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Large-scale introduction of biobased fuels for transportation sector using residual biomass and waste in the EU area.

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Summary

1. Introduction

1.1 Greenhouse effect: a global problem

Greenhouse effect is a phenomenon of global heating caused by specific gases present in atmosphere. Those gases are defined as greenhouse gases.

Greenhouse gases are CO_2, water vapour, CH_4, O_3, N_2O[1].

Also other substances cause greenhouse effect: chlorofluorocarbons (CFS and HCFS), hydrofluorocarbons (HFC, PFC and SF_6) and brominated compounds (halon such as CF_3Br)[1].

There are two types of greenhouse effects[2]:

1) Natural greenhouse effect, that is caused by greenhouse gases emitted naturally by the environment (by organic decomposition, volcanoes, etc.). This effect is completely reabsorbed by chlorophyll photosynthesis.
2) Anthropic greenhouse effect, that is caused by human activities (such as industry, transports, agriculture, breeding)[2].

Anthropic greenhouse effect becomes, over the years starting from the XIX century with the industrial revolutions, more important and dangerous.

The most important reason for GHG emissions rising in XIX century, is the usage of carbon in industry, transport and domestic heating.

In XX century, CO_2 emissions increase exponentially with the use of products derived from petroleum and for many of those, with their combustion. In particular "anthropic CO_2 emissions in atmosphere increased by 40% because of combustion of petroleum, methane and carbon in transport sector, domestic heating, industrial production and electricity production"[2]. Also methane emission is growing a lot, because of intensive breeding. "It is estimated that, in the last 2 centuries, CO_2 and CH_4 emissions grew up by 30 % and 200 % respectively"[2].

Human activities produce different greenhouse gases that have different impacts on global warming. To quantify the impact of each greenhouse gas, a particular number is set: GWP (global warming potential). "It expresses the effect of a greenhouse gas with respect to CO_2 whose reference potential is 1. Each value of GWP is calculated in a specific period of time: 20, 100, 500 years"[3]. In table 1, is defined the GWP potential of various substances with respect to CO_2 over the years.

Table 1: GWP of substances taken into consideration. Source: IPCC 2007 [1]

Gas	Lifecycle (y)	GWP (20 y)	GWP (100 y)
CO_2	50 – 200	1	1
CH_4	12	72	25
Nitrogen oxide	114	310	298
HFC	1,4 – 270	437 – 12000	124 – 14800
PFC	2600 – 50000	5210 – 8630	7390 – 12200
SF_6	3200	16300	22800
CFC	45 – 1700	5310 – 11000	4750 – 14400
HCFC	1,3 – 17,9	273 – 5490	77 – 2310
Halon	16 – 65	3680 – 8480	1640 – 7140

1.2 Historical agreements on climate change

To solve the problem of greenhouse effect, many agreements over the last 35 years have been subscribed. As can be seen in the site of the Italian Ministry of Ecologic Transition: in 1988 was created the Intergovernmental group on climate change. A scientific committee is summoned to study the causes, impacts of climate changes and possible solutions to the problem[4];

in 1992 was adopted the United Nations Framework Convention on Climate Change (UNFCCC) [4]. Conference on environment and development of United Nations, called also “Earth Summit”, done in Rio De Janeiro, adopt the framework convention[4]. The convention aims at stabilization of greenhouse gas concentration in atmosphere at a level quite low to prevent anthropogenic interferences harmful for the climate system[4];

in 1997 the subscription of Kyoto Protocol. It foresees reductions or limitations of GHG emissions for 38 industrialized countries and EU with the possibility of using flexible mechanisms like emission trading. It becomes effective in 2005, without the ratification of US[4];

in 2005, the directive “Emission Trading” of European Union becomes effective [4]. The first phase of European Union Emissions Trading Scheme starts[4]. It is the first and the biggest Emission trading system in the world[4];

in 2008, starts the first period of Kyoto Protocol commitment [4]. Countries who subscribed this protocol are committed to reducing their emissions on average by 5 % with respect to 1990 levels by 2012[4];

in 2009 at Cop15 in Copenhagen, developed countries make the commitment to mobilize jointly, starting in 2020, 100 mld dollars of resources per year [4]. These financial resources serve to assist developing countries in the actuation of mitigation and adaptation measures[4];

in 2011 an agreement on a new platform to negotiate a deal post-2020 is subscribed [4]. Stakeholders of UNFCCC launch the Ad Hoc Working Group on the Durban Platform for Enhanced Action (ADP), a subsidiary body of the Convention that has to reach a new binding agreement that, starting in 2020, adjust GHG emissions of all countries by 2015[4]. Jointly, a new deal is reached on a second period of reduction under Kyoto Protocol[4];

in 2012 was adopted the Doha amendment [4]. Stakeholders of Kyoto Protocol adopt, through an amendment, the second period of commitment for industrialized countries by 2013 to 2020[4]. Interested countries are committed to reduce their emissions of at least 18 % with respect to those of 1190 by 2020[4];

in 2014 agreement on *"Lima Call for Climate Action"* is subscribed [4]**.** Cop20, reunited in Lima, reconfirms the necessity that all countries present by the first four months of 2015, or before Paris Conference, the national contribution of reducing emissions for the new agreement, that must be concentrated on the mitigation or on the reductions/limitations of GHG emissions and that can contain possible actions of adaptation[4]. Such contributions will have to be clear, transparent and to contain quantifiable informations[4].

In December 2015, Paris agreement is subscribed: it establishes that all stakeholders are committed to maintain mean growing of the temperature of the world well below 2 °C with respect to pre-industrial levels as long-term objective, with the future aim to maintain it even below 1,5 °C [5]. This result must be achieved with the reduction of emission of ghg. Each country defines its own contribution on policies against climate change with the presentation of NDC (Nationally Determined Contributions)[5].

1.3 The role of EU on fighting against climate change

The role of EU was fundamental both in political aspect with a primary role of intermediation for the subscription of Paris Agreement and in reform policy on climate.[5]

On 5 October 2016, EU presented its first version of NDC, in which it is subscribed that "EU and its Member States are committed to a binding target of an at least 40 % domestic reduction in greenhouse gas emissions by 2030 compared to 1990, to be fulfilled jointly, as set out in the conclusions by the European Council of October 2014."[6]

Just one month later, "the European Commission published its 'Clean Energy for all Europeans' initiative. As part of this package, the Commission adopted a legislative proposal for a recast of the Renewable Energy Directive. In the context of the co-decision procedure, a final compromise text among the EU institutions was agreed in June 2018.

In December 2018, the revised renewable energy directive 2018/2001/EU entered into force" (RED II). [7]

In fact, already in 2009, was subscribed the first version of the renewable energy directive (RED).

It established "an overall policy for the production and promotion of energy from renewable sources in the EU. It requires the EU to fulfil at least 32% of its total energy needs with renewable energy by 2030 and builds on the already achieved progress, including the achievement of the EU target of 20% renewables by 2020".[8]

1.4 Actual policies on climate change: focus on EU

Actually, RED II is effective and establishes a new target of consumption of Renewable energy sources by 2030 has to be raised to 32 %, also with particular attention on transportation sector: in fact, 14 % of energy consumed in this sector must be provided by renewable energy sources. [7]

The final target, as written above, is to reduce GHG emissions of each EU Nation of 40 % by 2030 with respect to levels in 1990.

1.5 GHG emissions in Europe

In figure 1 is described in detail which are the main causes of GHG emissions in Europe. It can be highlighted that the energy supply causes mostly GHG emissions, even if it is in a gradual negative trend. It is followed by transportation sector, that has recently passed over the industrial sector.

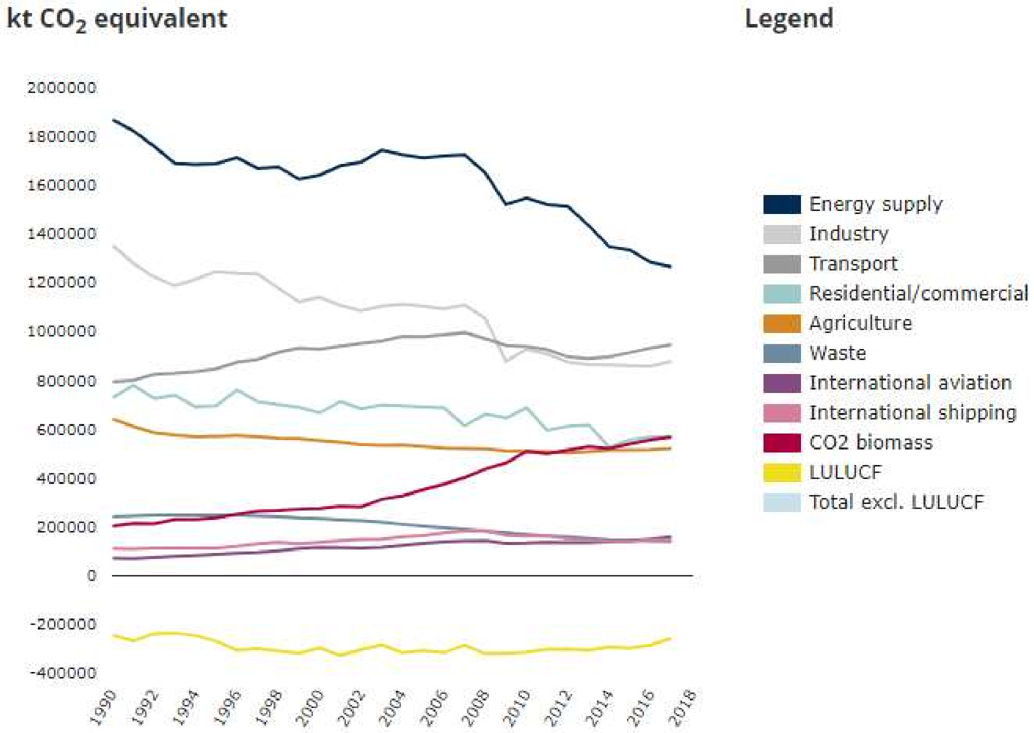


Figure 1: GHG emission of each sector in Europe [9]

Negative trends in energy and industrial sector are caused by the increasing implementation of renewable sources and nuclear energy, and meanwhile by the decreasing of fossil fuels contributions.

