenario from the Gas for Climate study shows that biomethane can be a zero emissions renewable gas by 2050 without competition with other biomass users. Biomethane can be produced from agricultural residues and crops through anaerobic digestion or from woody biomass via thermal gasification. These production pathways are discussed in Section 2.1 and 0. In the scenario, there is also a large role for green hydrogen, a renewable gas produced from renewable electricity, which will be discussed in Section 2.3.

2.1 Biomethane from anaerobic digestion

Anaerobic digestion is the dominant process to produce biogas today, often using agricultural biomass. This biogas can be upgraded to biomethane. Anaerobic digestion involves a series of biological processes in which microorganisms break down biodegradable material in the absence of oxygen. The process results in biogas and digestate. Biogas contains around 55% methane,[12] the rest being mainly short carbon cycle CO_2, O_2, and H_2O. The production pathway of biogas via anaerobic digestion consists of five main process steps (Figure 3):

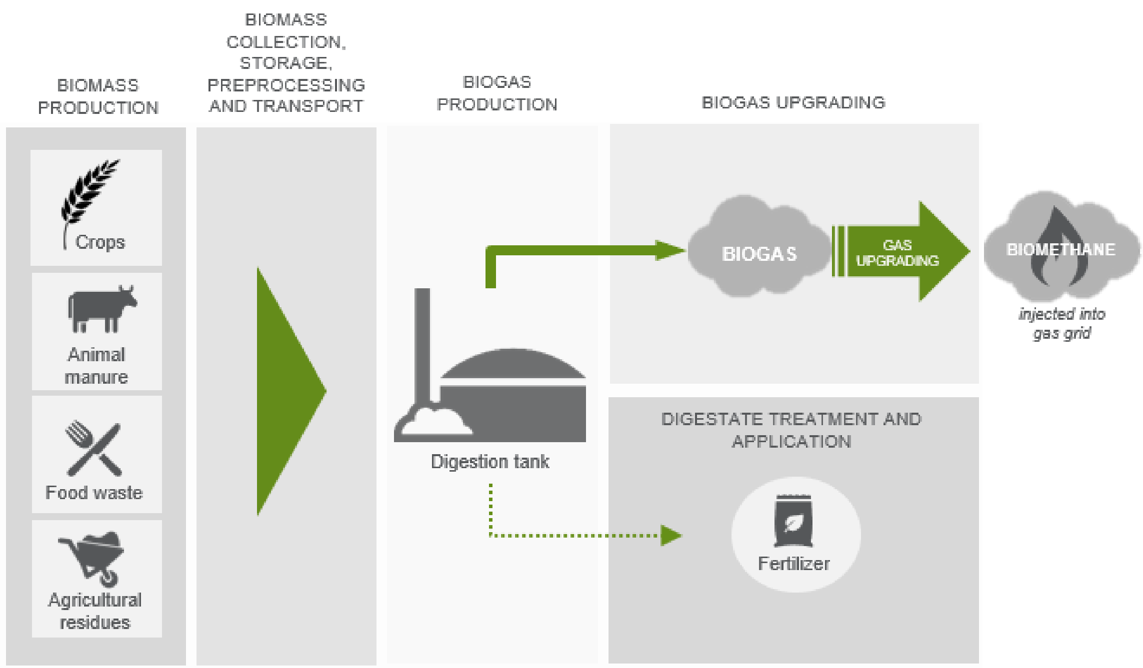

Figure 3. Production pathway for biomethane produced through anaerobic digestion

1. **The production of biomass.** Agricultural residues such as straw, animal manure, and food waste can be used to produce biomethane. Agricultural crops also play an important role. Navigant only considers crops that are produced in addition to the existing main crops using a sequential cropping scheme (Box 1).

2. **Biomass collection, storage, pre-processing, and transport.** Depending on the type of feedstock and the location of the biogas production facility (for example, in the case of farmer with a biogas digester), the biomass needs to be collected, stored, pre-processed, and transported.

[12] Depending upon the feedstock, the methane content of biogas may vary between 50%-65%.

3. **Biogas production.** In the digester, a series of biological processes take place in which microorganisms break down the feedstock, resulting in biogas and digestate.

4. **Digestate treatment and application.** The digestate formed in the digestion tank can be used as a fertiliser.

5. **Biogas upgrading.** To enable injection into the gas grid, biogas is assumed to be upgraded to biomethane with 97% methane content by removing CO_2.[13]

Box 1. Biogasdoneright concept

The report's analysis assumes that the largest contribution of biomass for biomethane comes from silage produced as sequential crops. It is assumed that 10% of the current EU Utilised Agricultural Area[14] on average will be used for sequential cropping in 2050. Sequential crops are produced as an additional (second) crop before or after the harvest of the main crop on the same agricultural land. The potential for sequential cropping is based on an optimised concept developed in Italy by Consorzio Italiano Biogas called Biogasdoneright.[15] Biogasdoneright increases the agricultural productivity of existing farmland without negative environmental impacts and without direct or indirect land use change. It leads to co-benefits such as a decrease in soil erosion risks, an increase in on-farm biodiversity, and a potential increase of the soil carbon content by leaving more agricultural residues on the land. It could also result in negative carbon emissions. Navigant assessed the environmental sustainability of Biogasdoneright in Italy with experts from Wageningen University and verified the concepts sustainability claims.[16] This study assumes a significant scale-up of sequential cropping outside of Italy. The study assumes that the second crop, in a sequential cropping scenario, can achieve 30% of additional biomass compared to the monocrop in central Europe. It has been demonstrated that in southern European countries the additional biomass production can amount to 60% (as seen in Italy). Sequential cropping is not considered effective for the Nordic climate. This additional biomass from sequential cropping is assumed to be available for sustainable biomethane production.

2.2 Biomethane from thermal gasification

Thermal gasification involves a complete thermal breakdown of solid biomass such as woody biomass and consumer wastes, which takes place in a gasifier in the presence of a controlled amount of oxygen and steam. The process results in biomethane that can be injected in the grid. Thermal gasification is expected to reach full commercial maturity well before 2050.

The production pathway of thermal gasification can be broken down into four main process steps (Figure 4):

[13] We note that in some countries, most notably the Netherlands, Germany and Belgium, the methane content of gas is about 80% today, in part of the gas grid, due to the production of low calorific gas in Groningen. This means that biomethane used in these countries today should have a methane content of 85% instead of 97% for injection in the low calorific gas grid. Groningen gas extraction will be phased out by 2030, we assume that by 2050, all biomethane in the EU will have a 97% methane content.

[14] Total Utilised Agricultural Area (UAA) in the EU is around 175 million hectares, obtained from: https://ec.europa.eu/eurostat/statisticsexplained/index.php/Farm_structure_statistics.

[15] Consorzio Italiano Biogas (CIB), 2017. *Biogasdoneright. Anaerobic digestion and soil carbon sequestration. A sustainable, low carbon and win-win BECCS solution*. Available at: https://www.consorziobiogas.it/wp-content/uploads/2017/05/Biogasdoneright-No-VEC-Web.pdf.

[16] Ecofys (now part of Navigant), 2016. *Assessing the case for sequential cropping to produce low ILUC risk biomethane.* Available at: https://www.consorziobiogas.it/wp-content/uploads/2017/02/Ecofys_Assessing-the-benefits-of-sequential-cropping-for-CIB_Final-report.pdf.

