Geographical analysis of biomethane potential and costs in Europe in 2050

Biomethane: potential and cost in 2050

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Executive summary

Green gases have a key role in the energy mix for the energy transition

It is generally acknowledged that the energy transition requires green gases, and particularly biomethane, in order to decarbonize all sectors.

Biomethane is obtained by upgrading biogas produced by transforming biomass such as agricultural residues, biowaste or forest wood through anaerobic digestion or pyrogasification processes. This raises the question of availability of adequate biomass in the long run.

Another important aspect for biomethane is whether it will become economic to replace natural gas for decarbonized uses. With current LCOE of biomethane around 90 €/MWh in Europe, this raises the question of how production costs could decrease in the long run.

Spatial distribution of biomethane potential and costs in 2050

The study provides a geographical view on the potential of biomethane production and costs at the 2050 horizon, in the EU and 10 neighbouring countries. Biomethane production units located near existing gas networks collect the biomass resources available locally to produce biomethane. The cost of the value chains is then estimated. For each European region (NUTS-1), this information is aggregated in a supply curve, summarizing the regional potential for biomethane and the associated cost curve.

Europe and neighbouring countries have a large potential of biomass available for producing biomethane

The study shows that biomass is largely available in some countries such as France, Germany or Spain. Outside the EU, Turkey has a large potential as well. Although there are uncertainties, the potential of biomass available in 2050 in EU27+10 could allow to produce over 1700 TWh_{HHV} of biomethane. The study shows that the among all the biomass available, intermediate energy crops, if developed, could provide a large share, around 26% of the total. The study also shows that the use of wood from forest growth could boost the potential in 2050.

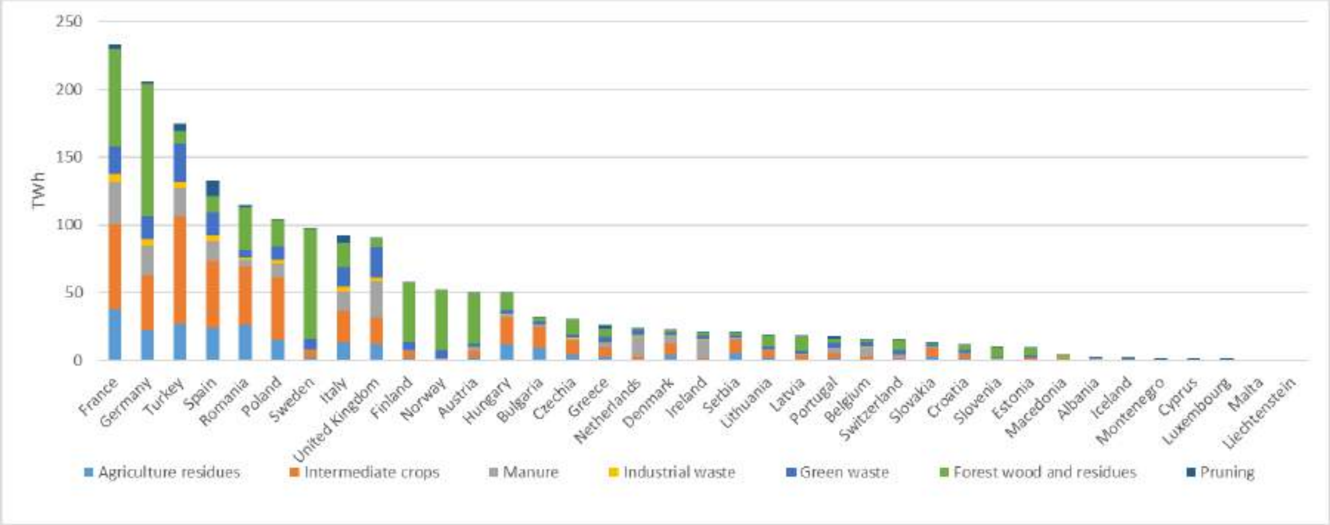

Figure 1: Biomethane potential 1G+2G per country in 2050 [TWh]

The cost of 1G biomethane could decrease below 70 €$_{2019}$/MWh$_{HHV}$ in average in 2050

The study shows that the cost of 1G biomethane injected into networks could be below 70 €$_{2019}$/MWh$_{HHV}$ in average in 2050, with 60% of the identified potential having a lower cost. This is obtained through a detailed modeling of the value chain to produce biomethane, from feedstock available locally to the injection into networks, through production units. Attaining such figures will require significant cost reduction in digesters. In particular, increases in the average size of digesters compared to today are a key element for the decrease of costs for 1G biomethane.

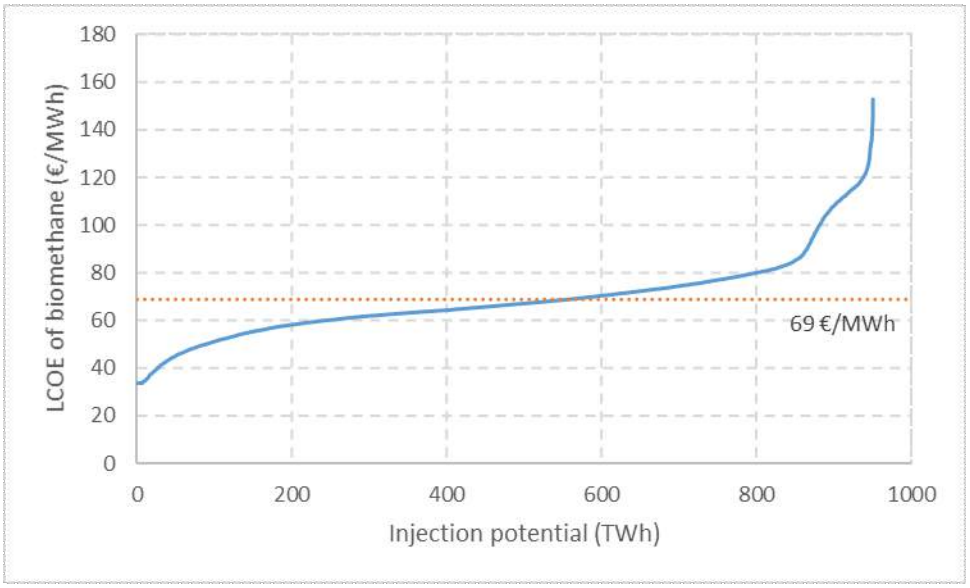

Figure 2:LCOE of 1G biomethane injected into gas networks for EU27+10 in 2050

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Introduction

Green gases to support the energy transition

If Europe wants to adhere to its commitment of limiting global warming to an increase of two degrees, the power sector will have to evolve almost zero carbon emissions in 2050. This entails a very large share of renewables in the electricity mix. At the same time, renewable technologies have seen sharp reductions in their cost and future cost reductions are expected. This makes a future with 100% or almost 100% renewable electricity an increasingly realistic prospect.

Nevertheless, some sectors such as industries requiring high-temperature heat or aviation cannot be electrified. Moreover, the power system requires flexibility, which can be provided by gas-fired power plants. For these uses, the pathway to decarbonization relies on green gases (biogas, synthetic gas, hydrogen). Many recent studies (CEER, Gas for Climate, ADEME, …) highlight that a decarbonized gas system should support the decarbonization of the economy.

A share of these uses could be fulfilled by biomethane, (IEA, 2020) has estimated that the sustainable worldwide feedstock potential for biogas and biomethane production could cover around 20% of today's gas demand. Moreover, in term of GHG emissions, the use of biomethane would allow to avoid around 1000 Mt of GHG emissions[1] in 2040.

The production of biomethane depends on the availability of feedstock such as agriculture residues, manure. The amount of biomethane that can be produced within Europe, and at which cost, is at the core of the present study.

Estimating the potential and cost of biomethane within Europe

The objective of this report is to study the geographical distribution of the potential and the costs of biomethane in Europe (EU-27 + 10[2]) in 2050.

A geographical assessment of the biogas potential is first done based on the estimation of the availability of different feedstock which can be used and on different assumptions such as competitive uses or mobilization factors. Maps with the distribution of each feedstock's potential are obtained and the results aggregated to obtain regional (NUTS-1) potentials.

Biomethane cost projections are then estimated by locating biomethane production units which can collect the feedstock around them. Depending on feedstock type and distance, the cost of producing and injecting biomethane into the grid can be computed. The biomethane production obtained with these units and the associated cost of the value chains allows to define a supply curve for each region (NUTS-1).

Structure of the report

This report is organized in 2 chapters. After introducing the context and the objectives, the evaluation of the feedstock potential in the geographical scope defined is presented in chapter 1. In chapter 2, the cost of biomethane is discussed and the hypotheses used in the study from feedstock cost to unit cost are exposed. Chapter 2 also covers the methodology for the localization of the units and provides the results of the study.

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[1] Avoided emissions include emissions generated by the use of natural gas rather biomethane and also methane emissions that would have occurred during feedstock decomposition.

[2] EU 27 + Albania, Iceland, Macedonia, Montenegro, Norway, Switzerland, Liechtenstein, Turkey, United Kingdom, Serbia

1 Geographical assessment of biomass potential

1.1 Biomethane production is part of a circular economy

Biogas production is based on the transformation of feedstock through specific technologies. It is part of a circular economy (see Figure 3) and offers the following services:

- Waste management solution
- Production of energy
- Production of digestate (fertilizer)

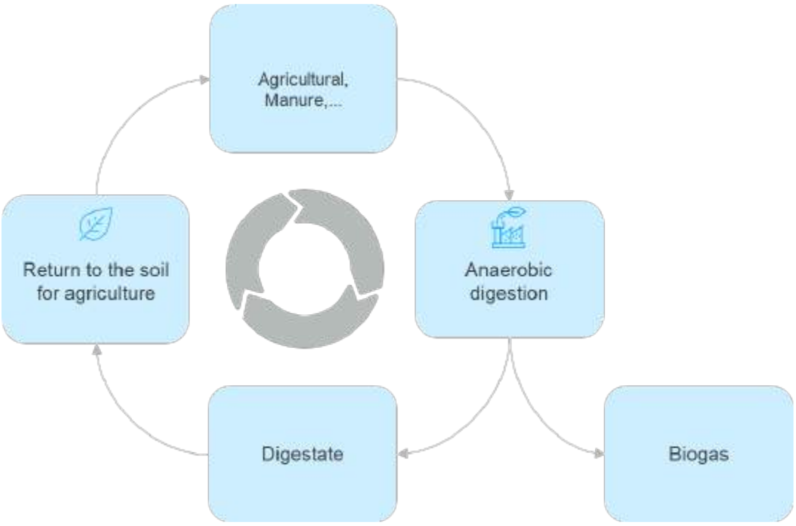

Figure 3: Illustration of biogas in circular economy with Anaerobic digestion

Figure 4 presents the biogas/biomethane production process.

A large set of feedstocks can be used to produce biogas. Following the stricter rule for being labeled sustainable, feedstocks used to produce biogas will increasingly come from residues and waste, generated by animals or humans, which are for the moment not or partially valorized. Waste are an interesting opportunity for the sector of biomethane production and have a great potential which is for now underused. (IEA, 2020) estimate that in 2018, the amount of feedstock used allow to produce only 5% of today's biomethane production potential.

The choice of the production pathway to use to produce biogas depends on the type of feedstock processed. In the report, the focus is put on two technologies: **anaerobic digestion and pyrogasification (see** Figure 3**).** Anaerobic digestion usually relies on feedstocks such as agriculture residues and pyrogasification uses woody biomass. More details are provided later on the precise list of feedstocks considered in the scope of this study.

The biogas produced from the feedstock transformation is composed of around 50 to 70% of methane, the rest being CO2 and other gases. It can be used to produce heat or electricity, or upgraded through a purification process to remove the CO2 and obtain biomethane, a gas which has similar properties to natural gas and which can be injected into existing gas grid. Other products are generated when producing biogas: digestate from anaerobic digestion and char from pyrogasification. The first one can be valorized as a fertilizer allowing to reduce the use of chemical ones. In this report, the focus is made on the production of biomethane.

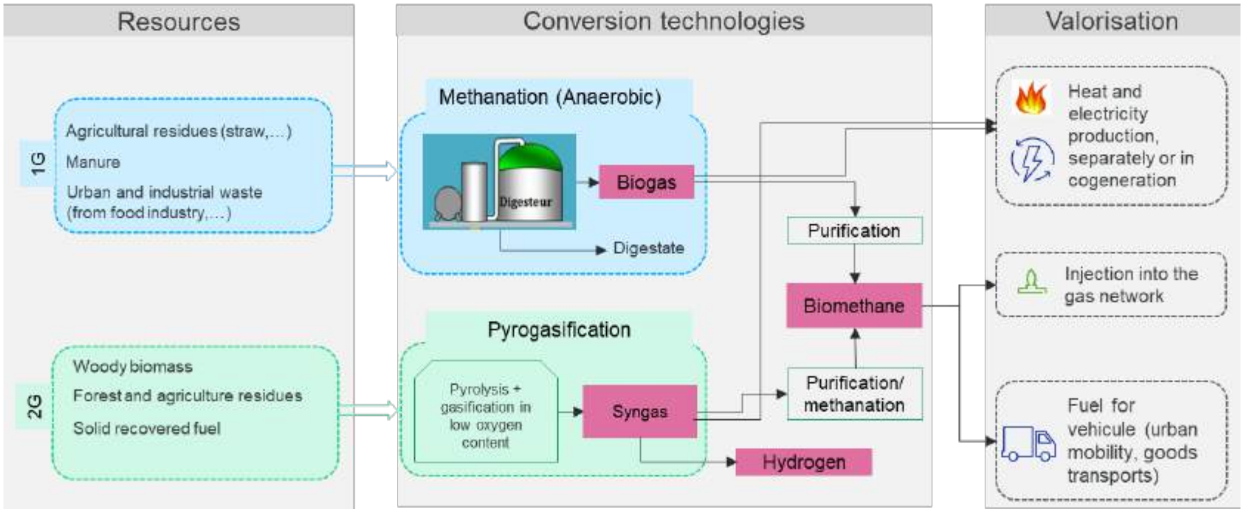

Figure 4: Conversion pathways considered in the study

Nowadays, anaerobic digestion is the process which is the more widely installed whereas pyrogasification is still in its infancy. In 2020, the European Biogas Association (European Biogas Association, 2020) has identified up to 729 biomethane plants (the number of plants producing biogas, e.g. which do not upgrade the biogas in biomethane, is much higher) in Europe[3]. Several researches and experimentation are ongoing for pyrogasification which aim to improve the process. An example of such experimentation is the Gaya project in France[4].