1.6 Focus on transportation sector

Transportation sector is highlighted in this work, because as can be seen in figure 1, between the first three sectors that cause GHG emissions, it is the only one in a growing trend.

That's why in RED II is defined that 14 % of rail and road transport consumption must be covered by renewable sources by 2030.

Between renewable sources considered in transportation sector, a relevant part is made up of biofuels.

In particular in article 26 part 1 of RED II is set that “the share of biofuels and bioliquids, as well as of biomass fuels consumed in transport, where produced from food and feed crops, shall be no more than one percentage point higher than the share of such fuels in the final consumption of energy in the road and rail transport sectors in 2020 in that Member State, with a maximum of 7 % of final consumption of energy in the road and rail transport sectors in that Member State.” [10]

It is also set that “the contribution of advanced biofuels and biogas produced from the feedstock listed in Part A of Annex IX as a share of final consumption of energy in the transport sector shall be at least 0,2 % in 2022, at least 1 % in 2025 and at least 3,5 % in 2030.” [10]

1.7 Definition of biofuels

Biofuels are fuels produced by specifical treatments from biomass. These fuels are used for transportation sector. [11] Biofuels are defined in four categories:

1) **First-generation biofuels**. The first-generation biofuels are obtained from sources like starch, sugar, animal fats, and vegetable oil[11]. The oil is gained using conventional production techniques. Famous examples of first-generation biofuels are ethanol, biodiesel, other bioalcohols, green diesel, biofuel gasoline, vegetable oil, bioethers, biogas, syngas, and solid biofuels [11].
2) **Second-generation biofuels**. The second-generation biofuels, also known as advanced biofuels, are fuels gained from various types of biomass, including plant materials as well as animal materials [11]. The feedstock is a non-food biomass, in contrast to the first-generation biofuels. Famous examples of second-generation biofuels are hydrotreating oil, bio-oil, FT oil, lignocellulosic ethanol, butanol, and mixed alcohols[11].
3) **Third-generation biofuels**. The third-generation biofuels are gained by aquatic autotrophic organism (e.g., algae) [11].
4) **Fourth-generation biofuels**. “In fourth-generation production systems, biomass crops are seen as efficient “carbon capturing” components that take CO_2 out of the atmosphere and lock it up in their branches, trunks, and leaves. The carbon-rich biomass is then converted into fuel and gases by means of second-generation techniques. Crucially, before, during, or after the bioconversion process, the carbon dioxide is captured by utilizing the so-called precombustion, oxyfuel, or

post-combustion processes. The fourth-generation biofuels are biohydrogen, biomethane, and synthetic biofuels".[11]

In table 2, are summarized three generations of biofuels based on biomass feedstock and production process.

Table 2: generations of biofuels, overview [11]

	Biofuel	Biomass feedstock	Production process
First-generation biofuels	Biobutanol	Sugar crops	Fermentation and saccharification
	Biodiesel	Oil crops	Transesterification
	Bioethanol	Sugar and crops	Fermentation
	Bioethanol	Lignocellulosic materials	Advanced enzymatic hydrolysis and fermentation
Second-generation biofuels	Biomethanol	Lignocellulosic materials	Gasification, synthesis, and catalytic cracking
	Dimethyl ether	Lignocellulosic materials	Gasification, synthesis and catalytic cracking
	Fischer- tropsch diesel	Lignocellulosic materials	Gasification, synthesis and catalytic cracking
	Biogas	Lignocellulosic materials	Synthesis and anaerobic digestion
	Biohydrogen	Lignocellulosic materials	Synthesis, gasification, fermentation
Third-generation biofuels	Vegetable oil, biodiesel	Algae	Transesterification

These biofuels can substitute partially or totally fossil fuels in transportation sector.
In order:

- Biobutanol from sugar crops can form blend with gasoline until 16 % in volume. [12]
- Biodiesel can replace fossil diesel. [13]
- Bioethanol can replace partially gasoline without changing engine until 20 %, or even more using particular engines. [14]
- Biomethanol can be used as a fuel, but is essentially an intermediate product, to produce other biofuels or chemical products such as: formaldehyde, olefins, DME and biodiesel. [12]

- Dimethyl ether is used as substitute of fossil diesel (it is used for example in Volvo trucks). [12]
- Fischer-Tropsch Diesel can substitute fossil diesel. [15]
- Biogas is an intermediate product to produce biomethane (as it can be seen in next chapters). Biomethane is a substitute of natural gas. In some case, for example in Sweden, to biomethane is added propane in order to be chemically equal to fossil natural gas [16]
- Biohydrogen needs particular fuel cell engines. It is mixed with oxygen. [17]

With the introduction of these biofuels in transportation sector, an increasing and important problem is developing. The growing use of first-generation biofuels and world population growth lead to the debate food vs fuel.

In fact, there is an increasing demand of using and converting land for energy cultures and for production of food. It is reported that if there was no biofuels policy from 2013 in Europe, 6 million hectares (0,7 % of world) of land would not be used for energy cultures in 2020. [18]

In figure 3 is represented how biodiesel and ethanol production in the world grew between 2000 and 2011:

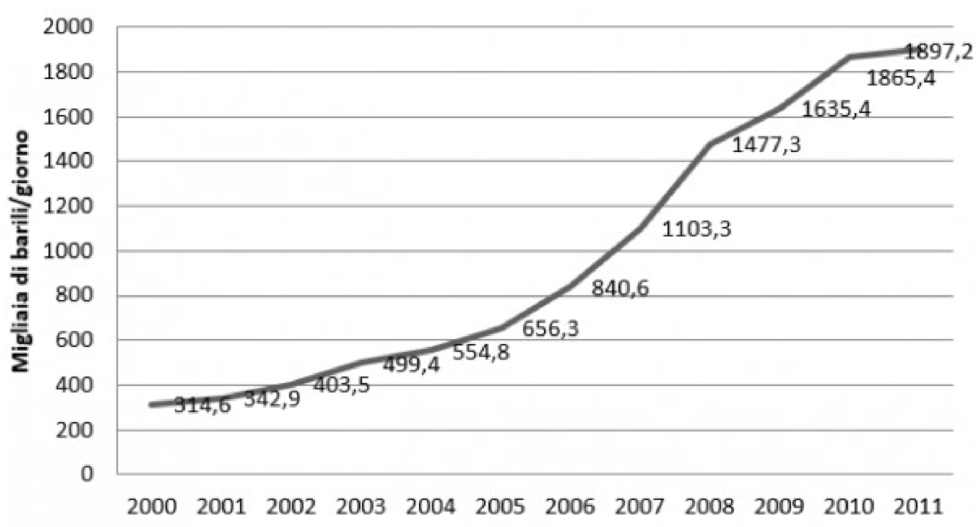


Figure 2: Ethanol and Biodiesel production: thousands of barrels per day [19]

This sudden and massive growth in production of these biofuels causes an important increase on the price of food in 55 countries classified by FAO as at low income with a major risk of poverty because for them will be hard to increase biofuels production together with food production. [19]

1.8 Definition of biomass

To define the generation of biofuels, it is necessary to highlight where they come from. The term "biomass means the biodegradable fraction of products, waste and residues from biological origin from agriculture, including vegetal and animal substances, from forestry and related industries, including fisheries and aquaculture, as well as the biodegradable fraction of waste, including industrial and municipal waste of biological origin"[10]. There are many types of biomass:

- Woody biomass
- Herbaceous biomass
- Aquatic biomass
- Animal and human waste biomass [20]

Chemical composition of biomasses is given in table 3:

Table 3: chemical composition of 86 varieties of biomass plus algae and four solid fossil fuel types based on proximate and ultimate analysis. The Cl contents are additionally given, wt. % [21]