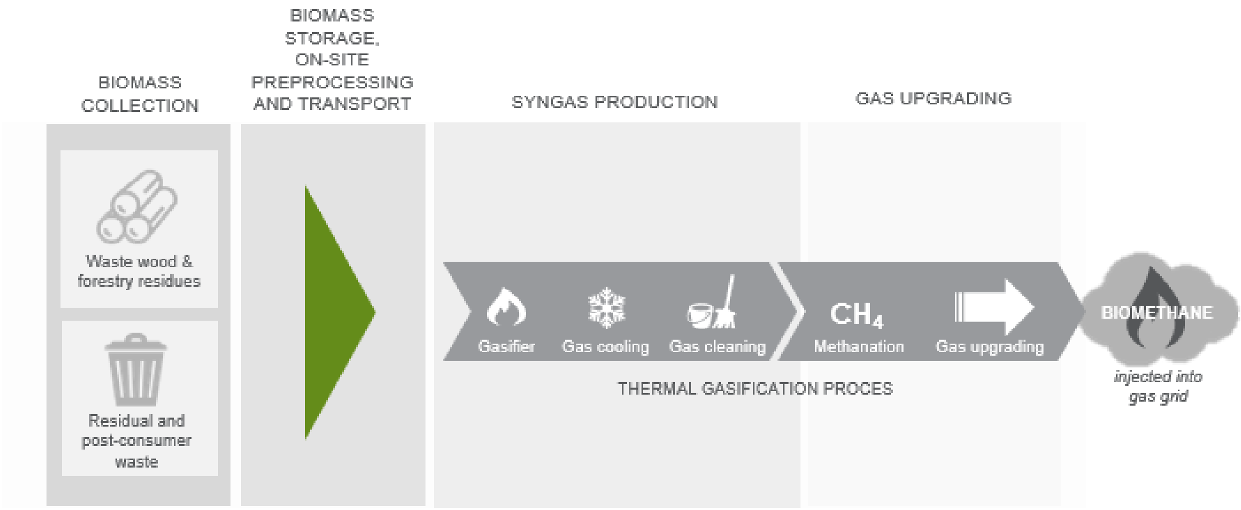

Figure 4. Production pathway for biomethane produced through thermal gasification

1. **Biomass collection.** Waste wood, forestry residues, residual, and post-consumer waste are used as a feedstock for thermal gasification.

2. **Biomass storage, onsite pre-processing, and transport.** Biomass collected in the previous step needs to be transported to the gasifier. Depending on the type of biomass, the biomass needs to be processed and treated (e.g., drying) before it can enter the gasifier.

3. **Syngas production.** During the thermal gasification process a mixture of carbon monoxide, hydrogen, and CO_2 is produced, which is called syngas or synthesis gas. The syngas is cooled, and ash content and pollutants are removed.

4. **Upgrading to biomethane.** Methanation of the syngas is performed in a catalytic reactor using nickel catalysts, converting the syngas into biomethane, CO_2, and water. The CO_2 and water are removed in a gas upgrading unit.

2.3 Hydrogen

Hydrogen is zero-carbon at point of use, potentially being a key enabler of the low carbon transformation as a chemical feedstock, fuel, and energy carrier in numerous sectors. However, hydrogen can be produced through different pathways and from different feedstocks, impacting its production greenhouse gas emissions footprint. Hydrogen is a storable energy source that can balance fluctuating demand and provide inter-seasonal storage, while having a prospective large-scale availability and a wide range of applications.

Green hydrogen is a renewable gas produced from renewable resources such as solar PV, wind, or hydropower. This report focuses on the most mature green hydrogen production route, the electrolysis of water. During this process, electricity is used to split water into hydrogen and oxygen. The production pathway of green hydrogen consists of the process steps shown in Figure 5.

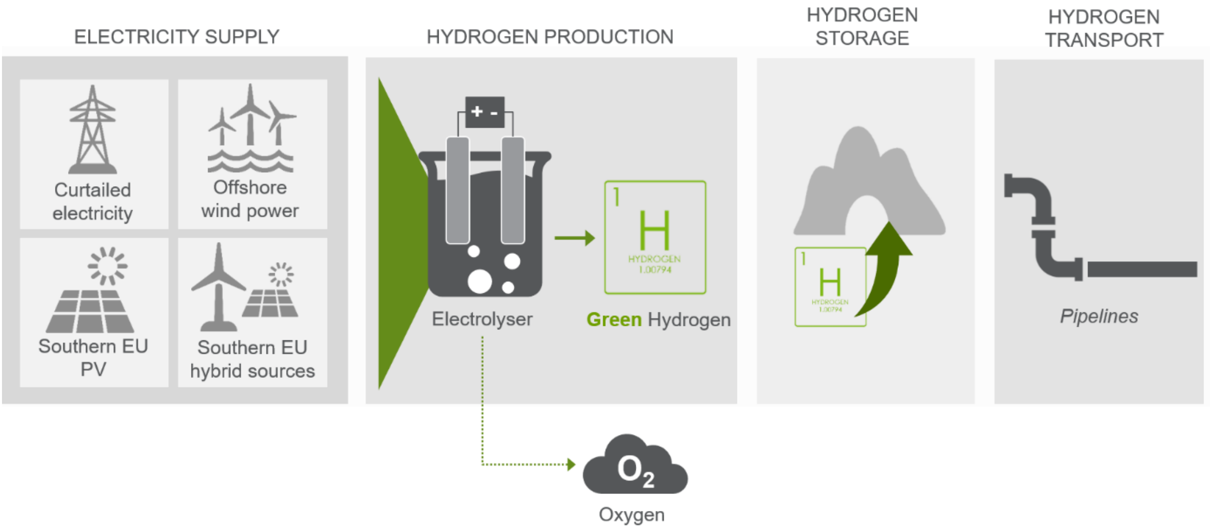

Figure 5. Production pathway for green hydrogen produced through electrolysis

1. **Electricity supply.** Feedstock for production of green hydrogen is electricity produced from renewable electricity.
2. **Hydrogen production.** Green hydrogen is produced through the electrolysis of water, through one of three technologies: alkaline electrolysers (ALK), proton exchange membrane, or solid oxide electrolysis cell. Each technology offers different benefits, levels of maturity, and costs.
3. **Hydrogen storage.** Depending on the intended application, cost, and volume, hydrogen can be processed and subsequently stored using a variety of methods. Compression, liquefaction, adsorption into a variety of materials or carriers, or conversion into a more complex chemical are all available options for hydrogen storage. Smaller hydrogen volumes (for example, for intraday storage) are typically stored in pressurized tanks. Metal hydrates or liquid organic hydrogen carriers represent a possible cost-competitive storage option. For large-scale hydrogen storage, underground salt caverns are typically considered, although other geological formations and used gas fields are also under investigation for this purpose.
4. **Hydrogen transport.** In large volumes, hydrogen can be most cost- and energy-efficiently transmitted via pipelines. Local distribution pipeline networks can then serve to deliver hydrogen to end-users. Hydrogen can be blended with natural gas in existing gas grids up to certain thresholds which may vary from 2% up to 20% depending on customer sensitivities, the need for compression in a system, etc. Existing natural gas grids may be converted to 100% hydrogen, which will in most cases require certain modifications such as change or retrofit of compressors and gas metering stations.