1.2 Biomethane production relies on various waste categories

In this report, the feedstocks considered are those used by the two aforementioned technologies. They are classified according to two categories: first generation (1G) and second generation (2G).

First generation of feedstocks contains agricultural residues, intermediate crops residues, biowaste, industrial waste, manure and green waste.

- **Agricultural residues** are cereal straw, cane and fane left after harvesting the following crops: wheat, barley, rice, rye, oat, sunflower, sugar beet, rapeseed, potato
- **Intermediate energy crops** are crops which are cultivated between two main crops as a soil management solution in order to protect the soil during winter or to avoid soil erosion.

NB: the choice has been made to exclude energy crops from the scope of the study. This practice was widely used in some countries such as Germany. The RED II directive specifies that biomass for sustainable biogas production is grown should not replace crops for human or animal food.

- **Biowaste residues** are the organic fraction of waste such as paper and cardboard wastes, household and similar wastes.
- **Industrial waste** from agroindustry are residues/by-products after processing olives and grapes, sugar beets, potatoes, fruits, citrus in oil and wine industries, sugar industries, but also residues from milk and meat industries.
- **Livestock manure** from poultry, cattle, pig, sheep and goat.
- **Green waste** are roadside vegetation residues such as grasses or leaves.

Second generation of feedstocks contains forest residues, forest wood and pruning:

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[3] 18 countries producing: Austria, Belgium, Denmark, Estonia, Finland, France, Germany, Hungary, Iceland, Ireland, Italy, Luxembourg, Netherlands, Norway, Spain, Sweden, Switzerland, United Kingdom

[4] Pyrogasification example research : https://www.grdf.fr/english/what-we-do/renewable-gases/pyro-gasification

- **Forest residues** are residues from forest harvesting operation such as thinning, cleaning or felling of forest stands.
- **Forest wood** are stemwood referring to commercial and pre-commercial thinning.
- **Pruning** of permanent crops are residues from pruning operation of permanent crops for olive plantation, vineyards and fruit and berry plantations.

1.3 Estimating the geographical distribution of biomass potential

The methodology used to assess the technical potential of the biomass which can be used to produce biomethane is inspired by the paper (N. Scarlat F. F.-F., 2019). It is determined in two stages, see Figure 5.

In a first stage, the theoretical potential of biomass is evaluated using a geographical analysis. Geographical databases on soil utilization are crossed with statistics to assess the spatial distribution of the biomass and then the theoretical potential. This potential refers to the total potential of feedstock.

In a second stage, the theoretical potential is reduced to obtained the technical potential of biomass, using assumption such as global mobilization hypothesis, competitive uses or soil protection rules. Indeed, not all the biomass can be collected or used to produce biomethane. A part of it already has an intended use: fodder and bedding for animal, remain on the soil for ecological purposes such as soil management solution (maintain the soil organic matter or protect the soil from erosion) or to provide habitat to animal (forest residues). Feedstocks exploited for biomethane production should not compete with these intended uses. In the study, the assumptions considered relies on literature review and on expert knowledge.

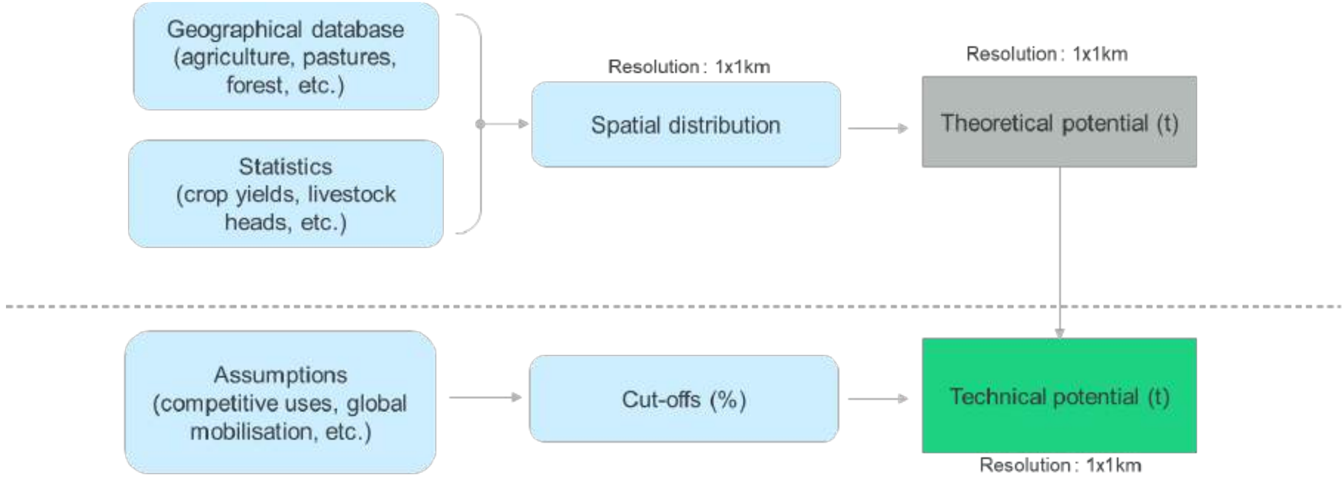

Figure 5: General methodology for spatial assessment of theoretical and technical biomass potential

More detailed descriptions of the methodology per type of biomass is given in annex 3.2.

Percentage of dry matter content and methanogenic power used in the calculation for each type of feedstock are stored in Table 1.

		Dry matter content [%][5]	Methanogenic power [m3CH4 /tDM] [6]	Methanogenic power [m3CH4 /tMB][7]
Wheat	Agriculture	0,87	221	
Barley	Agriculture	0,88	221	
Spring_Barley	Agriculture	0,88	221	
Winter_Barley	Agriculture	0,88	221	
Maize	Agriculture	0,63	243	
Rice	Agriculture	0,86	221	
Rapeseed	Agriculture	0,88	253	
Sunflower	Agriculture	0,88	253	
Rye	Agriculture	0,86	221	
Sugarbeet	Agriculture	0,23	179	
Oats	Agriculture	0,88	221	
Intermediate crops	Agriculuture	0,30	230	
Sugarbeet	Industrial waste agriculture			35
Potatoe	Industrial waste agriculture			50
Grape	Industrial waste agriculture			83
Olive	Industrial waste agriculture			82
Adult cattle	Industrial waste livestock			90
Calve and young cattley	Industrial waste livestock			90
Pig	Industrial waste livestock			90
Sheep	Industrial waste livestock			90
Grass	Green waste	0,35		93,00
Fruit and berry plantations	Pruning		261,682243	
Olive plantations	Pruning		261,682243	
Vineyards	Pruning		261,682243	

Table 1: Dry matter content and methanogenic power

1.3.1 1G: intermediate energy crops could represent a large share of the potential

Agriculture residues

The potential of biomass available in agriculture production was evaluated for the following crops: wheat, barley, rice, rye, oat, sunflower, sugarbeet, rapeseed, potato. The main residues from these crops are straw, cane and fane.

In first stage, the spatial theoretical potential of residues is estimated using geographical information on the soil occupation for agricultural category from Corine Land Cover (CLC) database, straw yield data (harvested production per area of cultivation) and the Residue to Product Ratio (RPR). RPR is the ratio of the amount of residue left after harvesting a product. For agricultural products, it refers to the ratio of straw/fane/cane after harvesting grain. Yield data was extracted from Eurostat and Residue to Product Ratio was derived from (N. Scarlat F. F.-F., 2019), see

Table 2.

The technical potential of residues is estimated by removing competitive uses for straw such as maintaining straw on soil for soil management solution or use to fed animals. In this study the global mobilisation rate of 50% was considered for the residues from agriculture based on (N. Scarlat F. F.-F., 2019). The potential of biomethane production from agriculture residues for EU 27 + 10 in 2050 is estimated at 234 TWh, see Figure 6.

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[5] From (JRC, 2017)

[6] Extracted from (ADEME, 2018) for wheat to intermediate crops, calculated from the estimated potential of pruning feedstock of 152 PJ from (BioBoost, 2013) for others.

[7] From (Collectif Scientifique National sur la Méthanisation, 2019) for industrial waste agriculture.

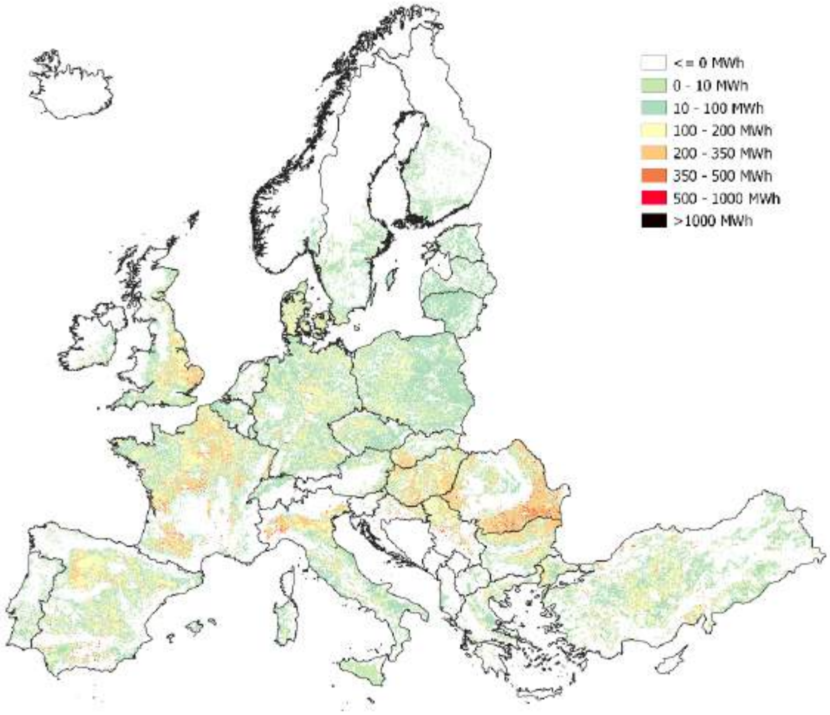

Figure 6: Theoretical potential of agriculture residues [MWh/km^2]

Intermediate energy crops

The potential of biomass from intermediate crops was evaluated. Intermediate crops are a mix of different plants which are planted between two main crops in order to cover the soil, for soil protection and biodiversity purposes. They are also called cover crops. In this study, intermediate crops are assumed to be cultivated between the following main cultures: wheat, barley, maize, sunflower, sugarbeet, rapeseed. Following (ADEME, 2018), the hypothesis is made that intermediate crops can occupy 100% of the arable land covered by the main crops considered in the months between cultures (e.g., September to February on fields of spring wheat).

The spatial theoretical potential of intermediate crops is estimated using a yield different from main crops: indeed, yield for intermediate crops are lower than for main crops and also differs depending on the country. In this study, an average yield of ca. 5 tons of dry matter/ha is considered for all intermediate crops and for all EU country. This yield was derived from (ADEME, 2018) estimation of 50MtMS in France in 2050. We make the additional assumption that all the intermediate energy crops available are transformed into biomethane.

The potential of biomethane production from intermediate energy crops for EU-27 + 10 in 2050 is estimated at 462 TWh in our scenario.

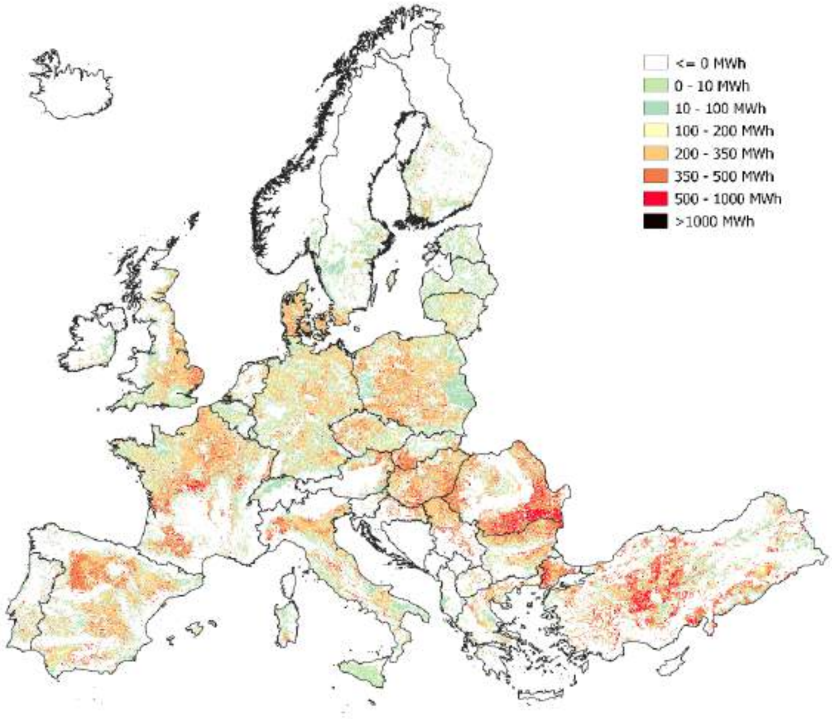

Figure 7: Theoretical potential of intermediate crops [MWh/km^2]

Biowaste

The scope is to evaluate the potential of biomass from biowaste regrouping paper and cardboard wastes and household and similar wastes. It is assumed that organic waste generated are already sorted from homes since 2025.

The spatial theoretical potential of residues is estimated using data on population density extracted from JRC, on biowaste production extracted from Eurostat and on a hypothesis on the organic fraction of waste at 52% for each CWE EU country.

To estimate the technical potential of biowaste, an hypothesis of 35% (Eurostat) of competing use for composting purpose was considered which left 65% of biowaste for biomethane production.

The potential of biomethane production from biowaste for EU-27 + 10 in 2050 is estimated at 106 TWh, see Figure 8.