Biomass group, sub-group and variety	Proximate analysis (am)[a]					Proximate analysis (db)[b]				Ultimate analysis (daf)[c]						Cl (db)[b]	n[d]
	VM	FC	M	A	Sum	VM	FC	A	Sum	C	O	H	N	S	Sum		
1. Wood and woody biomass (WWB)																	
1. Alder-fir sawdust	36.3	9.1	52.6	2.0	100.0	76.6	19.2	4.2	100.0	53.2	40.2	6.1	0.5	0.04	100.04	0.02	1
2. Balsam bark	70.9	18.3	8.4	2.4	100.0	77.4	20.0	2.6	100.0	54.0	39.5	6.2	0.2	0.10	100.00		1
3. Beech bark	67.5	17.0	8.4	7.1	100.0	73.7	18.5	7.8	100.0	51.4	41.8	6.0	0.7	0.11	100.01		1
4. Birch bark	71.9	17.8	8.4	1.9	100.0	78.5	19.4	2.1	100.0	57.0	35.7	6.7	0.5	0.10	100.00		2
5. Christmas trees	46.1	12.9	37.8	3.2	100.0	74.2	20.7	5.1	100.0	54.5	38.7	5.9	0.5	0.42	100.02		1
6. Elm bark	67.0	17.2	8.4	7.4	100.0	73.1	18.8	8.1	100.0	50.9	42.5	5.8	0.7	0.11	100.01		1
7. Eucalyptus bark	68.7	15.1	12.0	4.2	100.0	78.0	17.2	4.8	100.0	48.7	45.3	5.7	0.3	0.05	100.05	0.26	1
8. Fir mill residue	30.4	6.5	62.9	0.2	100.0	82.0	17.5	0.5	100.0	51.4	42.5	6.0	0.1	0.03	100.03	0.19	1
9. Forest residue	34.5	7.3	56.8	1.4	100.0	79.9	16.9	3.2	100.0	52.7	41.1	5.4	0.7	0.10	100.00	0.03	2
10. Hemlock bark	65.9	23.4	8.4	2.3	100.0	72.0	25.5	2.5	100.0	55.0	38.8	5.9	0.2	0.10	100.00		1
11. Land clearing wood	35.4	7.0	49.2	8.4	100.0	69.7	13.8	16.5	100.0	50.7	42.8	6.0	0.4	0.07	99.97	0.02	1
12. Maple bark	70.1	17.8	8.4	3.7	100.0	76.6	19.4	4.0	100.0	52.0	41.3	6.2	0.4	0.11	100.01		2
13. Oak sawdust	76.3	11.9	11.5	0.3	100.0	86.3	13.4	0.3	100.0	50.1	43.9	5.9	0.1	0.01	100.01	0.01	1
14. Oak wood	73.0	20.0	6.5	0.5	100.0	78.1	21.4	0.5	100.0	50.6	42.9	6.1	0.3	0.10	100.00		1
15. Olive wood	74.3	16.1	6.6	3.0	100.0	79.6	17.2	3.2	100.0	49.0	44.9	5.4	0.7	0.03	100.03		1
16. Pine bark	70.2	23.3	4.7	1.8	100.0	73.7	24.4	1.9	100.0	53.8	39.9	5.9	0.3	0.07	99.97	0.01	2
17. Pine chips	66.9	20.0	7.6	5.5	100.0	72.4	21.6	6.0	100.0	52.8	40.5	6.1	0.5	0.09	99.99	0.06	1
18. Pine pruning	43.3	7.9	47.4	1.4	100.0	82.2	15.1	2.7	100.0	51.9	41.3	6.3	0.5	0.01	100.01		1
19. Pine sawdust	70.4	14.2	15.3	0.1	100.0	83.1	16.8	0.1	100.0	51.0	42.9	6.0	0.1	0.01	100.01	0.01	1
20. Poplar	79.7	11.5	6.8	2.0	100.0	85.6	12.3	2.1	100.0	51.6	41.7	6.1	0.6	0.02	100.02	0.03	2
21. Poplar bark	73.6	16.0	8.4	2.0	100.0	80.3	17.5	2.2	100.0	53.6	39.3	6.7	0.3	0.10	100.00		1
22. Sawdust	55.1	9.3	34.9	0.7	100.0	84.6	14.3	1.1	100.0	49.8	43.7	6.0	0.5	0.02	100.02		1
23. Spruce bark	67.3	21.4	8.4	2.9	100.0	73.4	23.4	3.2	100.0	53.6	40.0	6.2	0.1	0.10	100.00	0.03	4
24. Spruce wood	75.7	17.1	6.7	0.5	100.0	81.2	18.3	0.5	100.0	52.3	41.2	6.1	0.3	0.10	100.00	0.01	1
25. Tamarack bark	63.7	24.1	8.4	3.8	100.0	69.5	26.3	4.2	100.0	57.0	32.0	10.2	0.7	0.11	100.01		1
26. Willow	74.2	14.3	10.1	1.4	100.0	82.5	15.9	1.6	100.0	49.8	43.4	6.1	0.6	0.06	99.96	0.01	11
27. Wood	77.5	14.5	7.8	0.2	100.0	84.1	15.7	0.2	100.0	49.6	44.1	6.1	0.1	0.06	99.96	0.01	1
28. Wood residue	57.4	12.2	26.4	4.0	100.0	78.0	16.6	5.4	100.0	51.4	41.9	6.1	0.5	0.08	99.98	0.05	2
Mean	62.9	15.1	19.3	2.7	100.0	78.0	18.5	3.5	100.0	52.1	41.2	6.2	0.4	0.08	99.98	0.02	28
Minimum	30.4	6.5	4.7	0.1		69.5	12.3	0.1		48.7	32.0	5.4	0.1	0.01		0.01	28
Maximum	79.7	24.1	62.9	8.4		86.3	26.3	16.5		57.0	45.3	10.2	0.7	0.42		0.05	28
2. Herbaceous and agricultural biomass (HAB)																	
Mean	66.0	16.9	12.0	5.1	100.0	75.2	19.1	5.7	100.0	49.9	42.6	6.2	1.2	0.15	100.05	0.20	44
Minimum	41.5	9.1	4.4	0.8		59.3	12.4	0.9		42.2	34.2	3.2	0.1	0.01		0.01	44
Maximum	76.6	35.3	47.9	18.6		85.5	37.9	20.1		58.4	49.0	9.2	3.4	0.60		0.83	44
2.1. Grasses (HAG)																	
29. Arundo grass	46.5	9.5	42.0	2.0	100.0	80.2	16.4	3.4	100.0	48.7	44.5	6.1	0.6	0.13	100.03	0.20	1
30. Bamboo whole	71.0	15.2	13.0	0.8	100.0	81.6	17.5	0.9	100.0	52.0	42.5	5.1	0.4	0.04	100.04	0.08	3
31. Bana grass	70.2	15.9	4.5	9.4	100.0	73.6	16.6	9.8	100.0	50.1	42.9	6.0	0.9	0.13	100.03	0.83	1
32. Buffalo gourd grass	73.5	12.3	10.0	4.2	100.0	81.6	13.7	4.7	100.0	46.1	44.5	6.5	2.6	0.27	99.97		1
33. Kenaf grass	73.5	15.7	7.5	3.3	100.0	79.4	17.0	3.6	100.0	48.4	44.5	6.0	1.0	0.15	100.05	0.17	1
34. Miscanthus grass	71.9	14.0	11.4	2.7	100.0	81.2	15.8	3.0	100.0	49.2	44.2	6.0	0.4	0.15	99.95	0.13	3
35. Reed canary grass	67.8	16.3	7.7	8.2	100.0	73.4	17.7	8.9	100.0	49.4	42.7	6.3	1.5	0.15	100.05	0.06	1
36. Sorghastrum grass	72.4	12.6	11.3	3.7	100.0	81.6	14.2	4.2	100.0	49.4	44.0	6.3	0.3	0.05	100.05	0.04	1
37. Sweet sorghum grass	71.8	16.8	7.0	4.4	100.0	77.2	18.1	4.7	100.0	49.7	43.7	6.1	0.4	0.09	99.99	0.30	1
38. Switchgrass	70.8	12.8	11.9	4.5	100.0	80.4	14.5	5.1	100.0	49.7	43.4	6.1	0.7	0.11	100.01	0.08	3
Mean	69.0	14.1	12.6	4.3	100.0	79.0	16.2	4.8	100.0	49.2	43.7	6.1	0.9	0.13	100.03	0.21	10
Minimum	46.5	9.5	4.5	0.8		73.4	13.7	0.9		46.1	42.5	5.1	0.3	0.04		0.04	10
Maximum	73.5	16.8	42.0	9.4		81.6	18.1	9.8		52.0	44.5	6.5	2.6	0.27		0.83	10
2.2. Straws (HAS)																	
39. Alfalfa straw	71.6	14.3	9.3	4.8	100.0	78.9	15.8	5.3	100.0	49.9	40.8	6.3	2.8	0.21	100.01	0.50	1
40. Barley straw	67.4	16.4	11.5	4.7	100.0	76.2	18.5	5.3	100.0	49.4	43.6	6.2	0.7	0.13	100.03	0.27	2
41. Corn straw	67.7	17.8	7.4	7.1	100.0	73.1	19.2	7.7	100.0	48.7	44.1	6.4	0.7	0.08	99.98	0.64	1