3. EMPLOYMENT IMPACT ANALYSIS

We estimate EU employment impacts of renewable gas deployment using a spreadsheet-based economic model developed by Navigant (Box 2). The model derives estimates of employment linked to the “optimised gas” scenario from the latest Gas for Climate study based on investments in renewable gas across the different sectors of the economy in 2050. The model covers both biomethane and hydrogen deployment. Because we focused on the renewable gas supply chains only, the model does not estimate the net employment effects across the overall energy system. As we focus on the supply side only, more job opportunities might be created on the demand side, for example, related to the refurbishment of buildings to enable the use of renewable gases.

Box 2. Spreadsheet-based economic model

Based on data on future generation of renewable gas from the scenario, we define the level of expenditures (costs) related to the installation of new required capacity and the operation and maintenance of existing and new required capacity through each sector through the overall gas production pathways. The analysis is based on capital investment (CAPEX), operation and maintenance costs (OPEX), and feedstock costs (Feedstock EX) data inputs for each technology and their split in the respective production pathways steps. The CAPEX used in the analysis is annualised over the lifetime of the project. As such, employment results represent the annual average number of jobs related to the deployment of renewable gases.

The input-output spreadsheet-based model then calculates direct job impacts in each sector related to the level of expenditures based on the share of expenditures allocated to employee compensation (salaries) and the average annual wage for each sector. Indirect impacts are derived in the same way using the input-output interactions between each sectors of the economy. The methodology is described in more detail in Appendix A.

The following sections described the expected employment impacts related to deployment of each of the three renewables gas supply chains. The assessment is based on the quantitative analysis and on qualitative elements derived from the literature review and stakeholder interviews.

3.1 Anaerobic digestion

Production of 660 TWh of biomethane through anaerobic digestion comes with positive employment effects throughout the production pathway. We estimate that its deployment (as presented in the “optimised gas” scenario in the Gas for Climate study) could create **200,000–275,000 local and high skilled direct jobs and another 300,000–400,000 indirect jobs by 2050** (Figure 6). This amounts to an employment factor, or the number of jobs per unit of energy produced, of about 775–1,050 jobs/TWh.[17]

About one-third of the jobs result from the development of anaerobic digestion plants, mainly in two sectors: machinery and equipment and construction and construction works. Two-thirds of the jobs are related to the facility’s ongoing operations, including running the plant and the sourcing of the required biomass in the agriculture sector.

As biomethane production through anaerobic digestion is primarily small scale and has a more decentral production setup based on agricultural residues, its deployment is expected to bring new local employment benefits to rural regions across whole of the EU.

The sequential cropping schemes that need to be initiated on farms to produce additional biomass will also create more stable jobs in the agricultural sector. Especially during the sowing, managing, and harvesting of the sequential crop, extra workforce is needed with respect to the historical production mode. Consorzio Italiano Biogas, which already works with farmers using the Biogasdoneright-concept (see Box 1), estimates that sequential cropping can boost employment by stabilizing the created additional jobs in a long-term vision.

[17] The employment factor has been compared with the insights from the *“Biogas 2020 – 25.000 green jobs per l’agricolture italiana*” report from Consorzio Italiano Biogas. The findings from both analyses are in line with each other.

As the production of biogas will mostly take place on the farm's site, positive employment effects are also expected in the agricultural sector related to biomass collection, storage, pre-processing, transport, and digestate treatment and application at a local level.

Large numbers of additional biogas production facilities will be needed, increasing opportunities related to manufacturing and construction of the infrastructure with high skilled employment opportunities in technology synthesis, biomethane and biogas plant construction, biogas pipeline construction, and liquefaction technology development. To deliver such deployment, technology providers will need to increase their related R&D capabilities, resulting in new high skilled employment opportunities across the region. Operational jobs will also be created to run and maintain new and upgraded biogas digesters.

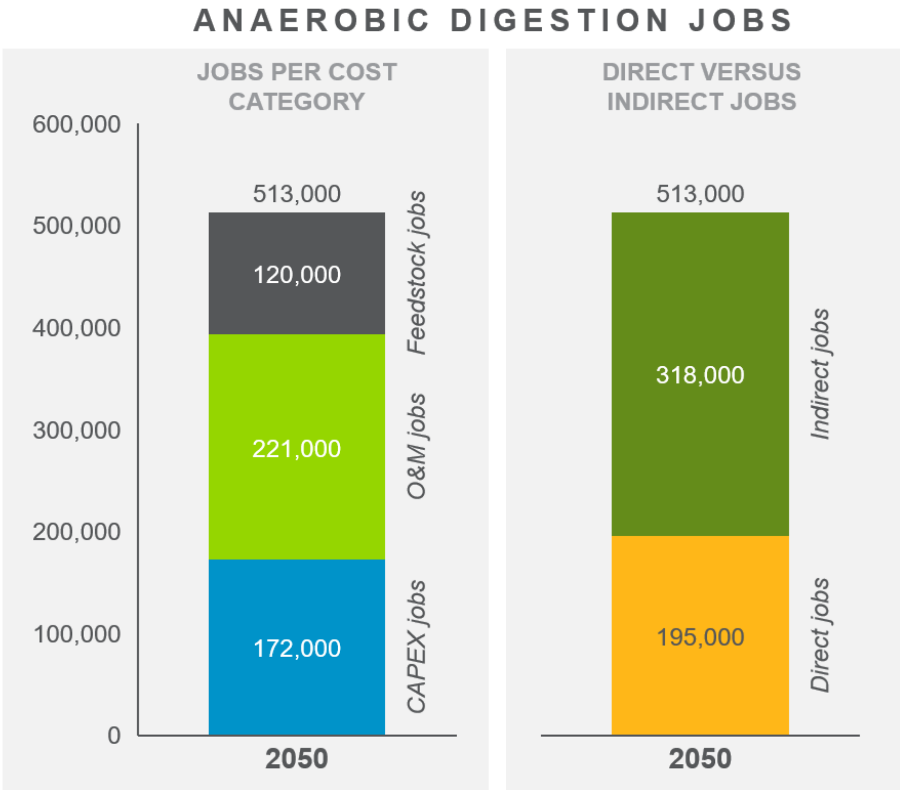

Figure 6. Anaerobic digestion jobs per cost category (left) and direct vs. indirect (right)

3.2 Thermal gasification

In comparison to anaerobic digestion, biogas production through thermal gasification focuses on large scale and more central production of biomethane from woody biomass. We expect that the deployment of thermal gasification will lead to employment benefits in local but more centralised production facilities and in the forestry sectors where the wood and forestry residues need to be collected.[18] We estimate that the production of 350 TWh of biomethane through thermal gasification (as presented in the "optimised gas" scenario in the Gas for Climate study) could create **100,000–150,000 high skilled direct jobs and another 150,000–200,000 indirect jobs by 2050** (Figure 7). For biomethane production through thermal gasification, the job creating capacity is around 700–925 jobs/TWh.

[18] Part of the feedstock will also come from the waste disposal sector. However, since the potential for forestry residues is much higher, we focus on employment in the forestry sector.

Labour intensity of the pre-processing is highly dependent on the type of feedstock. If the biomass only needs to be dried (in the case of waste wood), this process can be completely automated, with only one or two controllers monitoring the process and troubleshooting onsite if necessary. However, residual and post-consumer waste needs a more extensive pre-treatment and requires more workforce.