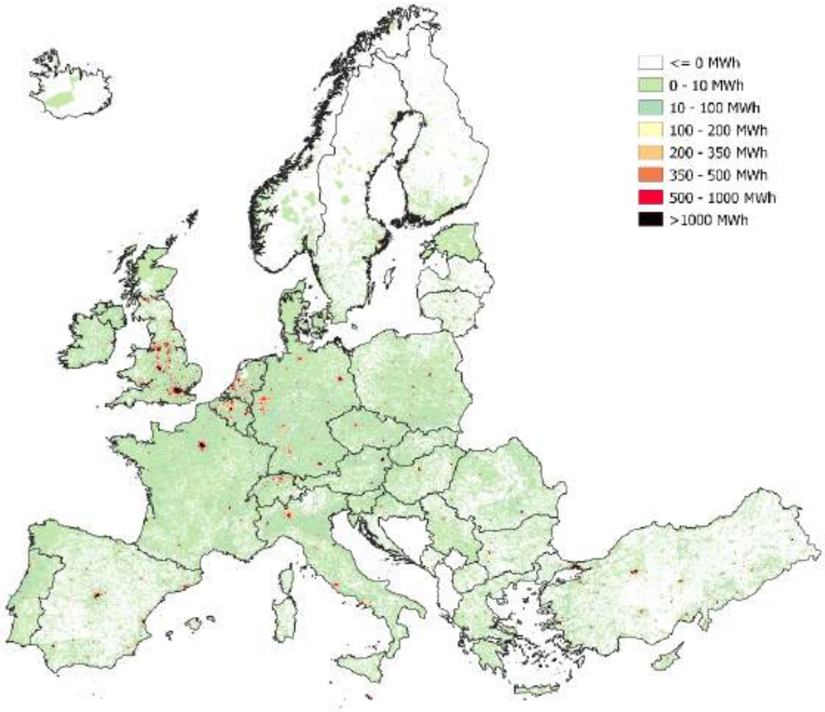

Figure 8: Theoretical potential of biowaste [MWh/km²]

Industrial waste

The scope is to evaluate the potential of biomass from agro-industrial co-product after processing agricultural products in oil and wine industries, sugar industries, but also co-products from milk and meat industries. In France, 85% of the agro-industrial co-products are generated in industries for fruits and vegetables, meat, milk and beverage[8]. Currently, these co-products are already well valorized by using them for produce feed for animal, fertilizers, or used as raw material for cosmetics and pharmaceutics. The industrial waste can be categorised in two groups: residues from products coming from agriculture and residues from products coming from livestock. The method used to evaluate the potential is different for the two groups.

The spatial theoretical potential of industrial waste from processing agricultural products relies on spatial data of the following crops: sugar beet, potato, grape, olive, grape, fruit and citrus. This spatial data is obtained with the CLC database. It is assumed that the industries using these products are installed not far from the field, so the residues obtained after processing these crops are located not far from the field. Yield data from Eurostat are retrieved in order to obtain the yearly mass of residues.

To estimate the technical potential, the global mobilisation rate in Table 5 is considered. This mobilization rate is obtained by taking into account the availability of each type of waste and after considering potential competing uses.

In this study, industrial waste from processing livestock products covers the following co-products: meet co-products such as fat, bones and blood from adult cattle, Calve and young cattley, Pig, and Sheep; and milk lacteroserum co-product from dairy cows.

The spatial theoretical potential of these co-product is estimated using data on livestock population, on the amount of co-product per head for each type of livestock, on the amount of milk production per head for each dairy cows.

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[8] https://www.in-alim.fr/valorisation-coproduits-agroalimentaire/

The technical potential is estimated by using mobilization assumptions available in Table 6. Based on (ADEME, 2018) assumption, this study has considered that 100% of these co-products will be used to produce biomethane, except for Lactoserum for which a mobilization rate at 10% is considered because there already exist several competing use for this product.

The potential of biomethane production from all industrial waste for EU-27 + 10 in 2050 is estimated at 40 TWh.

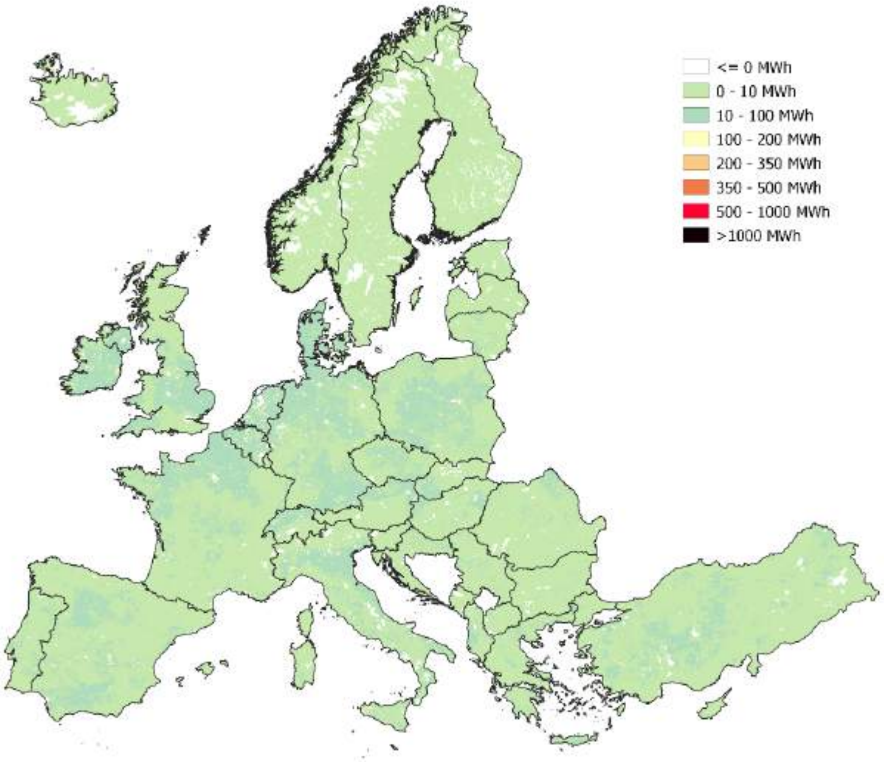

Figure 9: Total theoretical potential of industrial waste [MWh/km^2]

Livestock manure

The scope is to evaluate the potential of biomass from livestock manure. The study focuses on manure from poultry, cattle, pig, sheep and goat.

The spatial theoretical potential of manure is estimated using data on livestock population, livestock density, number of days spend by livestock in stable, quantity of dejection per livestock per year (see Table 4). A distinction is made in calculation between liquid and solid manure.

To estimate the technical potential, the competitive uses of manure was considered which are usage as fertiliser in agriculture allowing to avoid other types of fertilizer. A mobilization rate of 50% was considered based on (JRC, 2015). The potential of biomethane production from livestock manure for EU-27 + 10 in 2050 is estimated at 208 TWh (70 TWh for liquid manure and 139 TWh for solid manure), see Figure 10.

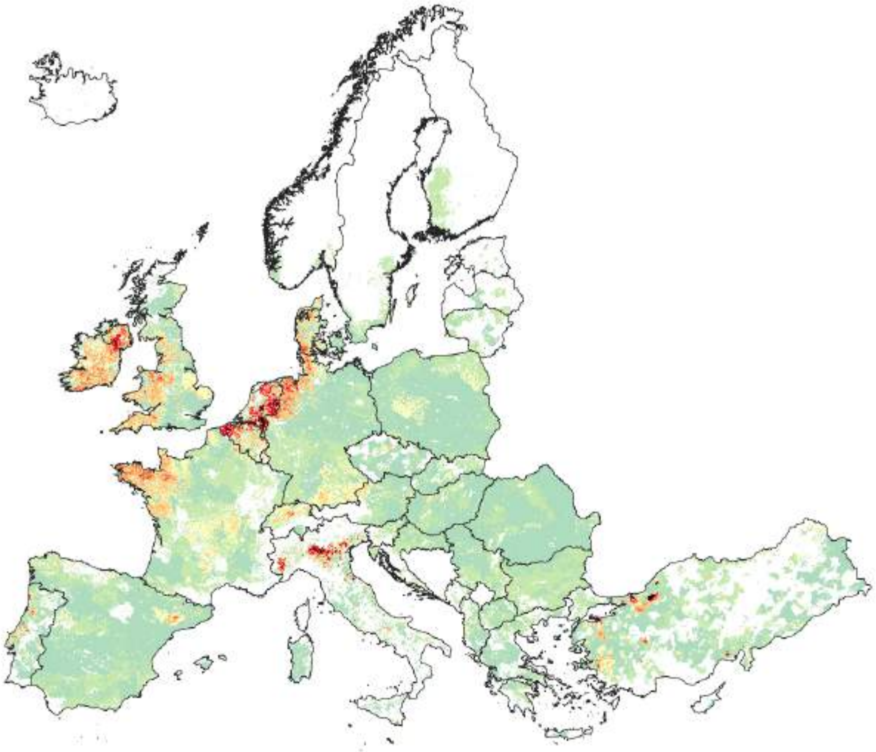

Figure 10: Totam theoretical potential of manure [MWh/km^2]

Green waste

The scope is to evaluate the potential of biomass from green waste. The study focuses on grasses or leaves left on road after roadside management.

The spatial theoretical potential of green waste is estimated using data on road network to retrieve the number of kilometers of road in non-urban area, and the yield of grass per kilometer, equal to 5.6 t/km. The former data is obtained from open data on world roads (Center for International Earth Science Information Network (CIESIN)/Columbia University and Information Technology Outreach Services (ITOS)/University of Georgia, 2013)[9]. The latter value was retrieved based on data from (ADEME, 2018).

To estimate the technical potential, the competitive uses of green waste was considered. Currently, there is no valorisation for these residues, thus a global mobilisation rate of 100% is considered for this biomass. The potential of biomethane production from green for EU-27 + 10 in 2050 is estimated at 105 TWh.

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[9] Great Britain is modeled with greater accuracy than other European countries in this source, which results in a greater potential.

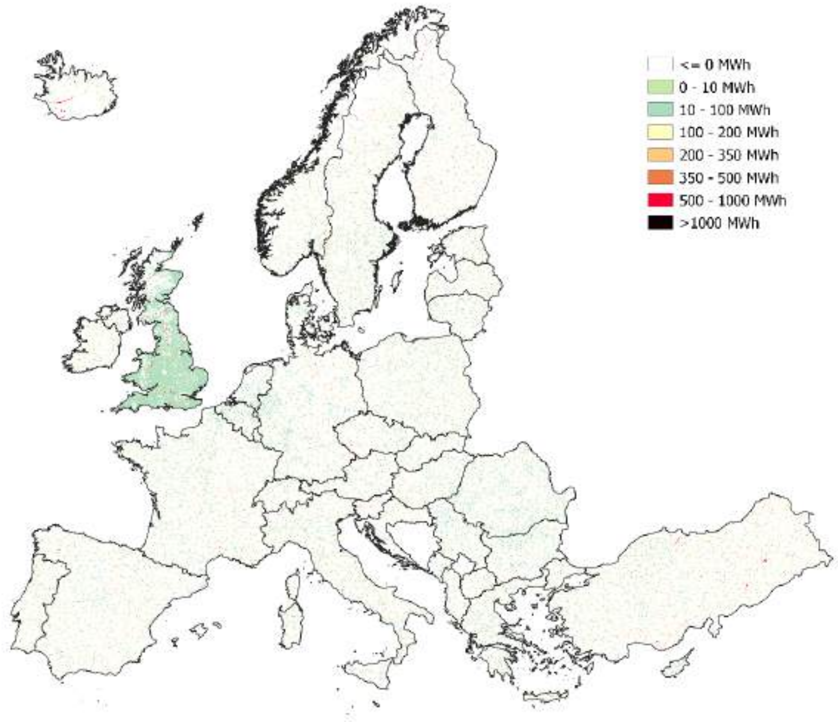

Figure 11: Theoretical potential of roadside vegetation [MWh/km^2]

1.3.2 2G: the use of wood from forest growth could boost the potential

Forests represent a high potential for biomass. In this study, the spatial potential of wood biomass is evaluated focusing on forest residues, forest wood and on pruning residues.

To evaluate the potential of wood biomass, it was mandatory to have assumption on the evolution of wood stock in the future years. The model EFISCEN (European Forest Information SCENnario) has been used to retrieved projection of stemwood removal volume and projection of extracted residues volume for 2050, based on EFISCEN projections for each country going until 2030.

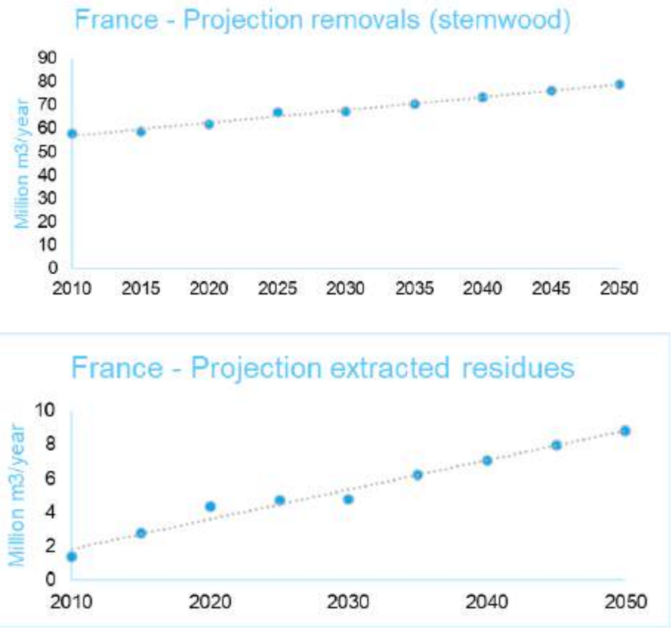

Figure 12: Projections of stemwood removal and extracted residues volumes[10]

Forest wood

Forest wood refers in this study to stemwood, which are commercial and pre-commercial thinning.

The technical potential of stemwood was estimated by using geographical information on the soil occupation for forest category from CLC database, assumption of evolution of stemwood coming from EFISCEN model. We make the assumption that current uses of wood (such as construction or energy) are kept at the same volume, and that the additional stemwood from the growth of forests is used to produce biomethane.

The potential of biomethane production from forest wood for EU-27 + 10 in 2050 is estimated at 439 TWh.

Forest residues

The scope covers forest residues such as residues from forest harvesting operation as thinning, cleaning or felling of forest stands.

The technical potential of forest residues was estimated by using the same methodology than for forest wood, using in this case assumption on the evolution of forest residues from EFISCEN.

The potential of biomethane production from forest residues for EU-27 + 10 in 2050 is estimated at 123 TWh.

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[10] Projections to 2050 based on EFISCEN projections from 2010 to 2030.