42. Mint straw	58.0	16.2	16.8	9.0	100.0	69.7	19.5	10.8	100.0	50.6	40.1	6.2	2.8	0.28	99.98	0.43	1
43. Oat straw	73.9	12.5	8.2	5.4	100.0	80.5	13.6	5.9	100.0	48.8	44.6	6.0	0.5	0.08	99.98	0.09	1
44. Rape straw	70.7	16.3	8.7	4.3	100.0	77.4	17.9	4.7	100.0	48.5	44.5	6.4	0.5	0.10	100.00	0.03	1
45. Rice straw	59.4	14.4	7.6	18.6	100.0	64.3	15.6	20.1	100.0	50.1	43.0	5.7	1.0	0.16	99.96	0.58	3
46. Straw	64.3	13.8	12.4	9.5	100.0	73.4	15.8	10.8	100.0	48.8	44.5	5.6	1.0	0.13	100.03	0.54	2
47. Wheat straw	67.2	16.3	10.1	6.4	100.0	74.8	18.1	7.1	100.0	49.4	43.6	6.1	0.7	0.17	99.97	0.61	12
Mean	66.7	15.3	10.2	7.8	100.0	74.3	17.1	8.6	100.0	49.4	43.2	6.1	1.2	0.15	100.05	0.41	9
Minimum	58.0	12.5	7.4	4.3		64.3	13.6	4.7		48.5	40.1	5.6	0.5	0.08		0.03	9
Maximum	73.9	17.8	16.8	18.6		80.5	19.5	20.1		50.6	44.6	6.4	2.8	0.28		0.64	9
2.3. Other residues (HAR)																	
48. Almond hulls	69.0	18.8	6.5	5.7	100.0	73.8	20.1	6.1	100.0	50.6	41.7	6.4	1.2	0.07	99.97	0.02	1
49. Almond shells	69.5	20.2	7.2	3.1	100.0	74.9	21.8	3.3	100.0	50.3	42.5	6.2	1.0	0.05	100.05	0.06	2
50. Coconut shells	70.5	22.0	4.4	3.1	100.0	73.8	23.0	3.2	100.0	51.1	43.1	5.6	0.1	0.10	100.00		1
51. Coffee husks	68.2	18.5	10.8	2.5	100.0	76.5	20.7	2.8	100.0	45.4	48.3	4.9	1.1	0.35	100.05		2
52. Cotton husks	73.0	16.9	6.9	3.2	100.0	78.4	18.2	3.4	100.0	50.4	39.8	8.4	1.4	0.01	100.01		1
53. Grape marc	59.2	23.8	10.0	7.0	100.0	65.8	26.4	7.8	100.0	54.0	37.4	6.1	2.4	0.15	100.05		1
54. Groundnut shells	68.1	20.9	7.9	3.1	100.0	73.9	22.7	3.4	100.0	50.9	40.4	7.5	1.2	0.02	100.02	0.01	2
55. Hazelnut shells	71.5	19.9	7.2	1.4	100.0	77.1	21.4	1.5	100.0	51.5	41.6	5.5	1.4	0.04	100.04	0.20	1
56. Mustard husks	68.5	22.0	5.6	3.9	100.0	72.6	23.3	4.1	100.0	45.8	44.4	9.2	0.4	0.20	100.00		1
57. Olive husks	73.7	17.4	6.8	2.1	100.0	79.0	18.7	2.3	100.0	50.0	42.1	6.2	1.6	0.05	99.95	0.20	1
58. Olive pits	72.3	18.7	6.1	2.9	100.0	77.0	19.9	3.1	100.0	52.8	39.4	6.6	1.1	0.07	99.97	0.04	2
59. Olive residue	60.2	22.8	10.6	6.4	100.0	67.3	25.5	7.2	100.0	58.4	34.2	5.8	1.4	0.23	100.03	0.20	1
60. Palm fibres-husks	46.3	12.0	36.4	5.3	100.0	72.8	18.9	8.3	100.0	51.5	40.1	6.6	1.5	0.30	100.00		1
61. Palm kernels	68.8	15.6	11.0	4.6	100.0	77.3	17.5	5.2	100.0	51.0	39.5	6.5	2.7	0.27	99.97	0.21	1
62. Pepper plant	60.5	19.5	6.5	13.5	100.0	64.7	20.9	14.4	100.0	42.2	49.0	5.0	3.2	0.57	99.97	0.13	1
63. Pepper residue	58.5	24.4	9.7	7.4	100.0	64.8	27.0	8.2	100.0	45.7	47.1	3.2	3.4	0.60	100.00		1
64. Pistachio shells	75.5	15.7	7.5	1.3	100.0	81.6	17.0	1.4	100.0	50.9	41.8	6.4	0.7	0.22	100.02	0.01	1
65. Plum pits	53.7	11.8	33.6	0.9	100.0	80.8	17.8	1.4	100.0	49.9	42.4	6.7	0.9	0.08	99.98	0.01	1
66. Rice husks	56.1	17.2	10.6	16.1	100.0	62.8	19.2	18.0	100.0	49.3	43.7	6.1	0.8	0.08	99.98	0.12	2
67. Soya husks	69.6	19.0	6.3	5.1	100.0	74.3	20.3	5.4	100.0	45.4	46.9	6.7	0.9	0.10	100.00		1
68. Sugar cane bagasse	76.6	11.1	10.4	1.9	100.0	85.5	12.4	2.1	100.0	49.8	43.9	6.0	0.2	0.06	99.96	0.03	2
69. Sunflower husks	69.1	19.0	9.1	2.8	100.0	76.0	20.9	3.1	100.0	50.4	43.0	5.5	1.1	0.03	100.03	0.10	2
70. Walnut blows	61.8	12.9	23.5	1.8	100.0	80.7	16.9	2.4	100.0	54.9	36.9	6.7	1.4	0.11	100.01	0.02	1
71. Walnut hulls and blows	41.5	9.1	47.9	1.5	100.0	79.6	17.5	2.9	100.0	55.1	36.5	6.7	1.6	0.12	100.02	0.02	1
72. Walnut shells	55.3	35.3	6.8	2.6	100.0	59.3	37.9	2.8	100.0	49.9	42.4	6.2	1.4	0.09	99.99	0.15	1
Mean	64.6	18.6	12.4	4.4	100.0	74.0	21.0	5.0	100.0	50.2	41.9	6.3	1.4	0.16	99.96	0.09	25
Minimum	41.5	9.1	4.4	0.9		59.3	12.4	1.4		42.2	34.2	3.2	0.1	0.01		0.01	25
Maximum	76.6	35.3	47.9	16.1		85.5	37.9	18.0		58.4	49.0	9.2	3.4	0.60		0.21	25
3. Animal biomass (AB)																	
73. Chicken litter	43.3	13.1	9.3	34.3	100.0	47.8	14.4	37.8	100.0	60.5	25.3	6.8	6.2	1.20	100.00	0.50	1
74. Meat-bone meal	61.7	12.4	2.5	23.4	100.0	63.3	12.7	24.0	100.0	57.3	20.8	8.0	12.2	1.69	99.99	0.87	1
Mean	52.5	12.8	5.9	28.8	100.0	55.5	13.6	30.9	100.0	58.9	23.1	7.4	9.2	1.45	100.05	0.69	2
4. Mixture of biomass																	
75. Biomass mixture	63.3	16.5	8.8	11.4	100.0	69.4	18.1	12.5	100.0	56.7	33.1	6.6	2.7	0.85	99.95	0.09	1
76. Wood-agricultural residue	54.7	12.7	30.3	2.3	100.0	78.5	18.2	3.3	100.0	52.4	41.2	6.0	0.4	0.04	100.04	0.03	2
77. Wood-almond residue	59.7	12.3	22.7	5.3	100.0	77.2	15.9	6.9	100.0	50.9	42.5	5.9	0.6	0.08	99.98	0.03	1
78. Wood-straw residue	69.6	15.5	7.3	7.6	100.0	75.1	16.7	8.2	100.0	51.7	41.5	6.3	0.4	0.13	100.03	0.13	1
Mean	61.8	14.2	17.3	6.7	100.0	75.1	17.2	7.7	100.0	52.9	39.6	6.2	1.0	0.28	99.98	0.07	4
Minimum	54.7	12.3	7.3	2.3		69.4	15.9	3.3		50.9	33.1	5.9	0.4	0.04		0.03	4
Maximum	69.6	16.5	30.3	11.4		78.5	18.2	12.5		56.7	42.5	6.6	2.7	0.85		0.13	4
5. Contaminated biomass (CB)																	
79. Currency shredded	79.0	11.1	4.7	5.2	100.0	82.9	11.6	5.5	100.0	45.4	46.1	6.3	1.9	0.32	100.02		1
80. Demolition wood	63.4	14.5	16.3	5.8	100.0	75.8	17.3	6.9	100.0	51.7	40.7	6.4	1.1	0.09	99.99	0.06	4
81. Furniture waste	72.9	11.8	12.1	3.2	100.0	83.0	13.4	3.6	100.0	51.8	41.8	6.1	0.3	0.04	100.04	0.01	1
82. Mixed waste paper	76.8	6.8	8.8	7.6	100.0	84.2	7.5	8.3	100.0	52.3	40.2	7.2	0.2	0.08	99.98		1
83. Greenhouse-plastic waste	61.0	5.5	2.5	31.0	100.0	62.6	5.6	31.8	100.0	70.9	16.4	11.2	1.5	0.01	100.01	0.05	1
84. Refuse-derived fuel	70.3	0.5	4.2	25.0	100.0	73.4	0.5	26.1	100.0	53.8	36.8	7.8	1.1	0.47	99.97	0.83	2
85. Sewage sludge	45.0	5.3	6.4	43.3	100.0	48.0	5.7	46.3	100.0	50.9	33.4	7.3	6.1	2.33	100.03	0.04	2
86. Wood yard waste	40.9	8.4	38.1	12.6	100.0	66.0	13.6	20.4	100.0	52.2	40.4	6.0	1.1	0.30	100.00	0.30	1
Mean	63.7	8.0	11.6	16.7	100.0	72.0	9.4	18.6	100.0	53.6	37.0	7.3	1.7	0.46	100.06	0.31	8
Minimum	40.9	0.5	2.5	3.2		48.0	0.5	3.6		45.4	16.4	6.0	0.2	0.01		0.04	8
Maximum	79.0	14.5	38.1	43.3		84.2	17.3	46.3		70.9	46.1	11.2	6.1	2.33		0.83	8
All varieties of biomass																	
Mean	64.3	15.3	14.4	6.0	100.0	75.4	17.8	6.8	100.0	51.3	41.0	6.3	1.2	0.19	99.99	0.17	86
Minimum	30.4	0.5	2.5	0.1		47.8	0.5	0.1		42.2	16.4	3.2	0.1	0.01		0.01	86
Maximum	79.7	35.3	62.9	43.3		86.3	37.9	46.3		70.9	49.0	11.2	12.2	2.33		0.87	86
Natural biomass																	
Mean	64.4	16.0	14.7	4.9	100.0	75.8	18.6	5.6	100.0	51.1	41.4	6.2	1.1	0.20	100.00	0.17	78
Minimum	30.4	6.5	2.5	0.1		47.8	12.3	0.1		42.2	20.8	3.2	0.1	0.01		0.01	78
Maximum	79.7	35.3	62.9	34.3		86.3	37.9	37.8		60.5	49.0	10.2	12.2	1.69		0.87	78
Aquatic biomass																	
Marine macroalgae	45.1	23.1	10.7	21.1	100.0	50.5	25.9	23.6	100.0	43.2	45.8	6.2	2.2	2.60	100.00	3.34	11
Solid fossil fuels																	
Peat	57.8	24.3	14.6	3.3	100.0	67.6	28.5	3.9	100.0	56.3	36.2	5.8	1.5	0.2	100.0	0.04	1
Coal	30.8	43.9	5.5	19.8	100.0	32.8	46.3	20.9	100.0	78.2	13.6	5.2	1.3	1.7	100.0	0.03	37
Coal (minimum)	12.2	17.9	0.4	5.0		12.4	20.0	5.7		62.9	4.4	3.5	0.5	0.2		0.005	37
Coal (maximum)	44.5	70.4	20.2	48.9		51.8	71.8	52.0		86.9	29.9	6.3	2.9	9.8		0.11	37
Lignite	32.8	25.7	10.5	31.0	100.0	36.7	28.7	34.6	100.0	64.0	23.7	5.5	1.0	5.8	100.0	0.01	5
Sub-bituminous coal	33.4	34.1	8.2	24.3	100.0	36.4	37.2	26.4	100.0	74.4	17.7	5.6	1.4	0.9	100.0	0.03	10
Bituminous coal	29.1	52.6	3.1	15.2	100.0	30.0	54.3	15.7	100.0	83.1	9.5	5.0	1.3	1.1	100.0	0.04	22

[a] As measured at different basis. For some samples without moisture data the mean contents measured for similar biomass varieties were used.
[b] Dry basis.
[c] Dry, ash-free basis.
[d] Number of samples.