Compared to anaerobic digestion, thermal gasification is a more extensive process where the gas goes through several production steps. This positively influences the amount of construction and engineering work needed to build a thermal gasification plant. The central production requires a bigger plant compared to the decentralised onsite production of biomethane in anaerobic digestion, resulting in more engineering jobs. Because of the larger scale of production, the employment related to feedstock collection is more prominent and covers over one-third of the estimated employment effect.

Thermal gasification currently faces challenges around syngas cleaning and the integration of gasification with the subsequent methanation step; R&D efforts are required to facilitate the scale-up of gasifiers in Europe. These efforts would result in more employment opportunities in the sector.

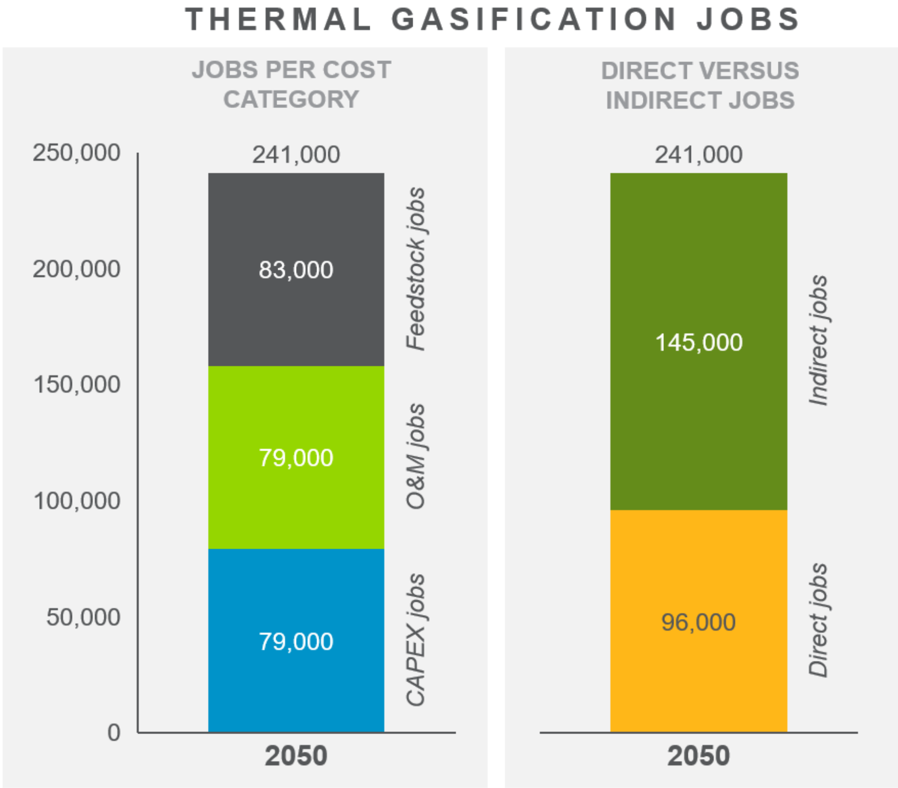

Figure 7. Thermal gasification jobs per cost category (left) and direct vs. indirect (right)

3.3 Hydrogen

The recent Gas for Climate study sketches a hydrogen scale-up pathway to 2060. In the short term, increased quantities of blue hydrogen (hydrogen produced from natural gas in combination with CCS) are expected, primarily to replace grey hydrogen in existing hydrogen applications. This transition requires the retrofit of existing steam methane reforming plants with CCS units, resulting in new employment opportunities because of R&D and technical implementation. In parallel to the growth of blue hydrogen production capacity, we expect large-scale demonstration projects for green hydrogen (hydrogen produced from renewable electricity in electrolysers). After 2030, an increasing market share of green hydrogen is expected, eventually replacing existing blue hydrogen capacity in the long term. In 2050, all hydrogen could be renewable, although it is likely that a fully renewable gas supply can only be reached by 2060. The employment analysis only focuses on green hydrogen.

Employment benefits shift increasingly from jobs related to R&D towards jobs related to the construction and operation of green hydrogen production plants and the required infrastructure for hydrogen. Employment benefits will mainly occur in the construction and industry sectors, related to the construction of the plant, the production of the necessary equipment, and the operation of the plant. We estimate that the production of 1,710 TWh of hydrogen through electrolysis (as presented in the “optimised gas” scenario in the Gas for Climate study) could create **300,000–450,000 high skilled direct jobs and another 650,000–900,000 indirect jobs** (Figure 8). Compared to biomethane production through anaerobic digestion and thermal gasification, the employment factor of around 575–775 jobs/TWh for hydrogen is lower. This is because of the large share of electricity costs, which is predominantly related to capital investment.

Where biomethane production involves the biological (digestion) and thermal (gasification) reactions, production of green hydrogen occurs to electrolysis. As a result, the employment effects of green hydrogen are different from those of biomethane production. Where biomethane production results in new rural jobs in the agricultural and forestry sectors, almost two-thirds of the jobs from hydrogen production comes from production of renewable electricity it requires as feedstock energy. A major part of these jobs will be related to the construction of renewable electricity and to some extent will be related to the operation of the plants.

For hydrogen production, it is expected that the employment benefits related to the operation of production facilities (both electricity production facilities and hydrogen production facilities) will be less compared to the employment benefits related to the feedstock collection and plant operation for biomethane production. Because of the large capital investment in hydrogen production—both related to the electrolysers and to the renewable electricity generation—jobs will be more temporary in nature and concentrated during the engineering and construction phase. In contrast, deployment of biomethane production will result in more stable jobs, more evenly spread over the operation duration of the plant.

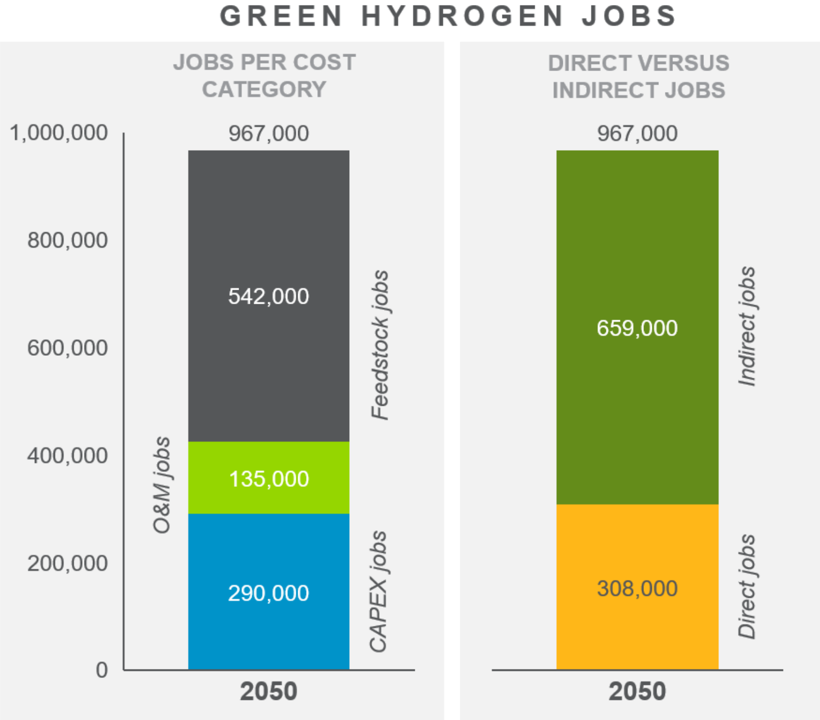

Figure 8. Green hydrogen jobs per cost category (left) and direct vs. indirect (right)

4. CROSS SUPPLY CHAINS CONCLUSION AND RECOMMENDATIONS

As described in the Gas for Climate “optimised gas” scenario, scaling up renewable gases to 2,880 TWh by 2050[19] combined with large quantities of renewable electricity enables achieving a climate-neutral EU energy system. This renewable energy system has significant benefits in creating employment opportunities, including new jobs in rural areas where often employment opportunities are scarce and high skilled technical jobs related to the manufacturing, installation, and operation of the plants. The analysis in this report shows that such scale-up of renewable gas can create 600,000–850,000 additional direct jobs, and another 1.1–1.5 million indirect jobs in the EU by 2050.