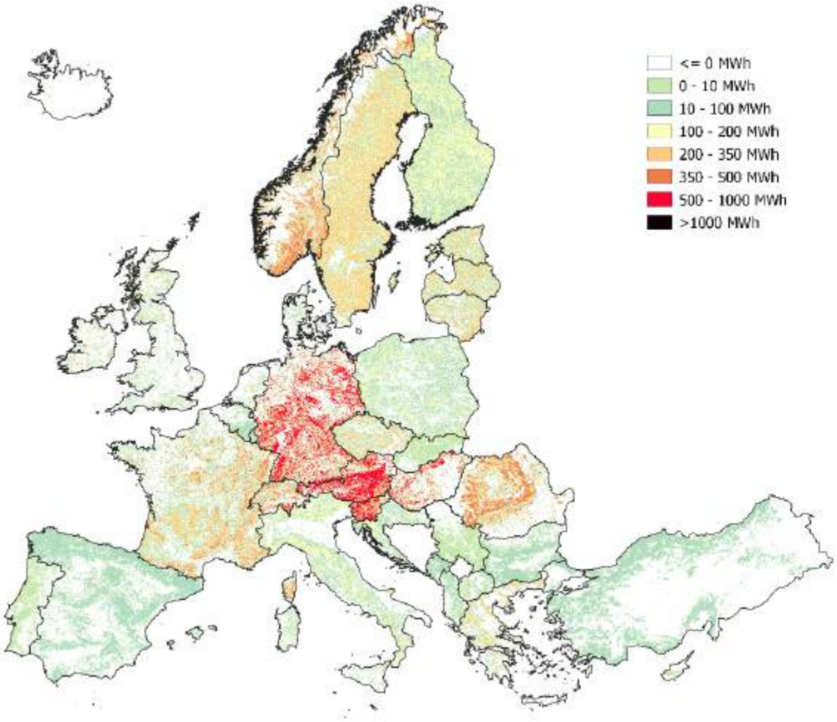


Figure 13: Theoretical potential of forest wood [MWh/km^2]

Pruning

The scope is to evaluate the potential of biomass from pruning operation. Pruning is a practice corresponding to the selection and the removal of certain part of a tree or a plant such as roots or branches. The objective of pruning operation is to remove part which are not necessary for growth in order to encourage growth and flowering. The study consider pruning residues from fruit and berry plantations, olive plantations and vineyards.

The potential of biomethane production from pruning residues for EU-27 + 10 in 2050 is estimated at 36 TWh.

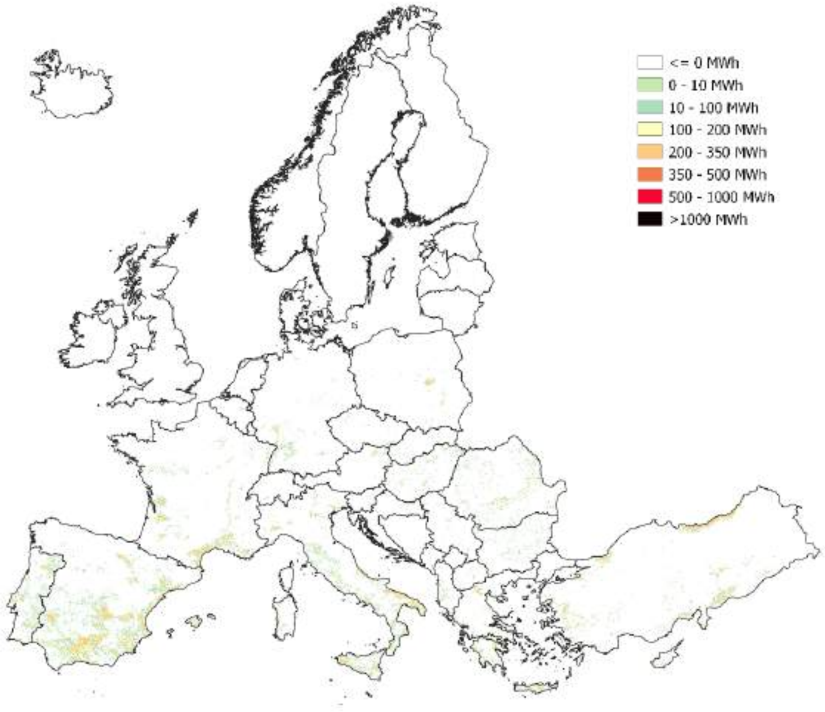


Figure 14: Theoretical potential of pruning [MWh/km^2]

1.3.3 The available biomass potential could represent over 1700 TWh of biomethane

The total potential of biomethane in EU 27 + 10 has been estimated to more than 1700 TWh, with more than 1100 TWh from 1G biomass and roughly 600 TWh from 2G biomass. The breakdown of this potential per type of feedstock is given in Figure 15 and the potential per country is displayed in appendix 0 Table 7.This potential is estimated in the case of a high scenario for intermediate crops (full development of intermediate crops with a mobilization rate at 100%) and also for wood biomass (no competing uses, 100% additional wood for 2G biomethane). Results display that these two types of feedstock could provide a large share of the potential in 2050 representing 26% of total from intermediate crops and 25% for forest wood.

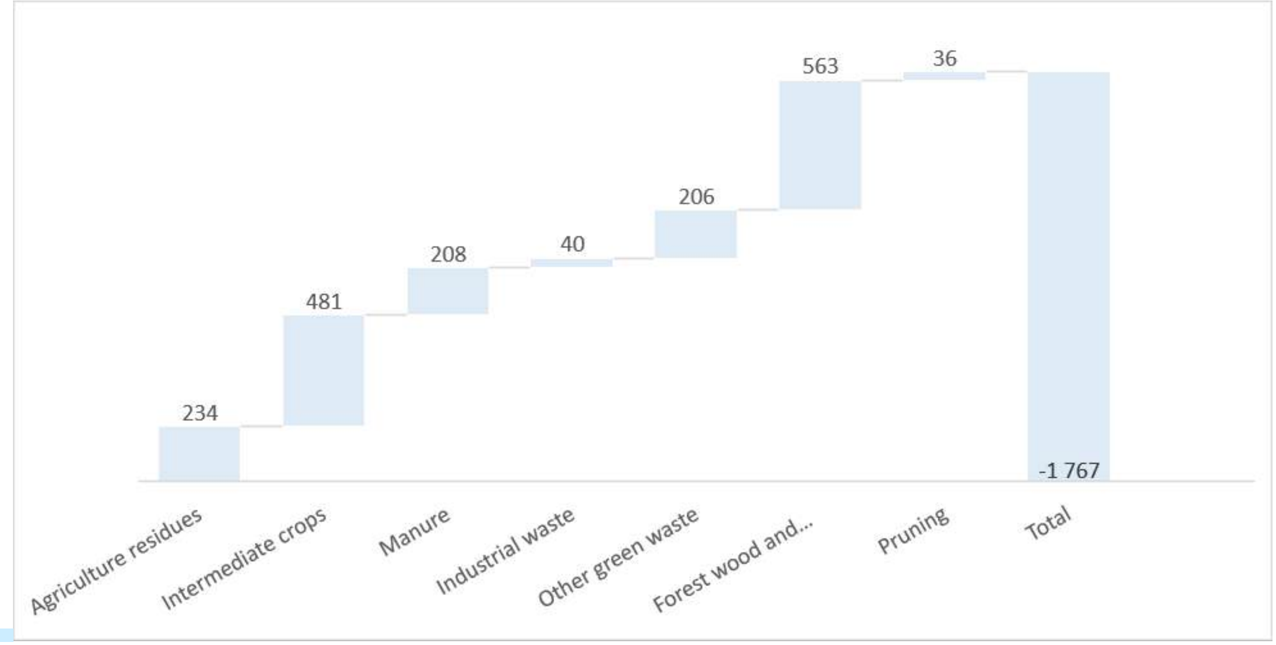


Figure 15: Biomethane potential 1G+2G per feedstock category in 2050 [TWh]

70% of the potential is located in less than one third of the countries (see Figure 16). France and Germany are the countries with the highest potential. The share of intermediate crops and 2G potential is high in each countries.

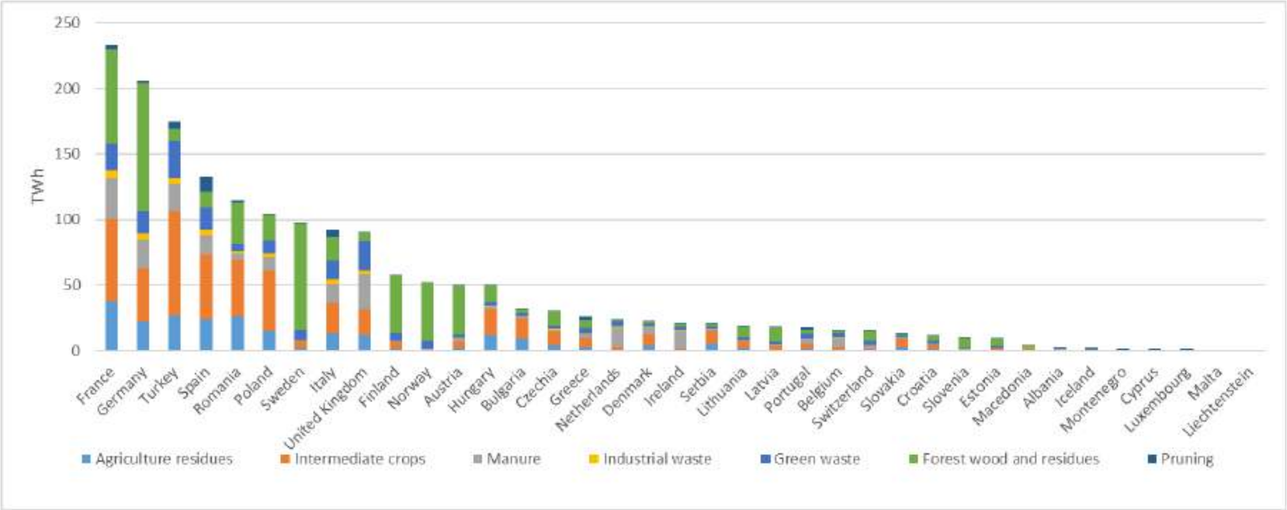
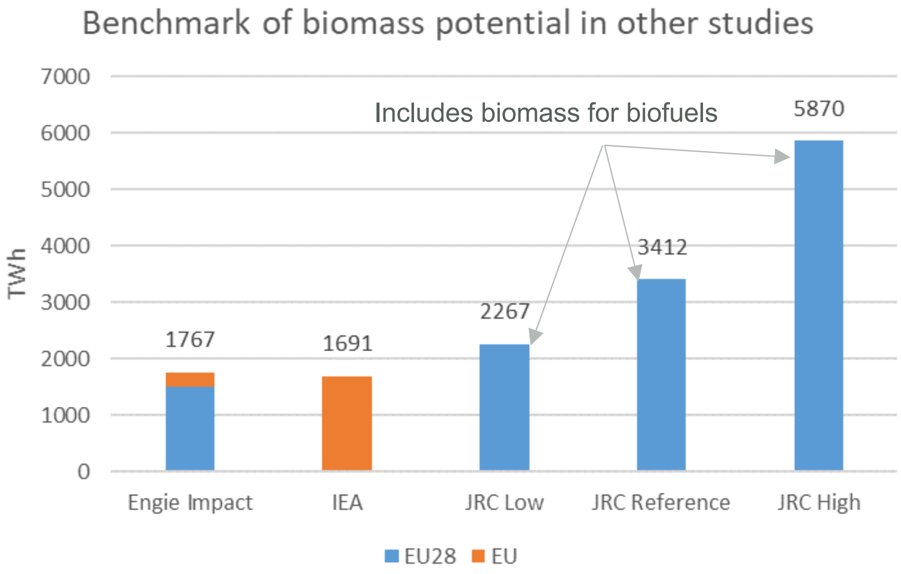


Figure 16: Biomethane potential 1G+2G per country in 2050 [TWh]

1.3.4 The estimated potentials are in line with existing studies



The biogas potential estimated with this methodology is in line with the potential estimated by (IEA, 2020). The potentials estimated by the (JRC, 2015) are much higher, even in their low scenario, as they include biomass for other bioenergies, not considered in the scope of the current study.

2 Biomethane production cost

The biomass potential identified in the previous section has to be transformed into biomethane. Anaerobic digestion or pyrogasification plants have to be built, and the biomass collected and transported to the plants. This results into costs dependent on the geographical location and the type of biomass available to produce biomethane.

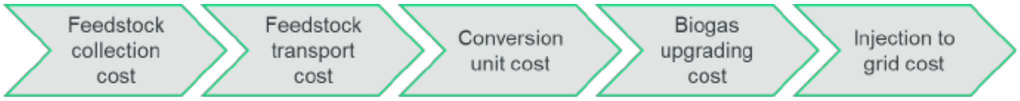


Figure 17: Biomethane value chain cost component

The cost of biomethane production is an important pillar because it has an impact on the competitiveness of the energy vector. The cost of biomethane relies on the following components:

- Feedstock cost encompassing feedstock collection cost, feedstock transportation cost from collection place until converting plant.
- Operating expense (OPEX) including conversion and upgrading cost.
- Capital expenditure (CAPEX) including conversion, upgrading and injection cost.

2.1 Feedstock cost

Feedstock cost data used in the study are based on data from (JRC, 2015) and are presented in Appendix 0 Table 8. JRC provides cost data for different type of feedstock as for agriculture residues, waste or forestry residues and for 3 years: 2010, 2030 and 2050. For cost projections to 2050, the corresponding values have been used. Average cost for each type of feedstock is presented in Figure 18.

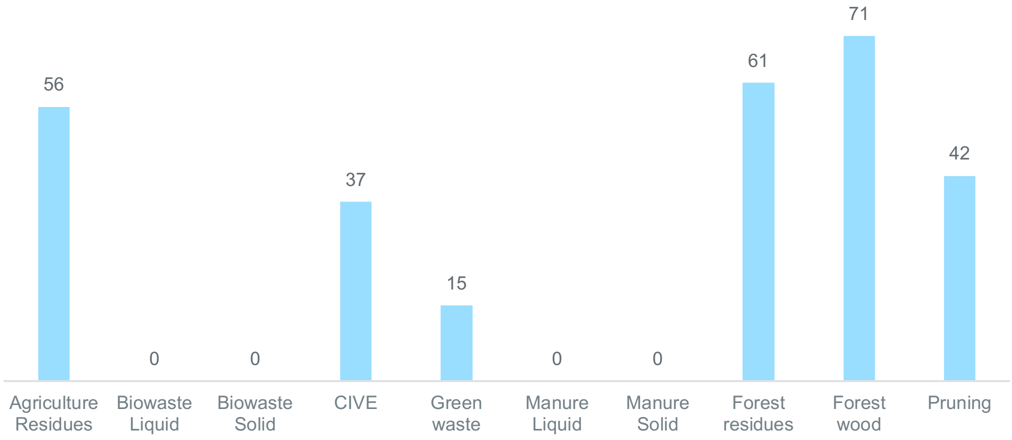


Figure 18: Average cost for feedstock in 2050, €2019/tons

In this study, biowaste and manure (liquid and solid) cost has been assume to be null. Most of the time, farmers give manure for free to the conversion plant in exchange of digestate used by the farmer as fertilizer. Producing biomethane from biowaste is a service to process the waste; the feedstock being waste, it is assumed to be free.