Table above can be divided in 3 parts: a proximate analysis as measured, a proximate analysis on dry basis, and an ultimate analysis on dry ash-free basis [21].

The main difference between the proximate analysis as measured and the ultimate analysis is caused by the consideration of moisture content [21].

VM is the volatile matter, FC is the fixed carbon, M is the moisture, A is the ash yield [21].

In the ultimate analysis on dry ash-free basis, chemical elements whose made up of the biomass are defined [21].

Then in table 4 are given composition of ashes of biomasses:

Table 4: chemical ash composition of 86 varieties of biomass plus algae and four solid fossil fuel types based on high temperature ash analyses (normalized to 100 %), wt. %. The Mn contents are additionally given, ppm. [21]

Biomass group, sub-group and variety	SiO_2	CaO	K_2O	P_2O_5	Al_2O_3	MgO	Fe_2O_3	SO_3	Na_2O	TiO_2	Sum	Mn (ppm)	n[a]
1. Wood and woody biomass (WWB)													
1. Alder-fir sawdust	37.49	26.41	6.10	2.02	12.23	4.04	8.09	0.83	1.81	0.98	100.00		1
2. Balsam bark	26.06	45.76	10.70	4.87	1.91	2.33	2.65	2.86	2.65	0.21	100.00	20160	1
3. Beech bark	12.40	68.20	2.60	2.30	0.12	11.50	1.10	0.80	0.90	0.10	100.00	3100	1
4. Birch bark	4.38	69.06	8.99	4.13	0.55	5.92	2.24	2.75	1.85	0.13	100.00	22870	2
5. Christmas trees	39.91	9.75	8.06	2.46	15.12	2.59	9.54	11.66	0.54	0.37	100.00		1
6. Elm bark	4.48	83.46	5.47	1.62	0.12	2.49	0.37	1.00	0.87	0.12	100.00	775	1
7. Eucalyptus bark	10.04	57.74	9.29	2.35	3.10	10.91	1.12	3.47	1.86	0.12	100.00	10850	1
8. Fir mill residue	19.26	15.10	8.89	3.65	5.02	5.83	8.36	3.72	29.82	0.35	100.00	13640	2
9. Forest residue	20.65	47.55	10.23	5.05	2.99	7.20	1.42	2.91	1.60	0.40	100.00	13180	3
10. Hemlock bark	11.12	59.62	5.12	2.34	2.34	14.57	1.45	2.11	1.22	0.11	100.00	9300	1
11. Land clearing wood	65.82	5.79	2.19	0.66	14.85	1.81	5.27	0.36	2.70	0.55	100.00		1
12. Maple bark	8.95	67.36	7.03	0.79	3.98	6.59	1.43	1.99	1.76	0.12	100.00	5430	2
13. Oak sawdust	29.93	15.56	31.99	1.90	4.27	5.92	4.20	3.84	2.00	0.39	100.00		1
14. Oak wood	48.95	17.48	9.49	1.80	9.49	1.10	8.49	2.60	0.50	0.10	100.00	14900	2
15. Olive wood	10.24	41.47	25.16	10.75	2.02	3.03	0.88	2.65	3.67	0.13	100.00		1
16. Pine bark	9.20	56.83	7.78	5.02	7.20	6.19	2.79	2.83	1.97	0.19	100.00	12400	2
17. Pine chips	68.18	7.89	4.51	1.56	7.04	2.43	5.45	1.19	1.20	0.55	100.00	2090	1
18. Pine pruning	7.76	44.10	22.32	5.73	2.75	11.33	1.25	4.18	0.42	0.17	100.00		1
19. Pine sawdust	9.71	48.88	14.38	6.08	2.34	13.80	2.10	2.22	0.35	0.14	100.00	10550	2
20. Poplar	3.87	57.33	18.73	0.85	0.68	13.11	1.16	3.77	0.22	0.28	100.00	4500	3
21. Poplar bark	1.86	77.31	8.93	2.48	0.62	2.36	0.74	0.74	4.84	0.12	100.00	2330	1
22. Sawdust	26.17	44.11	10.83	2.27	4.53	5.34	1.82	2.05	2.48	0.40	100.00	27910	2
23. Spruce bark	6.13	72.39	7.22	2.69	0.68	4.97	1.90	1.88	2.02	0.12	100.00	13950	3
24. Spruce wood	49.30	17.20	9.60	1.90	9.40	1.10	8.30	2.60	0.50	0.10	100.00		1
25. Tamarack bark	7.77	53.50	5.64	5.00	8.94	9.04	3.83	2.77	3.40	0.11	100.00	26360	1
26. Willow	6.10	46.09	23.40	13.01	1.96	4.03	0.74	3.00	1.61	0.06	100.00		11
27. Wood	23.15	37.35	11.59	2.90	5.75	7.26	3.27	4.95	2.57	1.20	100.00	35740	1
28. Wood residue	53.15	11.66	4.85	1.37	12.64	3.06	6.24	1.99	4.47	0.57	100.00		2
Mean	22.22	43.03	10.75	3.48	5.09	6.07	3.44	2.78	2.85	0.29	100.00	13160	28
Minimum	1.86	5.79	2.19	0.66	0.12	1.10	0.37	0.36	0.22	0.06		775	28
Maximum	68.18	83.46	31.99	13.01	15.12	14.57	9.54	11.66	29.82	1.20		35740	28

2. Herbaceous and agricultural biomass (HAB)													
Mean	33.39	14.86	26.65	6.48	3.66	5.62	3.26	3.61	2.29	0.18	100.00	1330	44
Minimum	2.01	0.97	2.29	0.54	0.10	0.19	0.22	0.01	0.09	0.01		155	44
Maximum	94.48	44.32	63.90	31.06	14.60	16.21	36.27	14.74	26.20	2.02		4570	44
2.1. Grasses (HAG)													
29. Arundo grass	47.38	2.98	32.16	6.60	0.86	3.29	0.92	5.17	0.53	0.11	100.00		1
30. Bamboo whole	9.92	4.46	53.38	20.33	0.67	6.57	0.67	3.68	0.31	0.01	100.00		3
31. Bana grass	38.59	4.09	49.08	3.14	0.92	1.96	0.73	0.97	0.44	0.08	100.00		1
32. Buffalo gourd grass	8.73	14.74	41.40	10.96	1.88	5.24	0.90	9.89	6.20	0.06	100.00		1
33. Kenaf grass	9.50	44.32	19.14	3.89	2.59	8.64	1.73	8.20	1.87	0.12	100.00		1
34. Miscanthus grass	56.42	10.77	19.75	5.54	0.79	3.01	0.94	2.28	0.47	0.03	100.00	3100	4
35. Reed canary grass	84.92	3.31	2.93	3.88	1.32	1.42	1.04	1.04	0.09	0.05	100.00		1
36. Sorghastrum grass	73.21	7.02	8.97	4.43	1.83	2.21	0.95	1.11	0.25	0.02	100.00		1
37. Sweet sorghum grass	66.85	10.41	9.49	3.47	0.81	3.12	0.58	3.47	1.74	0.06	100.00		1
38. Switchgrass	66.25	10.21	9.64	3.92	2.22	4.71	1.36	0.83	0.58	0.28	100.00		3
Mean	46.18	11.23	24.59	6.62	1.39	4.02	0.98	3.66	1.25	0.08	100.00	3100	10
Minimum	8.73	2.98	2.93	3.14	0.67	1.42	0.58	0.83	0.09	0.01			10
Maximum	84.92	44.32	53.38	20.33	2.59	8.64	1.73	9.89	6.20	0.28			10
2.2. Straws (HAS)													
39. Alfalfa straw	7.87	24.87	38.14	10.38	0.10	14.10	0.41	2.62	1.49	0.02	100.00		1
40. Barley straw	50.78	9.89	28.18	2.97	0.67	2.87	0.95	2.22	1.39	0.08	100.00		2
41. Corn straw	49.95	14.73	18.53	2.42	5.06	4.49	2.53	1.84	0.16	0.29	100.00	620	1
42. Mint straw	23.49	17.63	32.01	5.77	5.57	6.90	2.82	3.50	1.98	0.33	100.00		1
43. Oat straw	37.79	12.03	26.84	6.14	4.69	4.45	2.17	4.93	0.72	0.24	100.00	775	1
44. Rape straw	40.80	30.68	13.45	2.22	5.45	2.00	2.00	2.67	0.44	0.29	100.00	310	1
45. Rice straw	77.20	2.46	12.59	0.98	0.55	2.71	0.50	1.18	1.79	0.04	100.00	2790	3
46. Straw	57.14	6.70	25.82	2.74	0.76	1.67	0.53	3.89	0.70	0.05	100.00	155	2
47. Wheat straw	50.35	8.21	24.89	3.54	1.54	2.74	0.88	4.24	3.52	0.09	100.00	540	14
Mean	43.94	14.13	24.49	4.13	2.71	4.66	1.42	3.01	1.35	0.16	100.00	865	9
Minimum	7.87	2.46	12.59	0.98	0.10	1.67	0.41	1.18	0.16	0.02		155	9
Maximum	77.20	30.68	38.14	10.38	5.57	14.10	2.82	4.93	3.52	0.33		2790	9
2.3. Other residues (HAR)													
48. Almond hulls	11.21	9.75	63.90	6.17	2.52	4.00	0.92	0.41	1.06	0.06	100.00		1
49. Almond shells	16.96	11.55	53.48	4.93	2.99	4.51	2.78	0.93	1.76	0.11	100.00		2
50. Coconut shells	66.75	2.41	8.48	1.54	8.48	1.54	6.16	0.01	4.62	0.01	100.00		1
51. Coffee husks	14.65	13.05	52.45	4.94	7.07	4.32	2.06	0.53	0.66	0.27	100.00		3
52. Cotton husks	10.93	20.95	50.20	4.05	1.32	7.59	1.92	1.72	1.31	0.01	100.00		1
53. Grape marc	9.53	28.52	36.84	8.80	2.63	4.77	1.77	6.29	0.67	0.18	100.00		1
54. Groundnut shells	27.70	24.80	8.50	3.70	8.30	5.40	10.30	10.40	0.80	0.10	100.00		1