The results of the analysis suggest the following potential direct employment opportunities in some of the key economic sectors:

- 150,000–225,000 jobs in renewable electricity generation for hydrogen production[20] and another 50,000–75,000 jobs in the energy sector[21]
- 100,000–150,000 jobs in agriculture and forestry,[22] among others to provide the feedstock to biomethane production facilities
- 200,000–300,000 industrial jobs[23] related to the development and operations of digesters, thermal gasification plants, and electrolysers

The deployment of renewable gases also brings new jobs in the construction sectors, technical and non-technical services, and in operations and maintenance sectors.

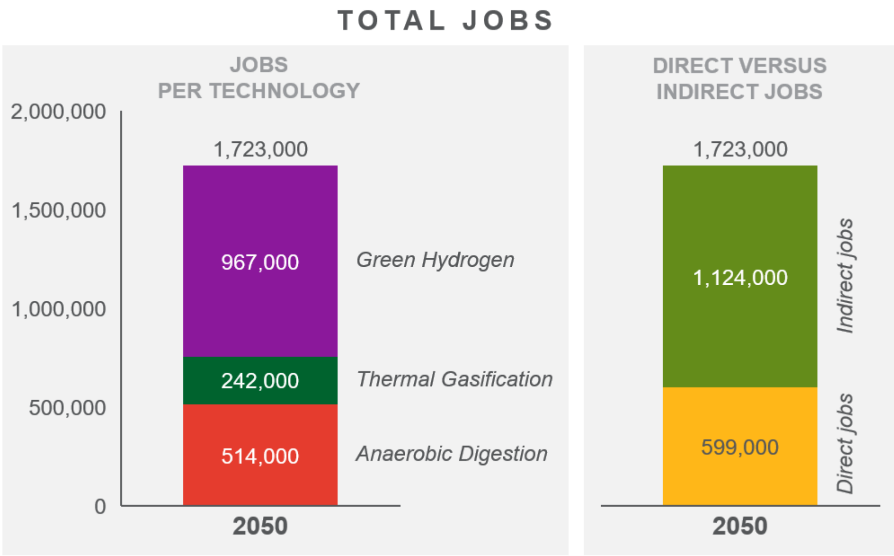

Figure 9. Jobs per technology (left) and direct vs. indirect (right)

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[19] From which 660 TWh biomethane from anaerobic digestion, 350 TWh biomethane through thermal gasification, 1710 TWh hydrogen, and 160 TWh methane from power-to-methane. In this report we focus on biomethane and hydrogen production.

[20] Direct jobs related to the electricity needed for hydrogen production.

[21] Direct jobs for the anaerobic digestion, thermal gasification and green hydrogen production pathways within the energy costs and O&M energy services sectors.

[22] Direct jobs for the anaerobic digestion and thermal gasification pathways within the agriculture and forestry sectors.

[23] Direct jobs for the anaerobic digestion, thermal gasification, and green hydrogen production pathways within the machinery and equipment, pipeline equipment, electrical equipment, and other technical services sectors.

The employment factor (the number of jobs created per unit of energy produced) for biomethane production through anaerobic digestions and thermal gasification in 2050 is around 700–1,050 jobs/TWh. Most of those jobs are expected to be highly qualified jobs, requiring high engineering and technical capabilities. About two-thirds of the jobs are related to operation and maintenance of the plants, creating long-term employment opportunities.

In our analysis, the employment factor for biomethane production is in line or higher than in some studies covering current biomethane production in the EU. The biomethane-related job market is shrinking because of low investments in new capacity.[24] That means that current employment factors do not reflect opportunities related to capital investments, which represents about one-third of the jobs in our results. The difference of employment factors might also be explained by differences in the scenario assumptions regarding the scope of the value chain and related costs, the share of imports expected in the future value chain, and the average wage. An overview of recent employment factors for various geographies and technologies is available in a Rutovitz report on global energy sector jobs.[25] In the Rutovitz report, jobs are expressed in jobs per MW, but those correspond to 200-300 jobs/TWh for onshore and offshore wind and up to 1000 jobs/TWh for solar PV.[26]

For hydrogen, the employment factor resulting of our analysis is lower than for biomethane, with about 575–775 jobs/TWh. Most of those jobs are expected to be highly qualified jobs, requiring high engineering and technical capabilities. Capital investment is more prominent in the hydrogen value chain based on higher investment needs for electrolysers and renewable electricity generation, resulting in more jobs related to the development of the plants, but likely less long-term employment opportunities.

There are few studies to compare the results of our analysis to in the hydrogen production sector. A recent study by Hydrogen Europe[27] highlights a large opportunity for new jobs in the sector by 2050 based on an “ambitious scenario.” The resulting number of jobs in that analysis is significantly larger than the Gas for Climate report because of the difference of scope (considering opportunities from the overall value chain—including all end-use related developments—and from export-related revenues).

The employment effects are analysed by breaking down the investments and expenditures in specific steps of production pathways for green hydrogen, biomethane from anaerobic digestion, and biomethane from thermal gasification. The picture that emerges is that the largest direct employment effect is achieved through investments in machinery and equipment related to digesters, gasifiers, and electrolysers. Employment in the operation and maintenance sector is also important in all production pathways. For biomethane, the production, harvesting, processing, and transport of agricultural and woody biomass is relevant in creating jobs.

A large scale-up of renewable and low carbon gas production requires further R&D efforts in various areas, leading to new research jobs:

- R&D in agriculture to further expand sequential cropping
- R&D in anaerobic digestion plants and thermal gasification plants to boost efficiency and drive cost reductions
- R&D in electrolysers boost efficiency and drive cost reductions

The March 2019 Gas for Climate study showed that biomethane and hydrogen transported through existing gas infrastructure have a valuable role in achieving climate neutrality by mid-century. In assessing the future role for renewable gas, it is also relevant to consider the potential for job creation. Investments in renewable energy creates opportunities for new local and high skilled jobs. This notion can foster societal support for deep decarbonisation. The development of renewable gas production technologies within Europe also enables the export of knowledge and technologies, which boosts employment even further.