2.2 Feedstock transport cost

The feedstock used for producing biomethane is generally not located on the site where the conversion plant is located. It is then necessary to take into account cost for transporting it from its generation place to the conversion plant site. This cost is composed of two part:

1. Transportation cost related to the transport of the feedstock between its production site to the conversion plant.

2. Logistic cost associated to the loading and unloading operation of the feedstock.

Depending on the distance to the plant, two types of transports are considered in the study: agricultural transport and truck transport. The costs have been retrieved from (Chambre d'Agriculture des Hauts de France, 2019) for agricultural transport as well as a truck rental company (Berger location, 2021) for long distance transport. Agricultural transport is dedicated to transport within a radius lower than 15 km whereas truck transport is for transport in a radius higher than 15 km. Feedstock from first generation can be transported either in a radius lower or higher than 15km depending on the proximity with the conversion plant. Feedstock from second generation are considered far from conversion plant so they can be transported only by truck, in a radius possibly higher than 15 km. Finally, cost calculation is done depending on the type of feedstock transported.

Machineries used in the report for transported the different type of feedstock:

- Telescopic truck for loading and unloading the feedstock
- Tray pulled by truck for straw
- Dump truck for solid feedstock
- Tanker pulled by truck for liquid feedstock

Cost assumption for truck transport (>15 km)
Straw is assumed to be transported on long distance with a 26 ton tray, driving on average at 60km/h. The straw is loaded in the tray with a telescopic truck, at a speed of 2.25 minute per ton. Biowaste liquid is transported in a 21m^3 tanker pulled by a truck. Biowaste solid, intermediate crops and green waste are assumed to be transported in a 26 m^3 dump truck pulled by a truck and loaded with the telescopic truck. Cost calculation is done by taking into account the density of each type of feedstock (see density data in appendix 3.8 Table 9).
Solid and liquid manure are assumed to be transported only on distance lower than 15 km thus there is no truck transport cost for these feedstock type.

Cost assumption for agricultural transport (<15 km)
Straw is assumed to be transported on distance lower than 15km with a 10 ton tray, driving on average at 25km/h. The loading is done with the telescopic truck. Intermediate crops and solid manure are assumed to be transported in a 20 m^3 dump truck pulled by a truck and loaded with the telescopic truck. For green waste and biowaste liquid/solid, it is assumed that these feedstock are only transported on distance higher than 15km, thus no agricultural cost is considered for them. Liquid manure is transported in a 15.5m^3 tanker pulled by a truck. The manure is loaded in the tanker using a compressor.

2.3 Biomethane production cost

In the study, five units are considered for anaerobic digestion and one for pyrogasification. Their characteristics are presented in Figure 19**Error! Reference source not found.**. Full cost data for these units are derived from (ADEME, 2018), (NAVIGANT, 2019) and (ENEA, 2018).

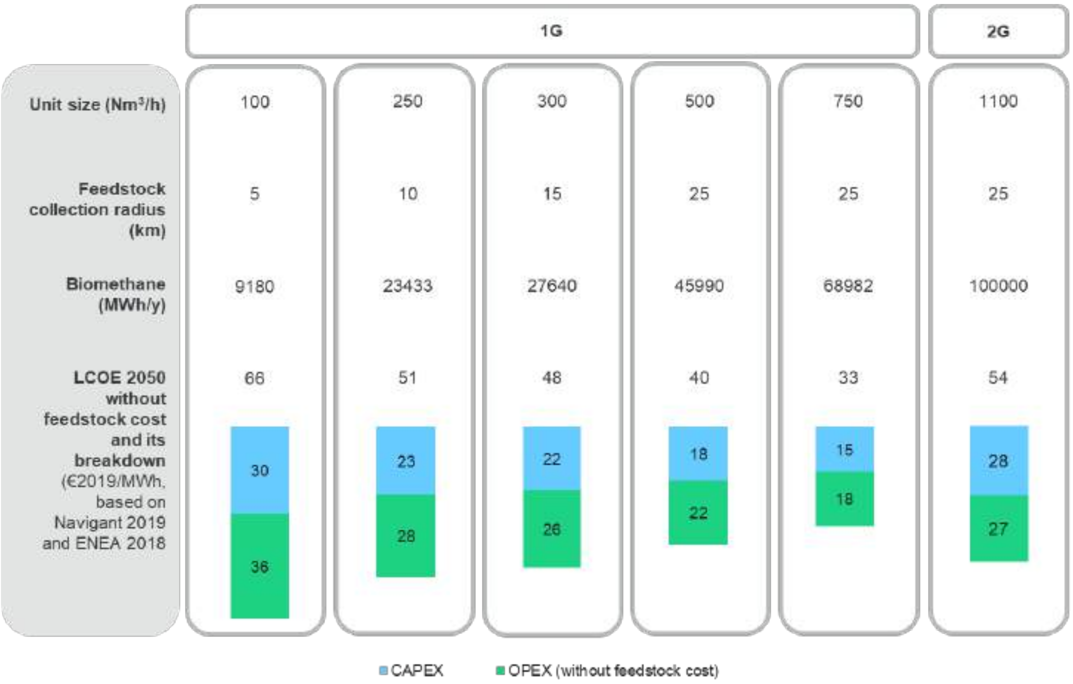


Figure 19: Units characteristics for anaerobic digestion and pyrogasification

The cost of digesters are expected to decrease with the industrialization of biomethane production. ENEA (ENEA, 2018) identifies the following levers to achieve the required cost reductions from today:

- Economy of scale with the increasing of installation of biomethane unit with bigger size (increasing plant reliability);
- A better valorisation of digestate as natural fertilizer;
- Increase of the biomass conversion efficiency process (e.g. improvement in syngas cleaning);
- Reduction of the feedstock cost and increase in the methanogenic power of the feedstock.

(NAVIGANT, 2019) assumes that in 2050, an anaerobic digester of 500 Nm3/h would have an LCOE reduced to 37 €/MWh (decomposed in 15 €/MWh of CAPEX and 22 €/MWh of OPEX - without feedstock management and feedstock cost). This cost does not include the cost of injection to the grid and the cost for transporting the gas. Navigant considers that in the current cost of 70 to 90 €/MWh, 5% is dedicated to the connection to the network, i.e., a cost of roughly 3 €/MWh for a 500 Nm3/h plant.

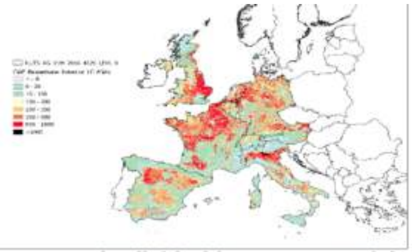
Assuming that 40 €/MWh would be the cost of a 500 Nm3/h digester (injection included) in 2050, we computed the economies of scale resulting from the costs of the three digesters from (ENEA, 2018) to derive the LCOE of the other units taken into considerations in the study.

Pyrogasification plants are not yet at industrial scale. Using the cost of various projects, (ADEME, 2018) considers a standard unit of *ca.* 1100 Nm3/h, and estimates that improvements in the technology will result in 2050 in an LCOE of 54 €/MWh, with 28 €/MWh of CAPEX and 26 €/MWh of OPEX.

2.4 Spatial biomethane units localization

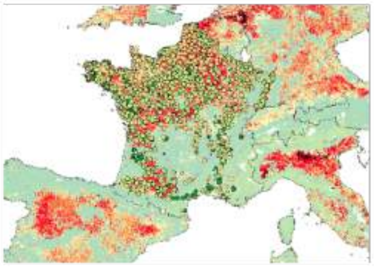
The potential of biomethane has been assessed previously and located geographically by type of feedstock and for each country. The cost associated to the process has been detailed from feedstock cost collection, transport cost to cost associated to each type of conversion plant considered. Based on the previous work, this section aim to answer to the following questions:

- Depending on the feedstock potential localisation, what is the optimal dispatch for the conversion plant allowing to minimize the biomethane production cost?
- Which type of conversion plant is required to reduce biomethane production cost? Small conversion plant or bigger ones?



Available biomass potential

Zones with gas network



Optimized location and sizing of units
Minimizing LCOE, taking into account:
- competition for resources
- feedstock collection and transport costs

Biomethane produced in conversion plant is intended to be injected into the gas network. The conversion units should then be located not too far from the network. This could exclude biogas production potentials that would require costly network expansions (or LNG transport). To locate production units, the following main assumptions are considered in calculation:

- The list of the cities connected to gas network for France
- The list of cities with a density higher than 80 inhabitants/km2 for other countries.

The methodology used to identified the best projects in a country is composed of two phases, starting from a greenfield:

1. Identification of best projects in terms of LCOE for each cities without taking into account the resources: each project can assess to the resource needed to reach its production potential.
2. Integration of the impact of resources elimination: the resources used by a project is not anymore available for other project.

For each city, the best project in terms of LCOE is identified. Each project within the units list is computed and the one with the lower LCOE is kept at the end. This first phase provides a list of all the cities in the country with its associated best project found. In this phase, the resources already used by a unit plant is not removed from the resources available for other projects.

In phase 2, the impact on project ranking of removing the resources already used by a project is taken into account. Staring from the cities which had the project with the lower LCOE in phase one, the methodology used in phase 1 is executed again by removing this time the resource already used by projects. That has an impact either on the LCOE or on the feasibility of the project. With resources being removed, a project may have to look in a higher radius to collect the feedstock necessary to reach its potential of production, which lead to higher transportation cost and then to higher LCOE.

The methodology is applied independently for 1G and 2G.

2.5 The cost of 1G biomethane could decrease below 70 €$_{2019}$/MWh$_{HHV}$ in 2050

For each EU27+10 country and for each type of conversion process (1G or 2G), a cost curve for biomethane is generated. The 1G biomethane potential that could be injected into gas networks could cost less than 70 €$_{2019}$/MWh$_{HHV}$ in 2050, with 60% of the identified potential having a lower cost.

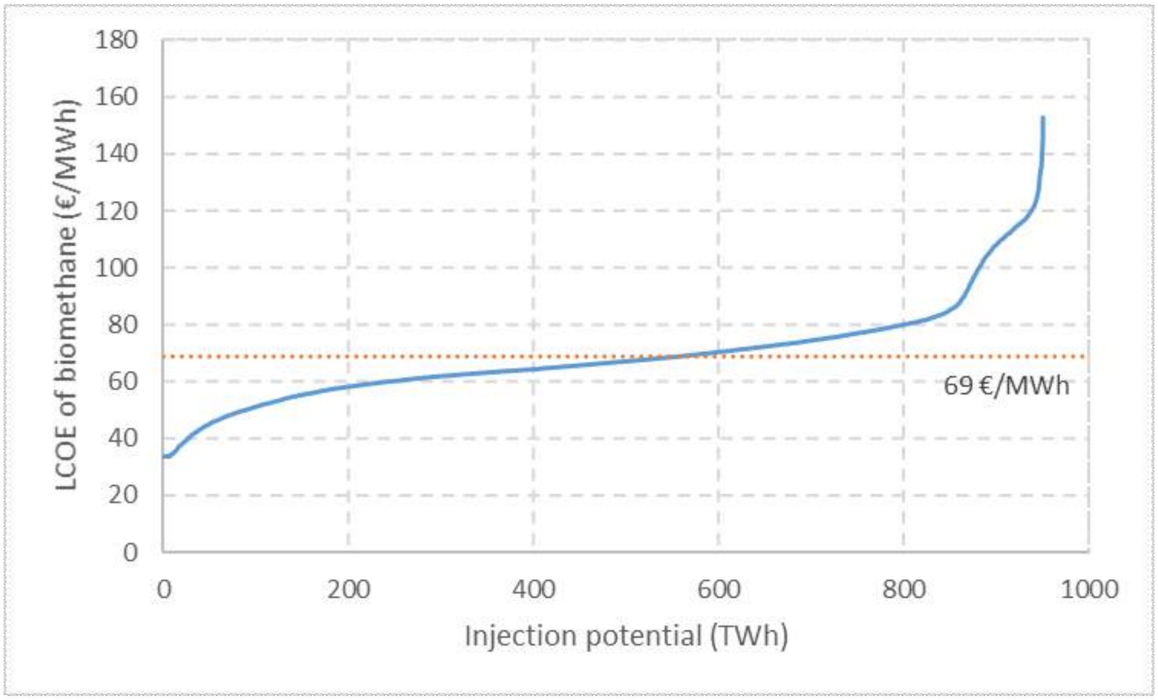


Figure 20: LCOE of biomethane injected into gas networks for EU27+10 in 2050

To reach this price, it will require the use of bigger unit conversion size than the one currently existing. Figure 21 display the distribution of the unit types used: most of the unit types are 500 Nm3/h and 750 Nm3/h units (see units conversion list in Figure 19).