Biomass group, sub-group and variety	SiO_2	CaO	K_2O	P_2O_5	Al_2O_3	MgO	Fe_2O_3	SO_3	Na_2O	TiO_2	Sum	Mn (ppm)	n[a]
55. Hazelnut shells	33.70	15.40	30.40	3.20	3.10	7.90	3.80	1.10	1.30	0.10	100.00		1
56. Mustard husks	17.43	44.13	7.63	2.06	1.55	9.48	0.82	14.74	2.06	0.10	100.00		1
57. Olive husks	32.70	14.50	4.30	2.50	8.40	4.20	6.30	0.60	26.20	0.30	100.00		1
58. Olive pits	21.48	19.97	16.44	9.71	5.95	3.84	4.25	2.30	15.77	0.29	100.00		2
59. Olive residue	22.26	12.93	42.79	6.09	4.10	5.84	1.99	3.73	0.12	0.15	100.00	310	1
60. Palm fibres-husks	63.20	9.00	9.00	2.80	4.50	3.80	3.90	2.80	0.80	0.20	100.00		1
61. Palm kernels	18.26	9.33	16.54	31.06	6.19	6.59	9.23	2.54	0.14	0.12	100.00	4570	1
62. Pepper plant	12.60	32.20	24.60	5.20	4.90	7.40	2.00	9.70	0.90	0.50	100.00	1320	1
63. Pepper residue	15.39	10.02	35.32	11.19	8.39	4.55	3.38	10.61	1.05	0.10	100.00		1
64. Pistachio shells	8.43	10.26	18.66	12.10	2.23	3.34	36.27	3.89	4.61	0.21	100.00		1
65. Plum pits	3.64	14.86	45.51	20.40	0.11	11.79	0.69	2.51	0.47	0.02	100.00		1
66. Rice husks	94.48	0.97	2.29	0.54	0.21	0.19	0.22	0.92	0.16	0.02	100.00	155	5
67. Soya husks	2.01	25.26	36.00	5.79	8.74	8.38	2.95	4.37	6.26	0.24	100.00		1
68. Sugar cane bagasse	46.79	4.91	6.95	3.87	14.60	4.56	11.12	3.57	1.61	2.02	100.00		2
69. Sunflower husks	23.66	15.31	28.53	7.13	8.75	7.33	4.27	4.07	0.80	0.15	100.00		2
70. Walnut blows	6.41	27.64	34.67	10.28	2.25	14.34	1.05	2.33	0.92	0.11	100.00		1
71. Walnut hulls and blows	8.29	20.03	39.65	7.52	2.92	16.21	1.37	2.71	1.19	0.11	100.00		1
72. Walnut shells	23.32	16.72	33.03	6.21	2.40	13.51	1.50	2.20	1.00	0.10	100.00		1
Mean	24.47	16.58	28.25	7.27	4.90	6.62	4.84	3.80	3.05	0.22	100.00	1590	25
Minimum	2.01	0.97	2.29	0.54	0.11	0.19	0.22	0.01	0.12	0.01		155	25
Maximum	94.48	44.13	63.90	31.06	14.60	16.21	36.27	14.74	26.20	2.02		4570	25
3. Animal biomass (AB)													
73. Chicken litter	5.77	56.85	12.19	15.40	1.01	4.11	0.45	3.59	0.60	0.03	100.00	853	1
74. Meat-bone meal	0.02	41.22	3.16	40.94	2.37	1.38	0.25	4.24	6.41	0.01	100.00	78	1
Mean	2.90	49.04	7.67	28.17	1.69	2.75	0.35	3.91	3.50	0.02	100.00	466	2
4. Mixture of biomass													
75. Biomass mixture	34.75	13.15	3.11	18.07	11.35	2.31	10.44	4.62	1.25	0.95	100.00	1550	1
76. Wood-agricultural residue	37.18	25.70	7.76	2.22	11.07	4.77	5.77	2.03	2.57	0.93	100.00		2
77. Wood almond residue	47.00	19.55	6.45	1.52	11.08	4.35	4.19	2.12	3.18	0.56	100.00		1
78. Wood-straw residue	57.83	11.51	6.67	1.08	9.77	2.66	4.97	1.88	3.11	0.52	100.00		1
Mean	44.19	17.48	6.00	5.72	10.82	3.52	6.34	2.66	2.53	0.74	100.00	1550	4
Minimum	34.75	11.51	3.11	1.08	9.77	2.31	4.19	1.88	1.25	0.52			4
Maximum	57.83	25.70	7.76	18.07	11.35	4.77	10.44	4.62	3.18	0.95			4

5. Contaminated biomass (CB)													
79. Currency shredded	3.39	14.05	2.20	0.89	13.53	1.57	22.18	10.55	4.06	27.58	100.00		1
80. Demolition wood	36.27	21.36	6.98	5.09	9.67	4.77	7.31	4.12	2.83	1.60	100.00	1940	3
81. Furniture waste	57.17	13.78	3.74	0.50	12.14	3.25	5.59	0.99	2.34	0.50	100.00		1
82. Mixed waste paper	28.62	7.63	0.16	0.20	53.53	2.40	0.82	1.73	0.54	4.37	100.00		1
83. Greenhouse-plastic waste	28.40	25.80	9.70	3.84	3.90	5.70	18.40	2.65	0.80	0.81	100.00	2330	1
84. Refuse-derived fuel	38.67	26.81	0.23	0.77	14.54	6.45	6.26	3.01	1.36	1.90	100.00		1
85. Sewage sludge	33.28	13.04	1.60	15.88	12.91	2.49	15.70	2.05	2.25	0.80	100.00	155	2
86. Wood yard waste	60.10	23.92	2.98	1.98	3.08	2.17	1.98	2.46	1.01	0.32	100.00		1
Mean	35.73	18.30	3.45	3.64	15.41	3.60	9.78	3.45	1.90	4.74	100.00	1475	8
Minimum	3.39	7.63	0.16	0.20	3.08	1.57	0.82	0.99	0.54	0.32		155	8
Maximum	60.10	26.81	9.70	15.88	53.53	6.45	22.18	10.55	4.06	27.58		2330	8
All varieties of biomass													
Mean	29.76	25.27	17.91	5.71	5.51	5.42	4.00	3.28	2.48	0.66	100.00	7540	86
Minimum	0.02	0.97	0.16	0.20	0.10	0.19	0.22	0.01	0.09	0.01		78	86
Maximum	94.48	83.46	63.90	40.94	53.53	16.21	36.27	14.74	29.82	27.58		35740	86
Natural biomass													
Mean	29.14	25.99	19.40	5.92	4.49	5.60	3.41	3.27	2.54	0.24	100.00	8096	78
Minimum	0.02	0.97	2.19	0.54	0.10	0.19	0.22	0.01	0.09	0.01		78	78
Maximum	94.48	83.46	63.90	40.94	15.12	16.21	36.27	14.74	29.82	2.02		35740	78
Aquatic biomass													
Marine macroalgae	1.65	12.39	15.35	9.76	0.85	12.50	1.87	25.74	19.88		99.99	326	11
Solid fossil fuels													
Peat	37.53	9.97	1.12	2.75	20.14	2.14	13.83	12.11	0.10	0.31	100.00	775	1
Coal	54.06	6.57	1.60	0.50	23.18	1.83	6.85	3.54	0.82	1.05	100.00	543	37
Coal (minimum)	32.04	0.43	0.29	0.10	11.32	0.31	0.79	0.27	0.09	0.62		233	37
Coal (maximum)	68.35	27.78	4.15	1.70	35.23	3.98	16.44	14.42	2.90	1.61		1780	37
Lignite	44.87	13.11	1.48	0.20	17.11	2.50	10.80	8.64	0.48	0.81	100.00	736	5
Sub-bituminous coal	54.74	7.05	1.67	0.08	22.86	2.14	5.30	4.07	1.09	1.00	100.00	509	10
Bituminous coal	56.14	4.90	1.61	0.22	24.82	1.55	6.68	2.16	0.77	1.15	100.00	511	22

[a] Number of samples.