[24] See for example: https://www.eurobserv-er.org/category/all-annual-overview-barometers/; http://atee.fr/sites/default/files/2014-0619_etude_emploi_rapport_clubbiogaz_0.pdf; https://www.ifri.org/sites/default/files/atoms/files/mathieu_eyl-mazzega_biomethane_2019.pdf;

[25] Rutovitz, J., Dominish, E., & Downes, J. (2015). Calculating global energy sector jobs: 2015 Methodology Update. Prepared for Greenpeace International by the Institute for Sustainable Futures (UTS)

[26] Estimation based on technical life time of 25 years and full load hours for solar PV (1100 h), onshore wind (3000 h) and offshore wind (4500 h)

[27] https://www.hydrogeneurope.eu/news/hydrogen-roadmap-europe-has-been-published

APPENDIX A. METHODOLOGY

We estimate domestic employment impacts of renewable gas deployment using a spreadsheet-based input-output model developed by Navigant based on recognised literature sources.[28] The model derives estimates of employment linked to the "optimised gas" scenario from the Gas for Climate study based on investments in renewable gas across the different sectors of the economy in 2050. The model covers both biomethane and hydrogen deployment. Because we focused on the renewable gas supply chains only, the model does not estimate the net employment effects across the overall energy system. As we focus on the supply side only, more job opportunities might be created on the demand side, for example, related to the refurbishment of buildings to enable the use of renewable gases.

Based on data on future generation of renewable gas from the scenario, we define the level of expenditures (costs) related to the installation of new required capacity and the operation and maintenance of existing and new required capacity through each sector through the overall gas production pathways. The analysis is based on capital investment (CAPEX), operation and maintenance costs (OPEX), and feedstock supply costs (Feedstock EX) data inputs for each technology and their split in the respective production pathways steps. The CAPEX used in the analysis is annualised over the lifetime of the project. Employment results represent the annual average number of jobs related to the deployment of renewable gases.

The input-output spreadsheet model then calculates direct and indirect job creation.

- Direct jobs are calculated in each sector based on the level of expenditures allocated to each sector multiplied by the employment factor of the sector (jobs/€ invested). The employment factor is defined using the share of expenditures allocated to employee compensation (salaries) and the average annual EU-wide wage for the sector.
- Indirect impacts are derived in the same way using the input-output interactions between each sectors of the economy.

The required parameters for this analysis are determined as follows:

- Expenditures for each technology are determined based on insights from the Gas for Climate study and its underlying analysis. In addition, further assumptions on the distribution of cost over the various steps in the production pathway are made based on expert insights, validated in interviews. The assumptions are provided in Appendix B. Average shares of the expenditures allocated to employee compensation per sector is determined using the symmetric input-output table from Eurostat for 2017,[29] using the total expenditures in the sector and the employee compensation in the sector.
- Average wages per sector are obtained from labour costs statistics from Eurostat for 2018.[30]
- FTEs/€ invested in a sector are subsequently determined using the average shares of the expenditures allocated to employee compensation and average wages per sector.
- Direct jobs are calculated using the FTEs/€ invested and the investment in a certain sector.
- Indirect jobs are determined using the symmetric input-output table to determine the indirect expenditure as result of expenditures in a certain sector. This indirect expenditure describes which amount of the initial expenditure is reinvested in another sector. Based on this indirect expenditure, the indirect employment is calculated using the same approach as the direct

[28] Here are some recent examples of studies using the same approach:
https://www.plan.be/admin/uploaded/201702231020450.CBA_2017.pdf
http://www.ukerc.ac.uk/asset/0A611DB6-DCEA-4628-97FC16042EAD4F20/
https://climateactiontracker.org/documents/401/CAT_2018-11-27_ScalingUp_MethodologicalAnnex.pdf .
Also see this paper highlighting the various possible approaches to assess regional economic impact of renewable energy sources development: https://www.sciencedirect.com/science/article/pii/S1364032118303447

[29] Eurostat, 2019. Available at:http://appsso.eurostat.ec.europa.eu/nui/show.do?wai=true&dataset=naio_10_cp1700.

[30] Eurostat, 2019. Available at: https://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=lc_lci_lev&lang=en

employment based on direct expenditure. For example, for every €1 million spent in the machinery and equipment sector, over €200 thousand is indirectly going to the basic metals and fabricated metal products sectors. Based on the FTEs/€ invested factor (calculated as explained above) we know that the 1 million spend in the machinery and equipment sector will result in an indirect employment effect of 1.9 FTE in the basic metals and fabricated metal products sector.

- The ranges in the report are based on sensitivity analyses on the averages wages in different sectors (for the lower bound value we assume the average wage in Germany, France, and Italy instead of the average wage in Europe to reflect potential higher wages, resulting in lower employment effects) and a higher import share for materials across the value chains (for the lower bound value we assume a 20% import share, resulting in lower employment effects).

APPENDIX B. SCENARIO AND EMPLOYMENT PARAMETERS

This report is based on the "optimised gas" scenario from the latest Gas for Climate study.[31] The scenario parameters used in this employment estimation are summarized in Table B-1.

Table B-1. Scenario parameters on renewable gas production in 2050 from "optimised gas" scenario in the latest Gas for Climate (2019) study

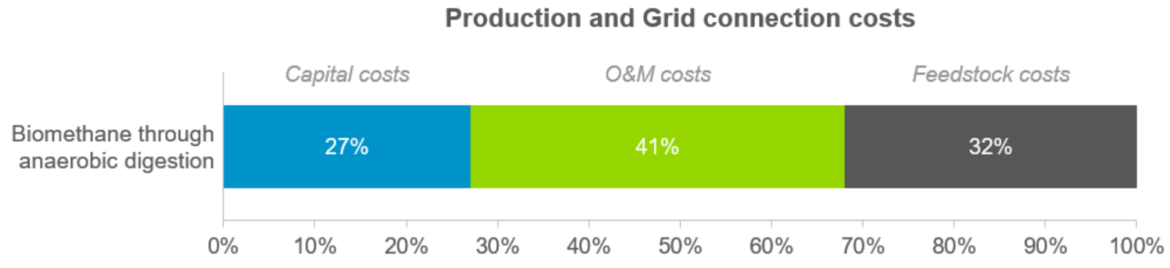
Parameter	Value	Unit	Notes
Biomethane	1,010	TWh	
From which: Biomethane through anaerobic digestion	660 63	TWh bcm	
From which: Biomethane through thermal gasification	350 33	TWh bcm	
Hydrogen	1,710	TWh	

Table B-2. Scenario parameters on renewable gas production costs in 2050 from "optimised gas" scenario in the latest Gas for Climate (2019) study

Parameter	Value	Unit	Notes
Biomethane through anaerobic digestion	62	euro/MWh	Including grid connection costs
Biomethane through thermal gasification	49	euro/MWh	Including grid connection costs
Hydrogen	53	euro/MWh	Including grid connection costs

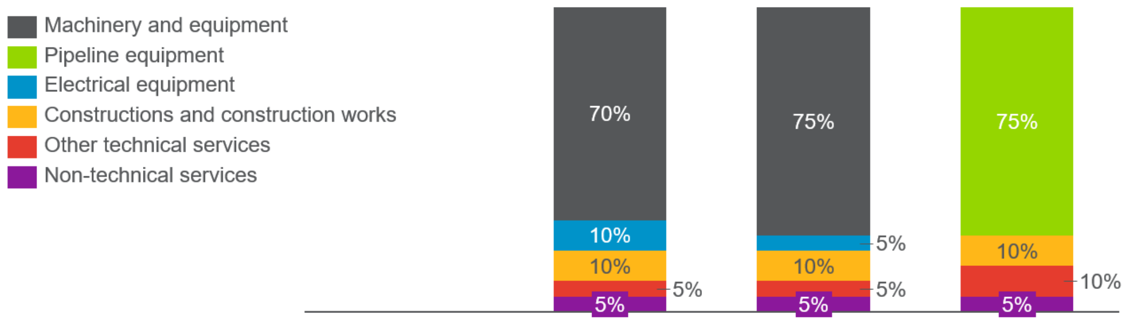
[31] Navigant, 2019. *Gas for Climate. The optimal role for gas in a net-zero emissions energy system*. Available at: https://www.gasforclimate2050.eu.