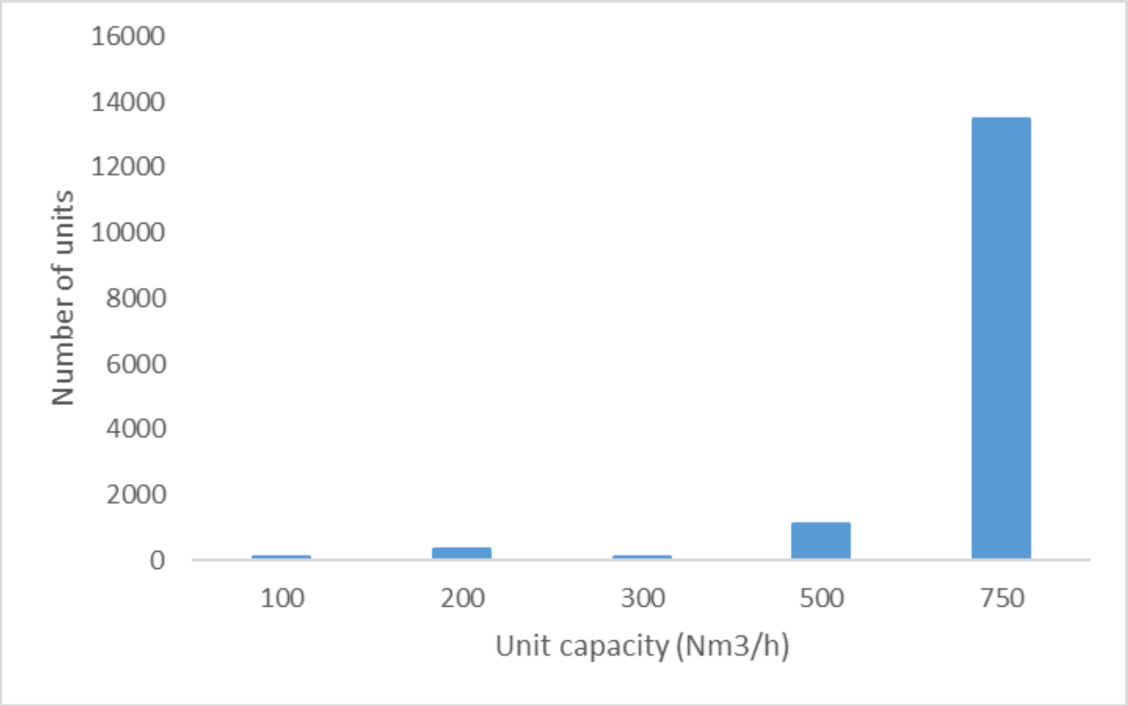


Figure 21: Distribution of 1G unit types in 2050 in EU27 + 10

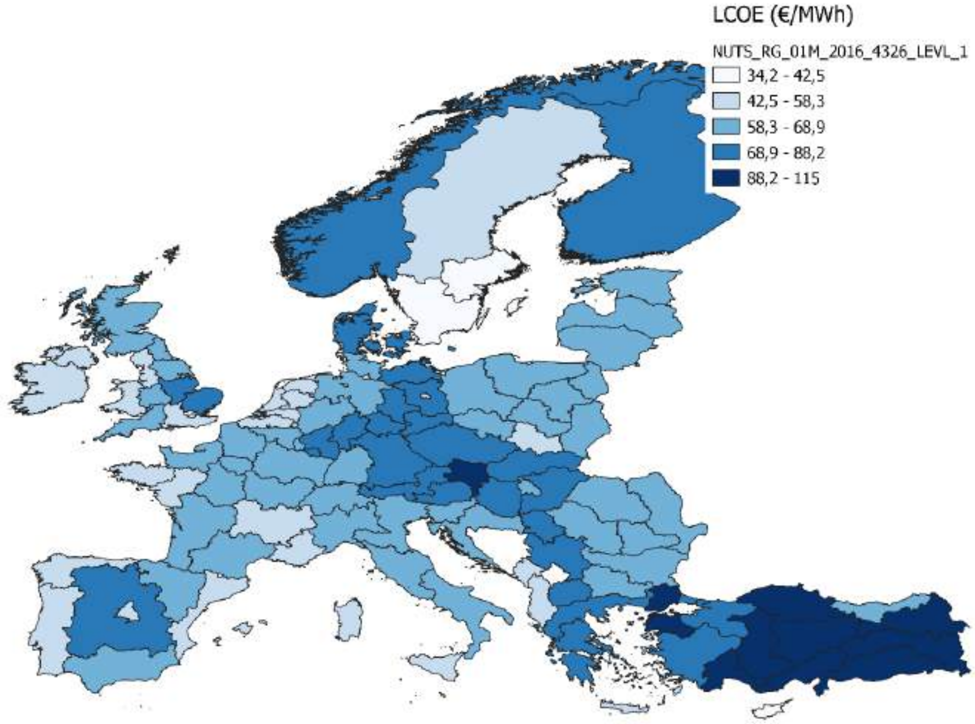


Figure 22: LCOE of 1G biomethane by NUTS1 region

2.6 The cost of 2G biomethane remains high due to costly feedstock and slow decrease of pyrogasification unit costs

In order for 2G biomethane to become competitive towards 2050, the cost of pyrogasification units would need to decrease sharply compared to today's cost. The average cost over the geographical scope considered in this study is above 90 €/MWh. Since current units are only prototypes, there is a high uncertainty regarding the potential for cost decrease. There is also a high uncertainty regarding the availability of feedstock from forests. In this study, it is considered that the additional wood available from forest growth is used in full, as a way to identify resources and compute the cost of the biomethane if all these resources were available. Depending on the economics, other uses for 2G feedstock might be more efficient for the energy transition, such as the production of biomaterials or bioliquids.

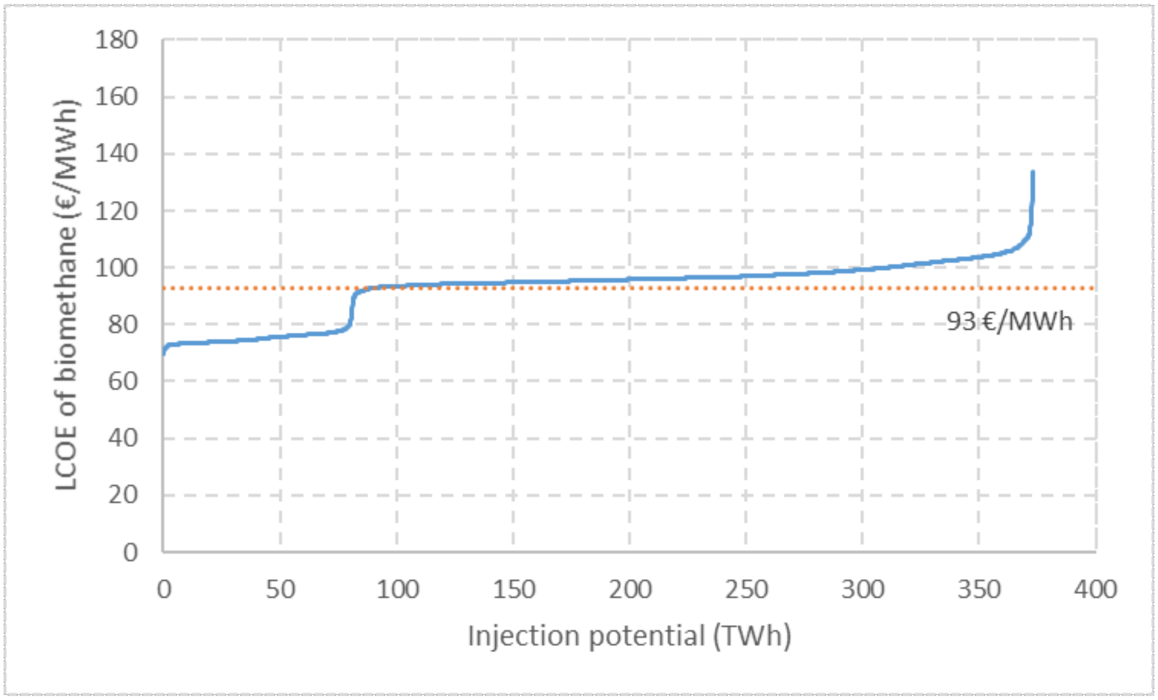


Figure 23: LCOE of 2G biomethane across EU 27 + 10

Conclusion

The purpose of this report was to study the geographical distribution of the potential for producing biomethane and to estimate the associated costs in Europe (EU-27 + 10[11]) in 2050 for anaerobic digestion and pyrogasification.

The study covers a large list of biomass feedstock that can be used for producing biomethane and locates where these feedstocks are available. Furthermore, the study assesses the cost of the whole value chain, to collect the biomass, transport it to the plant and inject biomethane into gas networks.

Europe has a large potential of biomass available for producing biomethane

The study shows that biomass is largely available in some countries such as France or Germany. Although there are uncertainties, the potential of biomass available in 2050 in EU27+10 could allow to produce over 1700 TWh_{HHV} of biomethane. The study shows that the among all the biomass available, intermediate energy crops, if developed, could provide a large share, around 26% of the total. The study also shows that the use of wood from forest growth could boost the potential in 2050.

The costs of 1G biomethane could decrease below 70 $€_{2019}/MWh_{HHV}$ in average in 2050

The study shows that the cost of 1G biomethane injected into networks could be below 70 $€_{2019}/MWh_{HHV}$ in average in 2050. This is obtained through a detailed modeling of the value chain to produce biomethane, from feedstock available locally to the injection into networks, through production units. Attaining such figures will require significant cost reduction in digesters. In particular, increases in the average size of digesters compared to today are a key element for the decrease of costs for 1G biomethane.

The methodology could be extended for other analyses

The methodology developed in this report could be extended for various other analyses:

- Take into account network extensions or bioLNG transport to enhance the injection potential;
- Take into account the production of biofuels, including the competition for the biomass resources;

It could also be used for other business cases, such as identifying the biomass resources available in a particular region, or the need for gas network adaptations to allow local biomethane injection.

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[11] EU 27 + Albania, Iceland, Macedonia, Montenegro, Norway, Switzerland, Liechtenstein, Turkey, United Kingdom, Serbia

3 Appendix

3.1 Appendix: Methodology for biomass potential evaluation

In this report, biomass potential is assess spatially by crossing geographical information with statistics on feedstock. In this section, more detailed is given on the methodology and on the databases used for each type of biomass.

Database's	Information
Corine Land Cover 2018 (CLC)	CLC is a database coordinate by the European Environment Agency (EEA) and produce within the frame of the Copernicus Land Monitoring Service. It has been initiated in 1985 and the reference year is 1990. It gives an inventory of land cover and land use in 44 classes for around 39 European countries using as main sources of information satellite images. Four updates has been done since: 2000, 2006, 2012, 2018. This report uses the 2018 updated database. **https://www.eea.europa.eu/data-and-maps/data/copernicus-land-monitoring-service-corine**
EarthStat	Earthstat is a collaboration between the EarthStat is a collaboration between the Global Landscapes Initiative (GLI) at The University of Minnesota's Institute on the Environment and the Land Use and Global Environment (LUGE) lab at the University of British Columbia. It provides geographical data on the global food system such as harvested Area and yield for 175 crops (year 2000), Greehouse Gas Emissions from croplands, Climate variation effects on crops, yields trend for crops,… **http://www.earthstat.org/**
Eurostat	Eurostat is the statistical office of the European Union which is in charge of providing high quality statistic and data on Europe. They are located in Luxembourg. They are part of a partnership with National Statistical Institutes and other national authorities in the EU Member States, partnership which is named the European Statistical System (ESS). Eurostat provides statistical database on different theme (e.g. Agriculture, forestry and fisheries; Industry, trade and services; Environment and energy,…). The data can be defined at different geographical level referring to different NUTS (Nomenclature of territorial Units for Statistics) such as NUTS 0 for country level, NUTS 1 for region level. This report uses database such as crops yield or household waste. **https://ec.europa.eu/eurostat**
FAO	FAO is the Food Agriculture Organization of the United Nations. It is an agency which aim is to achieve food security for all. FAO has a data center containing several dataset, among which FAOSTAT which providing statistics on food and agriculture including crop, livestock and forestry for over 245 countries. **http://www.fao.org/**
GLW	Gridded Livestock of the World (GLW) is a dataset providing the spatial distribution of the main livestock (cattle, sheep, goats, pigs, chickens, horses, buffalo, ducks). It is managed by FAO. **http://www.fao.org/livestock-systems/global-distributions/en/**
EFISCEN	The European Forest Information SCENnario (EFISCEN) model is jointly developed by Alterra and the European Forest Institute (EFI). It is a forest resource projection model which simulates the development of forest resources on regional to European scale. The model provides outputs on the forest characteristics (forest are, stemwood volume,…), Harvested wood and biomass by forest and harvest type (thinning, logging residues and stumps,…), Carbon stocks in forest biomass and ecosystem services (carbon sequestration, biodiversity recreation,…). **https://efi.int/knowledge/models/efiscen**

Figure *5* presenting the general methodology for assessing the potential of biomass is detailed for each biomass type.

3.1.1 Agriculture

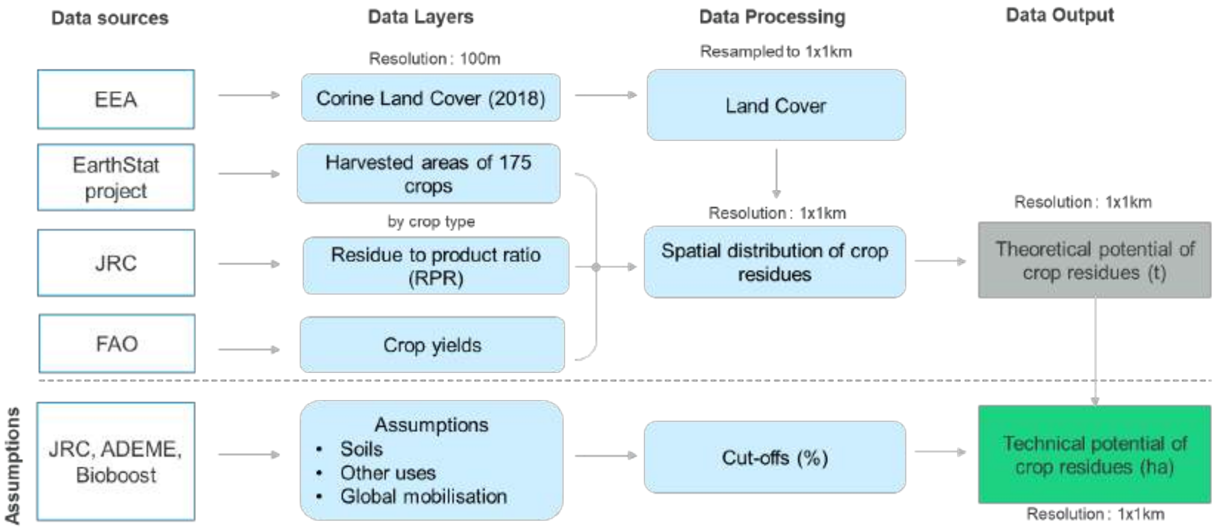

Figure 24: Methodology to estimate biomass potential from agriculture residues

3.1.2 Intermediate energy crops

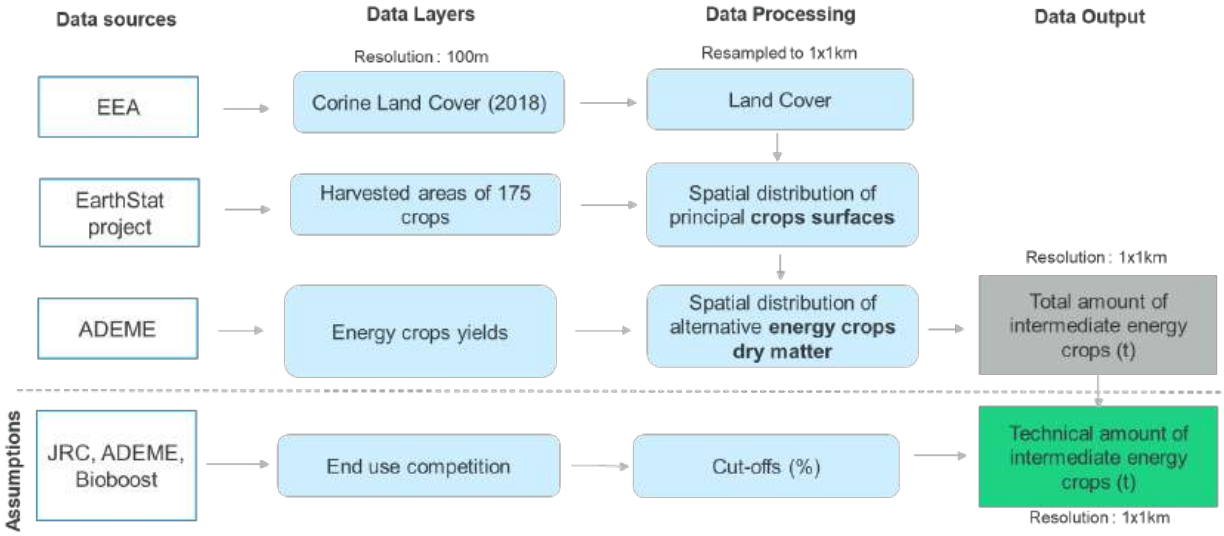

Figure 25: Methodology to estimate biomass potential from Intermediate energy crops