For the analysis of composition of ashes, a high temperature analysis is performed [21]. Temperature of 550 °C is reached in laboratory to produce ashes from threated biomass [21]. Using other types of analysis such low temperature analysis (100-250 °C) or even higher temperature analysis (>1000°C), changes the chemical composition of ashes and this table must be updated [21].

1.8.1 LHV of biomasses

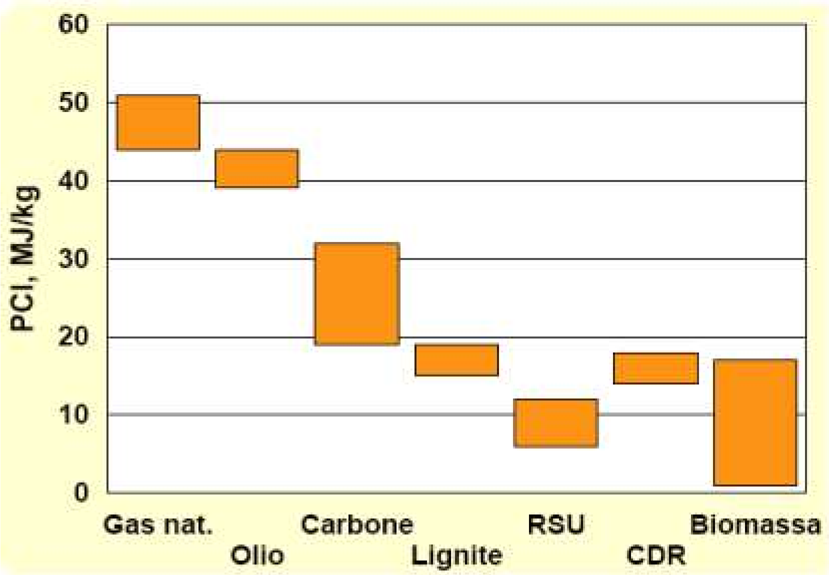


Figure 3: range of LHV of some types of primary sources [22]

In figure 3, can be highlighted that biomass have a certain range of LHV:

from few MJ/kg to a bit less than 20 MJ/kg. It is one of the primary sources with lower LHV with respect to other sources such as natural gas, oil, carbon, lignite, urban solid wastes (RSU) and fuel derived from wastes (CDR).

1.9 How much biomass? Overview of methods of calculation of biomass potential

To satisfy energy demand, it is needed to quantify the amount of biomass that can be used for energy purpose. It means to calculate the appropriate potential.

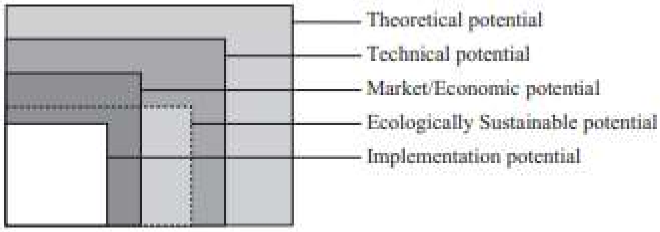


Figure 4: definition of various types of potential [23]

As can be highlighted in figure 4, there is a progressive reduction in definition of potential from theoretical potential, passing through the technical potential, economic and ecological potential until the implementation potential[23].

In fact, theoretical potential is the maximum quantity of biomass theoretically available, technical potential implements the restriction of competition with other land uses and technology[23].

As subsets of technical potential, there are the economic and ecological potentials[23]. The first one poses the restriction of economic availability of production and recovery of biomass feedstock, the second one considers the restriction given by environment protection[23].

At last, there is the implementation potential that represents the exact amount of biomass that can be actually used for a specific purpose[23].

There are many methodologies to calculate potential of a specific biomass.

1.9.1 Resource-focussed assessment-statistical analysis

It is a bottom-up approach, it starts defining the demand of biomass for non-energy purposes. It starts from statistical data on land use and agricultural production [23]. "Statistical data contains empirically derived or modelled statistics of key determinants of biomass resource availability and use. These include information on arable land, cultivated areas, pasture areas, agricultural productivity data, agricultural management systems, harvested volumes, food and material supply and demand elasticities, demographic and economic dynamics, livestock statistics, etc."[23]

Examples of statistical datasets used in bioenergy potential analysis are the FAOSTAT database and Eurostat database [23].

This method is simple and low cost [23], but it has disadvantage of not taking into account macro-economic issues, that are of capital importance in defining the feasibility of increasing biomass production. [23]

1.9.2 Resource-focussed assessments-Spatially explicit analysis

Instead of using statistical data, spatial data are used. Spatial data define more clearly the use of land for producing biomass and also give a proper idea of the distribution of biomass potential across countries or regions [23]. A famous example of spatially explicit analysis is produced by GIS software. GIS is the acronym of Geographic Information System and is "designed to store, retrieve, manage, display, and analyze all types of geographic and spatial data. GIS software lets you produce maps and other graphic displays of geographic information for analysis and presentation"[24]. This "methodology is transparent and varying levels of data details and aggregation can be employed"[23] but the "reproduction of the results is, however, difficult, because the use of geographic information software and spatially explicit data can be labour intensive" [23].

1.9.3 Demand driven assessments-Cost–supply analysis

This kind of analysis includes bottom up bioenergy technical estimates and evaluation of the costs of biomass transportation, production and conversion [23].

"This methodology is simple, transparent, reproducible and cheap. However, it does not allow the matching of demand and supply through prices, and thus competition is not accurately modelled. Another disadvantage is that there are limited possibilities to account for environmental or social limitations"[23].

1.9.4 Demand driven assessments—Energy-system modelling

These types of models imitate energy market dynamics, considering the competitiveness of bioenergy sources. They evaluate accurately advantages and drawbacks at economic level [23]. These methods analysis is used in many studies, for example those conducted by IEA and OECD.

“A general drawback with energy system modelling is that economic correlations used in the models are partially based on expert judgement, to complement historical data on energy use and prices (which are often distorted by, for instance, changes in energy policies). Further, energy-economic models lack physical reality, especially validation of land availability and productivity for energy crop production” [23].

1.9.5 Integrated assessments-Various methodologies

These models are a combination of the described models.

The study, [25], “is an example of a study that uses an integrated economic–biophysical framework to assess the impacts of biofuels on biodiversity, climate change and land use change. It combines the agricultural trade model (the extended GTAP: Global Trade Analysis Project), the global integrated environmental assessment model (IMAGE: Integrated Model to Assess the Global Environment) and the global biodiversity assessment model (GLOBIO3)”[23].

This type of models has a great advantage because it can take into account all the aspects that are considered just separately in the models described above but on the contrary, it is very difficult to implement and are very expensive. [23]

2. Objective of the thesis

The main objective of the thesis is the simulation of a large-scale introduction of biobased fuels from residual biomass (DME, FT-Diesel, Biomethane) in the EU area. The feasibility and interest of a massive introduction of biobased products is function of the amount of loads to be supplied (e.g. private transportation, etc), the availability of residual and waste biomass, and the energy consumption in the transformation processes (heat and power).

In this work, production data of waste and residual biomass will be taken by Eurostat database and from own calculations. Data considered define theoretical potential of biomass available. This type of consideration solves the relevant problem of the debate food vs fuel mentioned in the section of biofuels.

In particular, woody residues from roundwood production and from NACE Rev.2 activities and, a percentage of manure and slurry from breeding bovines and pigs for energy purpose are taken into account.

Holt method is adopted to forecast the production of biomass for each EU nation until 2030. The data obtained for 2030 by the usage of Holt method are the inlet fluxes of biomass in the studied plants.

Then, three plants for the production of biofuels are considered. The first one, is taken into account for the production of DME, the second one for the production of FT-diesel and the last one for the production of biomethane through anaerobic digestion and upgrading biogas plant.

Then, the amount of biofuels produced is calculated by the technical sheet of the plants.

At last, the CO_2 saved by using these biofuels is defined.

3. Methodology

In this section the steps for obtaining the results described in the previous chapter are highlighted.

This part of the thesis follows a primary source to product approach; first, it is described in detail which biomass and its characteristics, and why that type of biomass is taken into account.

It is of capital importance considering that woody biomass and animal heads defined, are the theoretical potential highlighted in Eurostat by collecting data from EU-27 members and harmonising techniques. So, restrictions from theoretical potential to implementation potential, as highlighted in figure 4, are not considered in this section.

Then, the plants for processing biomass are highlighted, defining energy flux needed together with biomass and the exiting fluxes of biofuels and eventually of energy.

3.1 Type of biomass

Biomass considered is woody residual biomass from roundwood production and from NACE Rev.2 activities and, manure and sludges from bovines and pigs breeding.

3.1.1 Woody residues biomass

Roundwood production considers all wood harvested in forest for all possible purposes. FAOSTAT gives the definition of roundwood as "an aggregate comprising wood fuel, including wood for charcoal and industrial roundwood (wood in the rough). It is reported in cubic metres solid volume under bark (i.e. excluding bark)"[26].

Wood fuel is part of the roundwood production "that will be used as fuel for purposes such as cooking, heating or power production" [26].

Industrial roundwood is wood used for non-energy purposes. It is the sum of:

- **sawlogs and veneer logs**, that is part of the roundwood that "will be sawn (or chipped) lengthways for the manufacture of sawnwood or railway sleepers (ties) or used for the production of veneer (mainly by peeling or slicing)" [26];
- **pulpwood, round and split**, that is "used for the production of pulp, particleboard or fibreboard" [26];

- **other industrial roundwood**, that is "used for poles, piling, posts, fencing, pitprops, shingles and shakes, wood wool, tanning, distillation and match blocks, etc" [26].

Obviously in the process of harvesting wood, as in all the other processes, there are residues and or waste products that are not used and that, in this case, are left in the forest.

In this work, what remains in the forest is taken into account as woody residue.