B.1 Anaerobic digestion production pathway assumptions



Capital expenditure

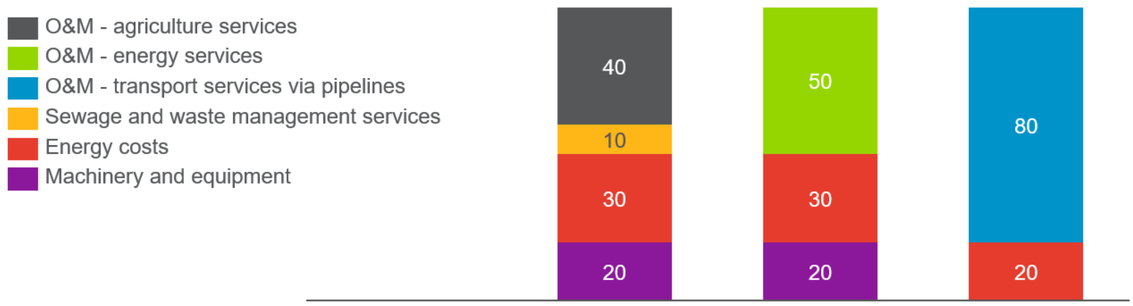
Anaerobic Digestion	Biomass/ feedstocks	Biogas production (plant)	Biogas upgrading + compression	Grid connection (pipeline)
CAPEX = €17 / MWh	-	70%	25%	5%



Imported share in materials	-	0%	0%	0%
Imported share in services	-	0%	0%	0%

Operational expenditure

Anaerobic Digestion	Biomass/ feedstocks	Biogas production (plant)	Biogas upgrading/ compression	Grid connection (pipeline)
OPEX = €25 / MWh	-	80%	10%	10%



Imported share in material/energy	-	0%	0%	0%
Imported share in services	-	0%	0%	0%

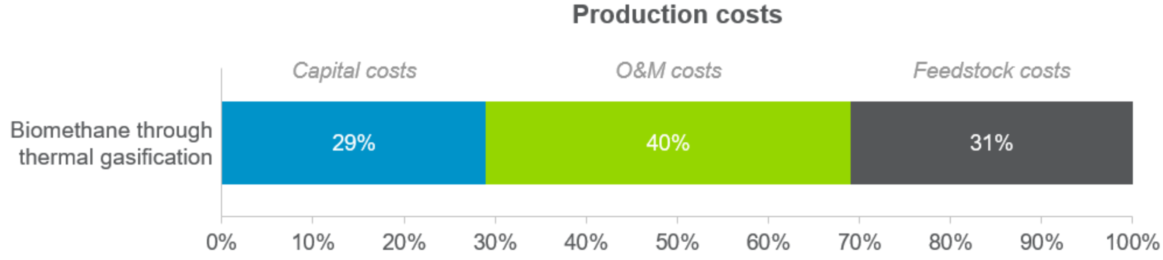
Feedstock expenditure

Anaerobic Digestion	Biomass / feedstocks	Biogas production (plant)	Biogas upgrading / compression	Grid connection (pipeline)
Feedstock EX = €20 / MWh	100%	-	-	-

Imported share in energy	0%	-	-	-
Imported share in services	0%	-	-	-

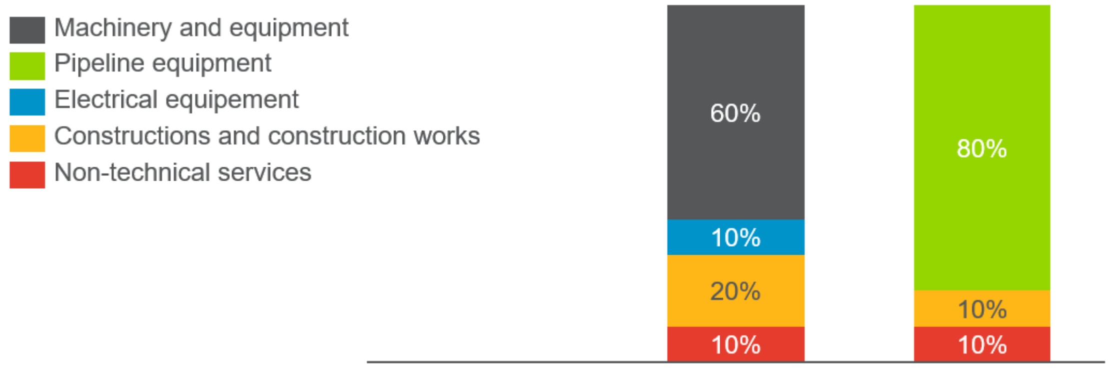
B.2 Thermal gasification production pathway assumptions

Total production costs



Capital expenditure

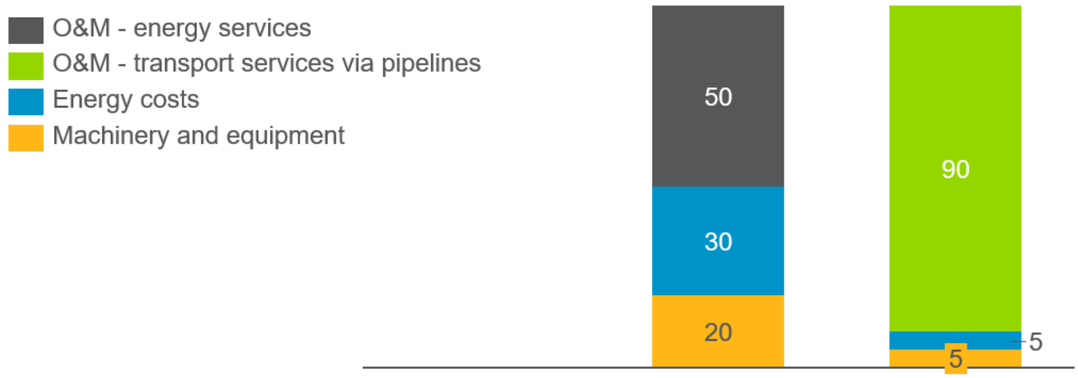
Thermal Gasification 2050	Biomass / feedstocks	Biomethane production	Grid connection
CAPEX = €14 / MWh	-	95%	5%