3.1.3 Livestock manure

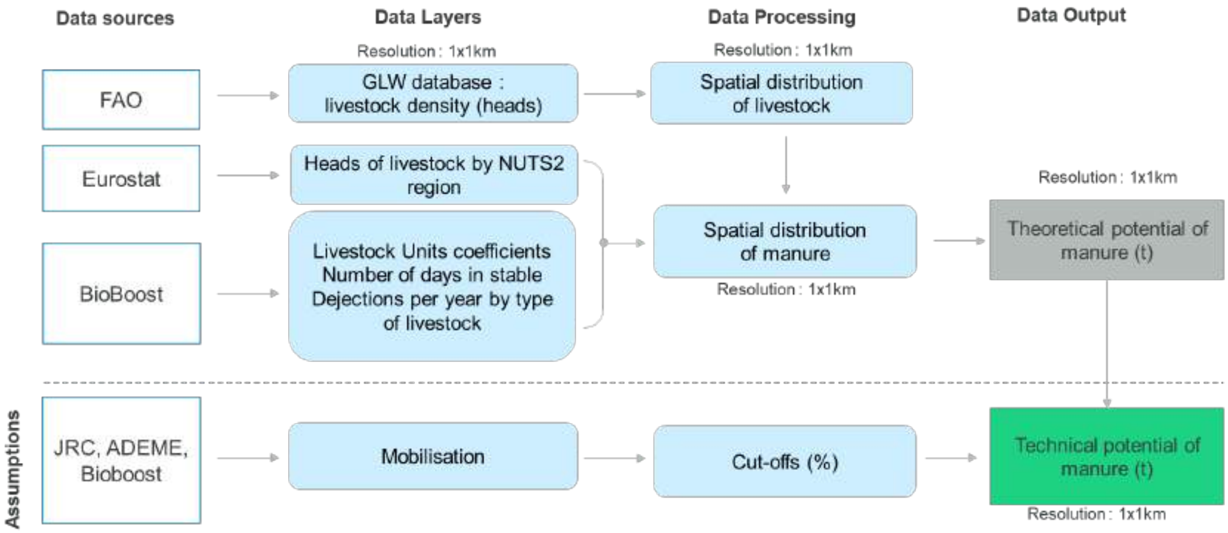

Figure 26: Methodology to estimate biomass potential from livestock manure

3.1.4 Biowaste

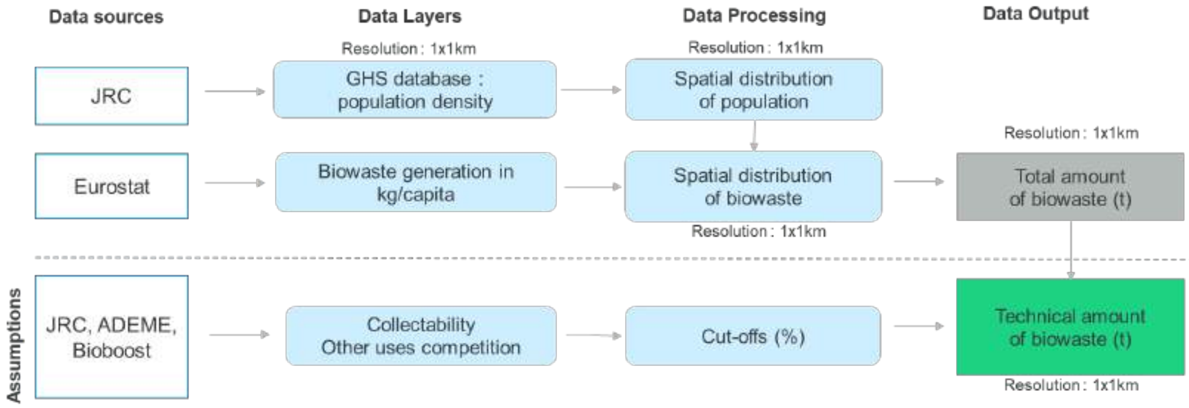

Figure 27: Methodology to estimate biomass potential from biowaste

3.1.5 Green waste

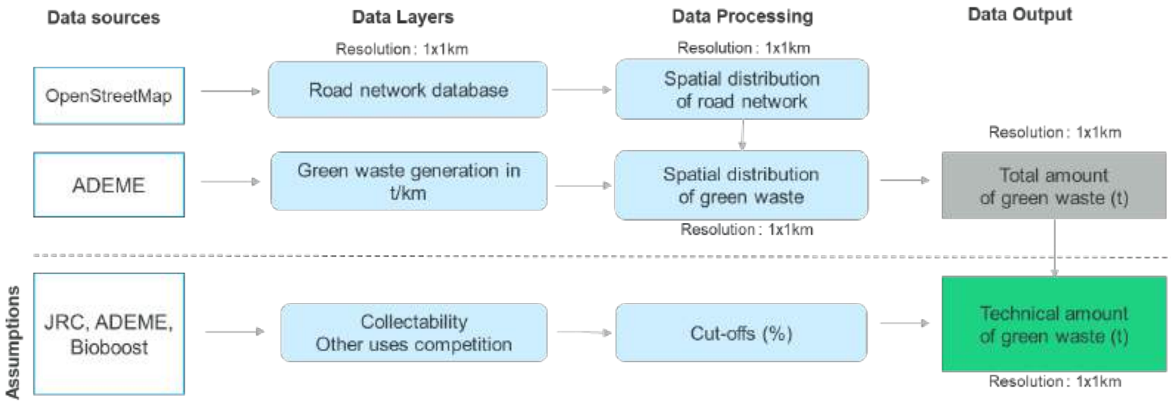

Figure 28: Methodology to estimate biomass potential from green waste

3.1.6 Wood biomass

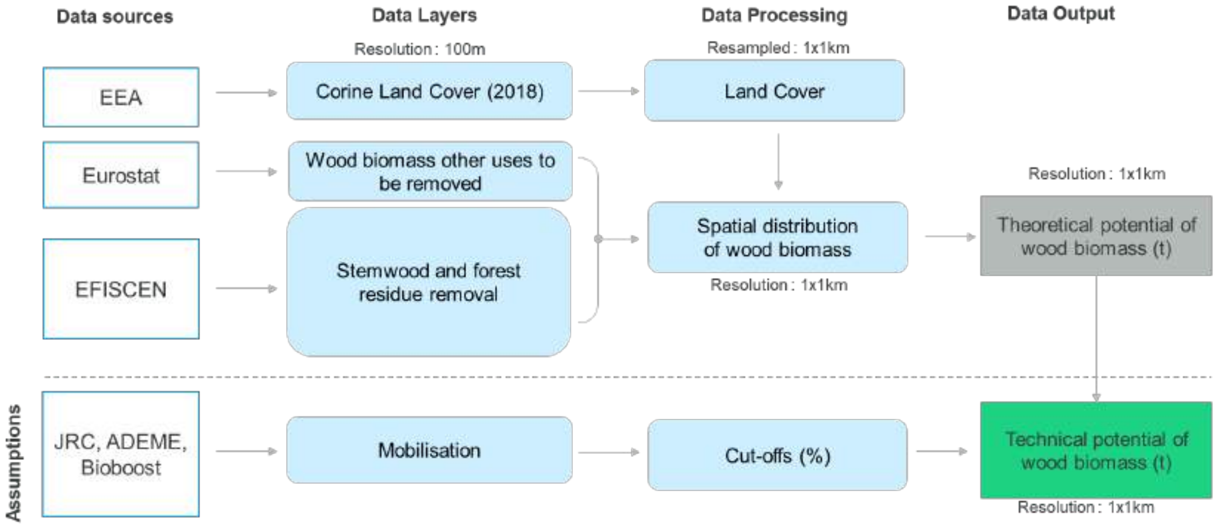

Figure 29: Methodology to estimate potential from wood biomass

3.2 Appendix: Residue to Product Ratios (RPR) for crops

Row Labels	Barley	Maize	Oats	Rapeseed	Rice	Rye	Sugarbeet	Sunflower	Wheat
Albania								1,9	
Albany	1,2	0,9	1,2			1,3	0,25		
Austria	0,9	0,8	1	1	1,6	1,1	0,25	1,5	1
Belgium	1,1	0,7	1	0,9		1,1	0,25	1,5	0,8
Bosnia and Herzegovina	1,2	0,9	1,2	1,2		1,3	0,25	1,5	1,2
Bulgaria	1,1	0,9	1,2	1,2	1,8	1,4	0,25	1,9	1,2
Croatia	1	0,8	1,1	1,1		1,2	0,25	1,5	1
Cyprus	1,2		1,1	1					1,3
Czechia	1	0,8	1,1	1,1		1,1	0,25	1,6	
Czechia Republique									1
Denmark	0,9	0,8	1	1	1,6	1	0,25	1,5	0,9
Estonia	1,1	0,8	1,2	1,3	1,6	1,3	0,25	1,5	1,2
Finland	1	0,8	1,1	1,3		1,2	0,25	1,5	1,1
France	0,9	0,8	1	1	1,7	1,1	0,25	1,6	0,9
Germany	0,9	0,8	1	1		1	0,25		0,9
Germany (until 1990 former territory of the FRG)							1,7		
Greece	1,1	0,8	1,2	1,1	1,3	1,3	0,25	1,7	1,3
Hungary	1	0,8	1,1	1,1	2,1	1,3	0,25	1,7	1,1
Iceland	1	0,8	1,1	1		1,3			
Ireland	0,9	0,8	0,9	1	1,6	1,3	0,25	1,5	0,8
Italy	1	0,8	1,1	1,2	1,5	1,2	0,25	1,7	1,1
Kosovo									1,1
Kosovo (under United Nations Security Council Resolution 1244/99)	1	0,8	1,1	1		1,3	0,25		
Latvia	1,2	0,8	1,2	1,3		1,3		1,5	1,2
Lithuania	1,1	0,9	1,2	1,2		1	0,25	1,5	1,1
Luxembourg	0,9	0,8	1	1	1,6	1,3	0,25	1,5	1
Malta	1			1	1,6		0,25	1,5	1,1
Montenegro	1,1	0,9	1,1	1		1,3		1,5	1,2
Netherlands	0,9	0,7	1	0,9		1,1	0,25	1,5	0,8
North Macedonia	1	0,8	1,1	1	1,6	1,3	0,25	1,5	1,1
Norway	1	0,8	1,1	1,3		1,1	0,25		1,1
Poland	1,1	0,8	1,1	1,1		1,3	0,25	1,9	1,1
Portugal	1,3	0,8	1,3		1,6	1,5	0,25	2,7	1,4
Romania	1,1	0,9	1,2	1,3	2,1	1,3	0,25	2	1,2
Serbia	1,1	0,9	1,2	1,2	1,6	1,3	0,25	1,7	1,1
Slovakia	1	0,8	1,2	1,2		1,2	0,25	1,7	1,1
Slovenia	1	0,8	1,1	1,1	1,6	1,2		1,5	1,1
Spain	1,1	0,8	1,2	1,2	1,3	1,3	0,25	2,2	1,2
Sweden	1	0,8	1	1,1		1	0,25	1,5	1
Switzerland	0,9	0,8	1	1	1,6	1	0,25	1,5	1
Turkey	1	0,8	1,1	1	1,6	1,3	0,25	1,5	1,1
United Kingdom	0,9	0,8	1	1		0,9	0,25	1,5	0,9

Table 2 Residue to Product Ratios[12]

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[12] Source: from (N. Scarlat F. F.-F., 2019)

3.3 Appendix: Feedstock average density

Country	Average density (kg/m3)
Agricultural residue	170
Liquid biowaste	1000
Solid biowaste	400
Intermediate crops	800
Green waste	400
Liquid manure	1000
Solid manure	400

Table 3: Feedstock average density[13]

3.4 Appendix: Parameters for manure

Name	Manure type	Dry matter content [%]	Coefficient straw in the manure	Number of days in stable	Dejection [kg DM/y/head]	Methanogenic power [m3CH4 /tDM]
Dairy cows	Solid	0,17	0,6	180	1948	168
Non dairy cows	Solid	0,25	1,1	150	1612	168
Other bovine animals	Solid	0,17	0,8	165	873	168
Sheep	Solid	0,3	1,1	150	148	192
Goat	Solid	0,45	1,1	365	336	184
Pig	Solid	0,3	1,1	365	76	192
Poultry	Solid	0,6	1,1	365	12	240
Dairy cows	Liquid	0,1	0,6	180	1948	160
Non dairy cows	Liquid	0,1	1,1	150	1612	160
Other bovine animals	Liquid	0,1	0,8	165	873	160
Sheep	Liquid	0,05	1,1	150	148	192
Goat	Liquid	0,15	1,1	365	336	184
Pig	Liquid	0,05	1,1	365	76	232
Poultry	Liquid	0,15	1,1	365	12	240

Table 4: Factor for manure[14]

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[13] Sources: from (Union Régionale des Experts Fonciers, Agricoles, et Immobiliers du Nord de la France, 2021) for agriculture residues manure, green waste; from (Sindra - observatoire des déchets en Auvergne-Rhône-Alpes, 2021) for biowaste liquid and solid.

[14] Sources: (ADEME, 2018), (N. Scarlat F. F.-F., 2018)

3.5 Appendix: Parameters for Industrial waste

Name	Residues type	Availability (%)[15]	Mobilisation (%)	Residue after processing (%)[16]	Global mobilisation (%)
Sugar beet	Pulp	86%	50%	50%	22%
Potato	Pulp	10%	100%	20%	2%
Grape	Grape pomace	100%	100%	20%	20%
Olive	Olive pomace	100%	100%	25%	25%
Fruit	Fruit waste				0%

Table 5: Assumptions for industrial waste from co-product of agriculture products

Animal	Waste	Total coproducts (kg/head)[17]	Methanogenic power(m3CH4/t)[18]	Mobilisation based on ADEME (ap. 3 TWh biomethane in France)	Final Coefficient (t/head)	Final Coefficient (m3CH4/head)
Adult cattle	Co-product	110	90	100%	0,11	9,9
Calve and young cattley	Co-product	40	90	100%	0,04	3,6
Pig	Co-product	12	90	100%	0,012	1,08
Sheep	Co-product	3,5	90	100%	0,0035	0,315

Animal	Waste	Total milk production (l/head)	Raw milk in the cheese industry	Lacteroserum ratio (coagulation)	Mobilisation ADEME, competing uses	Methanogenic power lacteroserum	Final Coefficient (l/head)	Final Coefficient (m3CH4/head)
Dairy cows	Milk	8400	44%	90%	10%	34	332,64	11,30976

Table 6: Assumptions for industrial waste from co-product of livestock products[19]

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[15] Source: (Feedipedia, 2021)

[16] Sources: (Achkar, 2018), (FAO, 1984)

[17] Sources: (France Agri Mer, 2013)

[18] Sources: (ADEME, 2013)

[19] Sources: (ADEME, 2018), (CIWF, 2021)

3.6 Appendix: Biomass potential in EU-27 + 10

TWh	Agriculture residues	Intermediate crops	Manure	Industrial waste	Green waste	Forest wood and residues	Pruning
France	38,00	62,60	30,40	6,58	20,61	71,12	3,95
Germany	21,83	41,04	21,72	4,47	17,64	97,67	0,89
Turkey	26,83	80,03	20,17	4,49	28,74	8,76	5,67
Spain	24,22	48,37	15,42	4,20	17,35	11,68	11,48
Romania	26,06	43,30	5,03	1,11	6,00	31,52	1,52
Poland	15,43	45,77	10,33	2,91	9,69	19,57	0,52
Sweden	1,78	5,04	0,37	0,20	8,78	80,52	0,01
Italy	12,96	23,31	14,42	3,87	14,11	18,04	5,39
United Kingdom	12,07	19,56	27,15	2,30	21,83	7,38	0,04
Finland	1,61	5,08	0,72	0,24	5,97	43,45	0,00
Norway	0,19	0,74	0,26	0,14	6,20	44,86	0,00
Austria	1,84	5,00	2,07	0,66	3,04	37,22	0,20
Hungary	11,57	19,91	2,17	0,57	2,84	12,40	0,53
Bulgaria	8,97	15,90	0,87	0,25	2,91	2,84	0,49
Czechia	4,39	9,83	1,55	0,54	2,72	10,42	0,13
Greece	2,92	6,87	2,31	0,71	4,47	6,30	2,34
Netherlands	1,00	2,04	14,12	1,29	4,12	0,89	0,02
Denmark	4,17	8,27	5,33	0,67	2,02	1,59	0,01
Ireland	0,67	1,06	13,27	0,97	2,55	2,35	0,00
Serbia	5,42	9,62	1,33	0,38	2,00	1,77	0,12
Lithuania	1,83	5,81	0,59	0,28	1,53	8,32	0,03
Latvia	0,80	2,38	1,66	0,17	1,59	11,57	0,01
Portugal	1,56	3,94	3,29	0,49	3,71	3,09	1,62
Belgium	1,00	1,54	7,25	0,74	3,47	1,08	0,03
Switzerland	0,58	0,99	2,47	0,39	3,09	7,52	0,06
Slovakia	3,13	6,14	0,75	0,27	1,38	1,67	0,10
Croatia	1,72	3,06	0,74	0,21	1,83	3,29	0,17
Slovenia	0,24	0,45	0,44	0,08	0,61	7,89	0,10
Estonia	0,44	1,57	0,10	0,04	1,11	5,88	0,00
Macedonia	0,37	1,04	0,35	0,15	0,52	1,30	0,11
Albania	0,15	0,33	0,88	0,24	0,46	0,21	0,15
Iceland	0,00	0,00	0,08	0,01	2,06	0,00	0,00
Montenegro	0,01	0,02	0,03	0,03	0,35	0,57	0,01
Cyprus	0,00	0,00	0,23	0,02	0,44	0,02	0,11
Luxembourg	0,05	0,09	0,31	0,03	0,16	0,17	0,01
Malta	0,00	0,00	0,10	0,00	0,09	0,00	0,00
Liechtenstein	0,00	0,00	0,01	0,00	0,01	0,00	0,00

Table 7: Biomass potential in EU-27 + 10

3.7 Appendix: Feedstock cost

€2019/ton	Agriculture Residues	Biowaste Liquid	Biowaste Solid	CIVE	Forest residues	Forest wood	Green waste	Manure Liquid	Manure Solid	Pruning
Albany	60,22	0,00	0,00	39,10	33,62	32,01	13,38	0,00	0,00	12,69
Austria	88,68	0,00	0,00	65,21	79,27	95,71	16,74	0,00	0,00	59,86
Belgium	59,91	0,00	0,00	40,22	79,88	96,87	17,11	0,00	0,00	65,94
Bulgaria	33,41	0,00	0,00	21,69	37,99	35,77	12,96	0,00	0,00	23,47
Switzerland	74,73	0,00	0,00	54,95	68,39	80,65	14,10	0,00	0,00	50,44
Cyprus	62,10	0,00	0,00	40,32	67,40	84,25	14,37	0,00	0,00	38,18
Czechia	56,78	0,00	0,00	36,87	74,70	90,71	15,92	0,00	0,00	28,21
Germany	70,54	0,00	0,00	40,43	80,30	90,71	16,56	0,00	0,00	67,70
Denmark	62,24	0,00	0,00	40,41	64,09	71,76	14,18	0,00	0,00	122,96
Estonia	44,17	0,00	0,00	28,68	45,94	42,81	18,40	0,00	0,00	25,65
Greece	68,82	0,00	0,00	44,69	70,97	88,04	15,29	0,00	0,00	42,31
Spain	53,49	0,00	0,00	30,80	79,17	95,50	16,20	0,00	0,00	51,81
Finland	60,05	0,00	0,00	38,99	88,71	107,34	17,91	0,00	0,00	57,42
France	37,59	0,00	0,00	24,51	69,18	86,16	15,13	0,00	0,00	60,28
Croatia	44,02	0,00	0,00	28,59	37,16	35,39	13,88	0,00	0,00	22,72
Hungary	48,34	0,00	0,00	31,39	38,87	34,70	13,26	0,00	0,00	22,01
Ireland	40,24	0,00	0,00	26,13	67,20	81,60	14,33	0,00	0,00	50,75
Iceland	69,42	0,00	0,00	45,08	94,19	121,10	19,28	0,00	0,00	65,44
Italy	53,70	0,00	0,00	30,92	70,65	85,79	15,06	0,00	0,00	61,36
Lithuania	36,38	0,00	0,00	23,62	47,01	41,64	15,39	0,00	0,00	19,88
Luxembourg	83,03	0,00	0,00	53,92	80,92	95,90	16,31	0,00	0,00	63,89
Latvia	37,60	0,00	0,00	24,41	42,66	39,75	14,55	0,00	0,00	22,41
Montenegro	67,10	0,00	0,00	43,57	24,28	40,02	13,38	0,00	0,00	12,69
North Macedonia	53,34	0,00	0,00	34,64	28,01	32,01	13,38	0,00	0,00	11,28
Malta	53,87	0,00	0,00	34,98	73,09	91,36	14,96	0,00	0,00	28,98
Netherlands	58,90	0,00	0,00	37,03	54,80	108,30	18,07	0,00	0,00	81,39
Norway	61,64	0,00	0,00	40,02	76,45	90,11	19,56	0,00	0,00	64,96
Poland	36,43	0,00	0,00	23,65	44,93	41,08	15,33	0,00	0,00	28,50
Portugal	53,75	0,00	0,00	34,91	79,56	95,98	16,28	0,00	0,00	20,03
Romania	41,52	0,00	0,00	26,96	39,19	36,39	14,04	0,00	0,00	19,24
Serbia	63,80	0,00	0,00	41,43	30,01	49,46	16,53	0,00	0,00	13,95
Slovenia	54,08	0,00	0,00	35,11	40,91	36,84	13,95	0,00	0,00	25,52
Slovakia	61,15	0,00	0,00	39,71	38,71	36,87	13,83	0,00	0,00	25,06
Turkey	51,62	0,00	0,00	33,52	74,70	93,38	15,92	0,00	0,00	26,80
United Kingdom	61,86	0,00	0,00	47,72	115,10	86,32	15,70	0,00	0,00	75,33

Table 8: Feedstock cost, source (JRC, 2015)

3.8 Appendix: Feedstock average density

Country	Average density (kg/m3)
Agricultural residue	170
Liquid biowaste	1000
Solid biowaste	400
Intermediate crops	800
Green waste	400
Liquid manure	1000
Solid manure	400

Table 9: Feedstock average density[20]

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[20] Sources: (Union Régionale des Experts Fonciers, Agricoles, et Immobiliers du Nord de la France, 2021) for agriculture residues manure, green waste; (Sindra - observatoire des déchets en Auvergne-Rhône-Alpes, 2021) for biowaste liquid and solid.

Acronyms

CAPEX	Capital expenditure
CH4	Methane
CLC	Corine Land Cover
DM	Dry matter
EEA	European Environment Agency
EFISCEN	European Forest Information SCENnario
FAO	Food and Agriculture Organization
GIS	Geographical Information System
GLW	Gridded Livestock of the World
HA	Hectare
MW	Megawatt
NUTS	Nomenclature of territorial Units for Statistics
OPEX	Operational expenditure
RPR	Residue to Ratio Product

Bibliography

Achkar, J. E. (2018). Méthanisation de marc de raisin - Caractérisation et optimisation du procédé et des prétraitements. *HAL Archives Ouvertes*.

ADEME. (2013). *Estimation des gisements potentiels de substrats utilisables en méthanisation.* Retrieved from https://www.ademe.fr/sites/default/files/assets/documents/88252_gisements-substrats-methanisation.pdf

ADEME. (2018). *Un mix de gaz 100% renouvelable en 2050?*

Berger location. (2021). Retrieved from https://www.bergerlocation.fr/location/

BioBoost. (2013). *The feedstock potential assessment for EU-27 + Switzerland in NUTS-3.* BioBoost.

Center for International Earth Science Information Network (CIESIN)/Columbia University and Information Technology Outreach Services (ITOS)/University of Georgia. (2013). Global Roads Open Access Data Set, Version 1 (gROADSv1). Retrieved from https://sedac.ciesin.columbia.edu/data/set/groads-global-roads-open-access-v1

Chambre d'Agriculture des Hauts de France. (2019). *Barème d'entraide agricole de l'Aisne.* Retrieved from https://hautsdefrance.chambres-agriculture.fr/fileadmin/user_upload/Hauts-de-France/029_Inst-Hauts-de-France/Exploitation-agricole/Gerer_son_exploitation/Bareme_entraide/20190930_BAREME_AOUT_2019_BD.pdf

CIWF. (2021). *La production standard (intensive) de lait*.

Collectif Scientifique National sur la Méthanisation. (2019). *Le pouvoir méthanogène des intrants de méthanisation.* Retrieved from http://cities.reseaudesvilles.fr/cities/5/documents/6gs6tid3ctsg76i.pdf

ENEA. (2017). *Etat des lieux du biométhane en France.*

ENEA. (2018). *Renforcer la compétitivité de la filière biométhane française: de nombreux leviers activables à court et moyen termes.*

European Biogas Association. (2020). *European Biomethane Map*. Retrieved from https://www.europeanbiogas.eu/the-european-biomethane-map-2020-shows-a-51-increase-of-biomethane-plants-in-europe-in-two-years/

FAO. (1984). *Importance de la production oléicole et des sous-produits de l'olivier*.

Feedipedia. (2021). *Sugar beet pulp, pressed or wet*. Retrieved from https://www.feedipedia.org/node/710

France Agri Mer. (2013). *Etude sur la valorisation du 5ème quartier des filières bovine, ovine et porcine en France, synthèse.*

French Ministry for Ecologic Transition. (2019). *Stratégie nationale bas carbone.*

IEA. (2020). *Outlook for biogas and biomethane.* IEA Publications.

JRC. (2015). *The JRC-EU-TIMES model. Bioenergy potentials for EU and neighbouring countries.* Joint Research Center.

JRC. (2017). *Biomass flows in the European Union.*

N. Scarlat, F. F.-F. (2018). A spatial analysis of biogas potential from manure in Europe. *Renewable and Sustainable Energy Reviews, 94*, 915-930.

N. Scarlat, F. F.-F. (2019). Integrated and spatially explicit assessment of sustainable crop residues potential in Europe. *Biomass and Bioenergy*, 257-259.

NAVIGANT. (2019). *Gas for climate. The optimal role for gas in a net-zero emissions energy system.*

Sindra - observatoire des déchets en Auvergne-Rhône-Alpes. (2021). *Densité des déchets*. Retrieved from http://www.sindra.org/les-dechets-en-auvergne-rhone-alpes/dechets-non-dangereux/fonctionnement-de-sindra/densite-des-dechets

Union Régionale des Experts Fonciers, Agricoles, et Immobiliers du Nord de la France. (2021). Retrieved from expertagricolenord.fr