Imported share in materials	-	0%	0%
Imported share in services	-	0%	0%

Operational expenditure

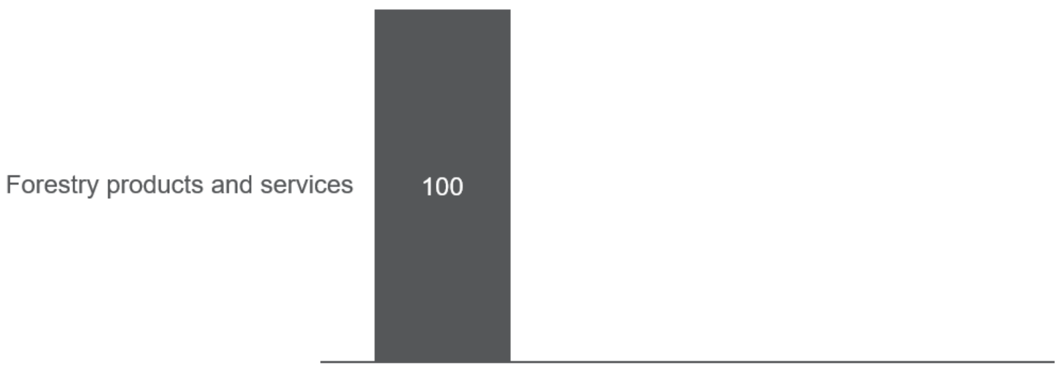
Thermal Gasification 2050	Biomass / feedstocks	Biomethane production	Grid connection
OPEX = €19 / MWh	-	95%	5%



Imported share in energy	-	0%	0%
Imported share in services	-	0%	0%

Feedstock expenditure

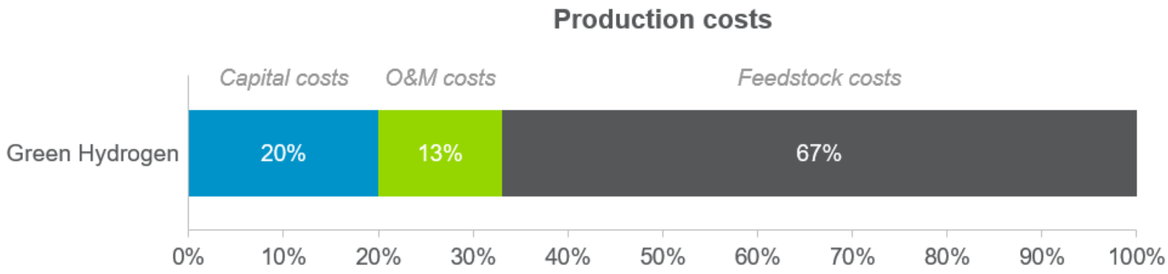
Thermal Gasification 2050	Biomass / feedstocks	Biogas production (plant)	Grid connection (pipeline)
Feedstock EX = €15 / MWh	100%	-	-



Imported share in energy	0%	-	-
Imported share in services	0%	-	-

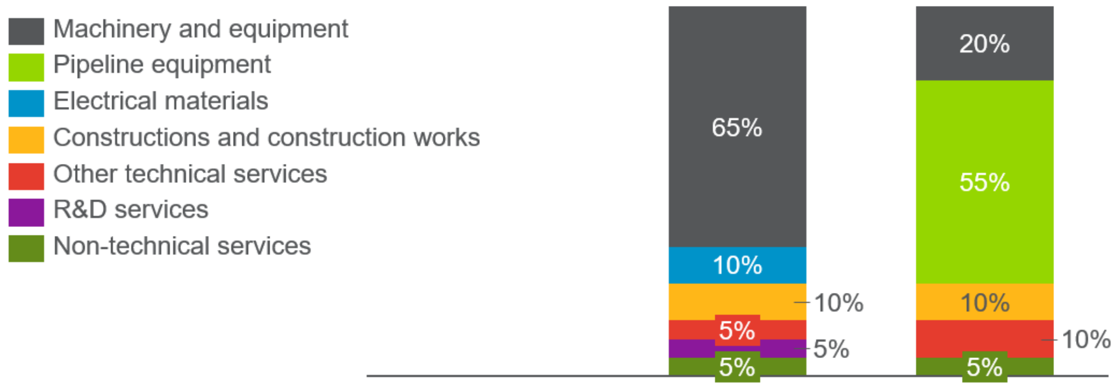
B.3 Hydrogen production pathway assumptions

Total production costs



Capital expenditure

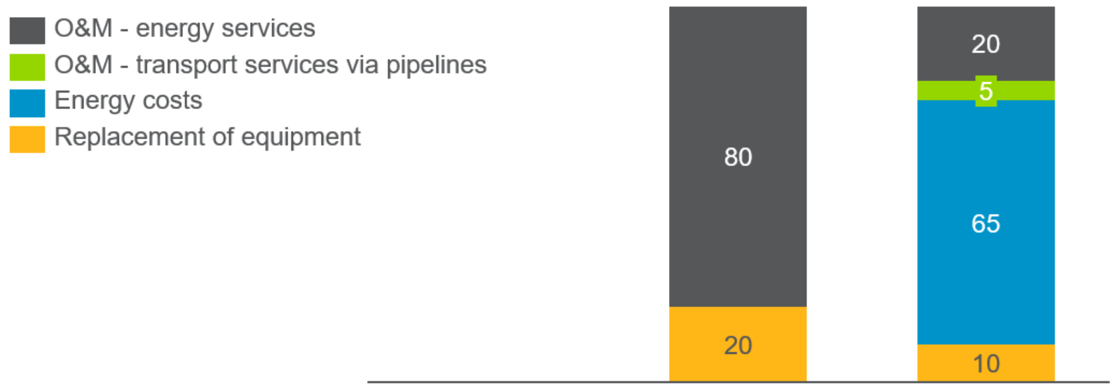
Green Hydrogen 2050	Electricity production	Hydrogen production	Transmission
CAPEX = €11 / MWh	-	88%	12%



Imported share in energy	-	0%	0%
Imported share in services	-	0%	0%

Operational expenditure

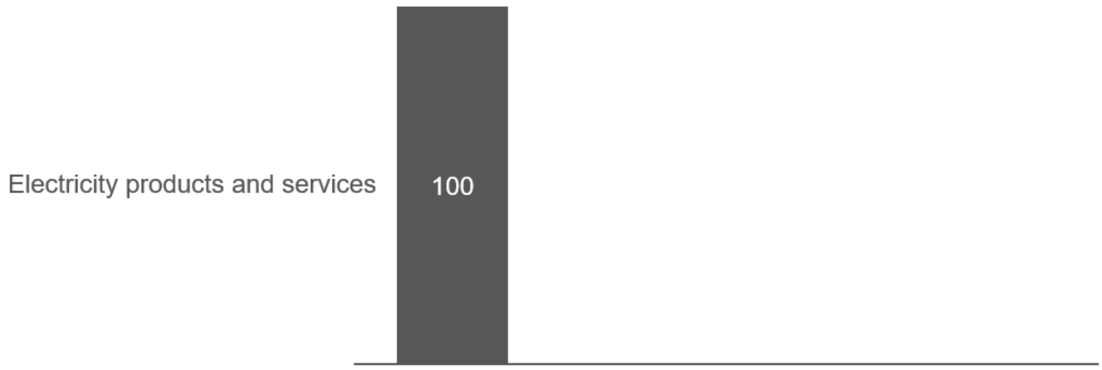
Green Hydrogen 2050	Electricity production	Hydrogen production	Grid connection (pipeline)
OPEX = €7 / MWh	-	62%	38%



Imported share in energy	-	0%	0%
Imported share in services	-	0%	0%

Feedstock expenditure

Green Hydrogen 2050	Electricity production	Hydrogen production	Grid connection (pipeline)
Feedstock EX = €36 / MWh	100%	-	-



Imported share in energy	0%	-	-
Imported share in services	0%	-	-