The process of harvesting wood from forestry leaves many residues as can be highlighted in figure 5.

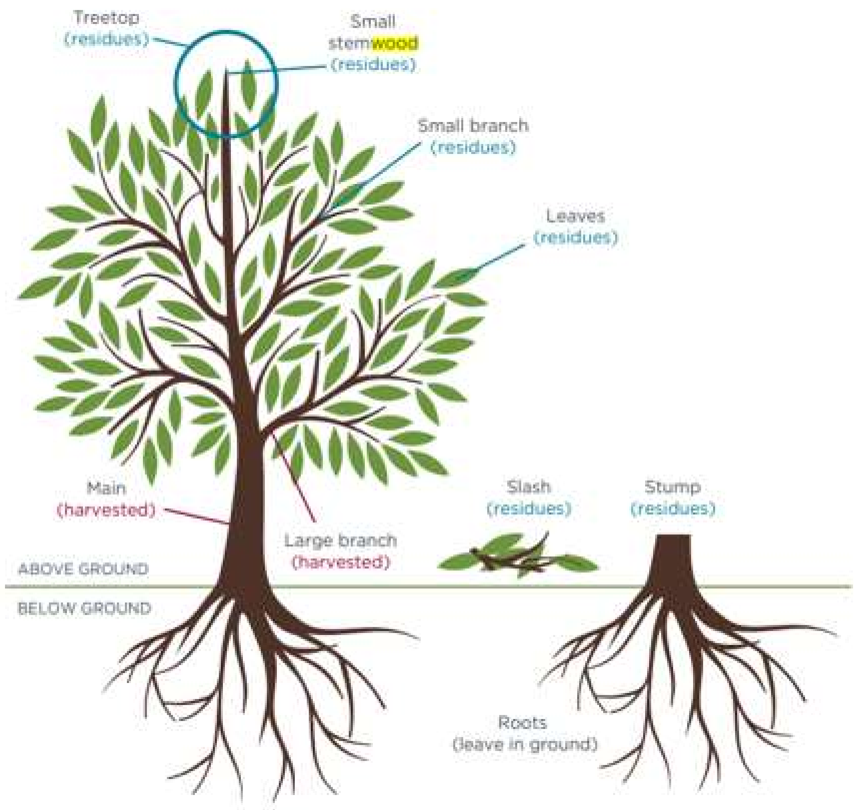


Figure 5: schematic of tree components [27]

In figure 5 is shown that the only main and large branch are harvested, all the others are residues. In a work produced by Mantau, in 2012, is set that 24,3 % of the total above-ground biomass will be left in the forest as residue[27]. So, this percentage will be actually used for the calculations in this work.

A further division is considered in defining roundwood production. It is between coniferous and non-coniferous.

In coniferous are defined “all woods derived from trees classified botanically as Gymnospermae, e.g., Abies spp., Araucaria spp., Cedrus spp., Chamaecyparis spp., Cupressus spp., Larix spp., Picea spp., Pinus spp., Thuja spp., Tsuga spp., etc. These are generally referred to as softwoods”[26].

In non-coniferous are considered “all woods derived from trees classified botanically as Angiospermae, e.g., Acer spp., Dipterocarpus spp., Entandrophragma spp., Eucalyptus spp., Fagus spp., Populus spp., Quercus spp., Shorea spp., Swietonia spp., Tectona spp., etc. These are generally referred to as broadleaves or hardwoods” [26].

This division is considered just because LHVs of coniferous and non-coniferous are slightly different. (19 MJ/kg and 18 MJ/kg for coniferous and non-coniferous dry matters) [28].

Data given from Eurostat are represented in table 5 and in table 6:

Table 5: data on coniferous roundwood production in EU-27 member [thousands of cubic metres under bark] [29]

Time	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Belgium	3187,9	3192,6	3197,32	3202,04	3206,75	3211,47	3216,2	3220,91	3225,63	3230,35
Bulgaria	1960	2310	2465,83	2621,65	2465,52	3031,15	3229,2	2998	3474,11	3677,26
Czechia	15066	13340	13056	13229	13472	14385	16060	17735	24213	31313
Denmark	2015,9	1949,75	2103,42	2257,09	2257,09	2641,09	2641,1	2777,64	2891,82	3006
Germany	42440	41709,8	38464,7	38892	40127,5	42049,7	39052	40895	55243,1	56052,9
Estonia	4284	4293	4347	4243,5	4800	5581,36	5717,7	5773	6630,91	7132,16
Ireland	2514,3	2513,14	2474,75	2665,72	2725,84	2807,26	2984	3119	3434,46	3669,09
Greece	314,73	314,347	313,963	313,58	313,197	312,813	312,43	312,047	311,663	311,28
Spain	5905,2	5324,88	5692,36	6059,83	7074,33	9079,36	9017,8	9211	9929,26	9914,58
France	23881	22250,4	19193,5	19167,2	19682,9	19029,1	19097	19301	19342,4	19351,9
Croatia	613	707	1012	1025	848,32	837,88	807,6	875	1059,03	965,01
Italy	2073,6	2091,13	2032,01	2003,94	1913,77	1947,81	2223,9	2500	2231,29	7565,16
Cyprus	8,22	7,56	7,44	7,32	7,09	8,7	14,2	14	9,7	7,85
Latvia	7985,3	9003,61	6509,34	7433,81	8358,27	8245,74	8824	9212,71	9627,75	10042,8
Lithuania	3800,9	3884	3642	3561	3716	3452	3747	3747	3689	3651
Luxembourg	117,26	111,17	121,938	132,706	143,474	154,242	165,01	252	284,03	253,34
Hungary	720,87	794,54	844,62	1015,58	982,16	948,74	1002,8	951	925	917,72
Malta	0	0	0	0	0	0	:	0	0	0
Netherlands	582,16	537,2	493,9	565	674,9	690	703,22	957	901,91	875
Austria	15297	15727,3	14932,5	14419,2	13921,8	14570,8	13854	14595	16038,6	15976,7
Poland	26529	27429,1	27649,7	28419,7	30156	30631,5	31613	34947	35891,5	33281,6
Portugal	3651,6	3715,29	3047,46	2542,3	2828,31	2871,98	2841,3	3980	4291,91	4656,13
Romania	5139,8	5857,62	6129,5	5901,56	6540,17	6024,41	5420,4	5278	5953,54	6373,84
Slovenia	1555,7	1758,91	1827,44	1895,97	2764,19	3062,52	3493	2905	3443,75	2781,99
Slovakia	6382,7	5448,84	4426,56	4053,04	5149,19	4662,26	5193,6	5518	5789,39	5356,35
Finland	41300	41780,9	41645,5	44991,4	45191,9	46871,1	48749	50206	54179,7	50152,2
Sweden	65340	64925	62595	62760	66630	67260	73909	65880	63900	66048

Table 6: data on non-coniferous roundwood production in EU-27 members [thousands of cubic metres under bark] [29]

Time	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Belgium	1639,55	1709,67	1779,79	1849,91	1920,04	1990,16	2060,28	2130,4	2200,52	2270,64
Bulgaria	3708	3895	3713,94	3532,87	3104,52	3340,95	3180,51	3200	3055,01	2973,26
Czechia	1670	2041	2005	2102	2004	1778	1715	1652	1476	1273
Denmark	653,58	743,277	832,973	922,67	922,67	841,67	841,67	814,274	790,087	765,899
Germany	11978	14431,8	13873,4	14315,5	14228,7	13563,1	13141,7	12596	19989,6	20114,6
Estonia	2916	2817	2943	3411	3200	3933,67	4017	4175	5403,33	6130,48
Ireland	103,65	122,18	105,67	93,9	102,14	100,73	66,43	102	106,16	116,976
Greece	733,23	748,43	763,63	778,83	794,03	809,23	824,43	839,63	854,83	870,03
Spain	10184,2	10102,9	9801,32	9499,74	9321,01	8348,13	8830,05	8354	9034,2	9046,11
France	31927	32790,1	32301,2	32136,9	32183,4	31983,1	32034,3	31899	30526,4	30278,7
Croatia	3864	4551	4702	4411	5077,63	4340,59	4357,68	4433	4330,69	4435,09
Italy	5770,19	5653,33	5050,58	4447,84	3845,09	3104,63	6828,32	10552	3819,79	3883,74
Cyprus	0,74	0,93	1,8	2,08	1,72	1,89	1,54	1	1,25	1,51
Latvia	4548,55	3829,89	6020,25	5273,66	4527,07	4048,68	3827,42	3444,01	3093,86	2743,71
Lithuania	3295,92	3120	3279	3492	3635	2962	3000	3000	3293	3037
Luxembourg	157,69	150,26	153,642	157,024	160,406	163,788	167,17	181	163,87	131,55
Hungary	5019,41	5437,91	5101,49	5011,62	4903,43	4795,23	4583,34	4738	4931	4657,7
Malta	0	0	0	0	0	0	:	0	0	0
Netherlands	498,43	444,6	460,8	457	576,24	1555,7	1568,25	2194	2242,49	1930
Austria	2534,31	2968,41	3088,15	2970,56	3166,73	2978,7	2908,83	3052	3153,46	2927
Poland	8938,4	9750,91	10365,8	10520,7	10706	10743,4	10523,1	10402	10819,7	10239,4
Portugal	5996,76	7246,13	7663,35	8067,29	8324,06	8782,68	9143,97	9553	9040,93	9485,12
Romania	7971,88	8501,01	9958,42	9293,16	8789,74	9290,29	9696,29	9213	10035,7	9547,97
Slovenia	1389,72	1628,95	1574,08	1519,21	2335,15	1991,92	1888,37	1604	1595,54	1836,17
Slovakia	3216,39	3764,06	3775,12	4009,55	4018,79	4332,35	4073,23	3843	3813,46	3600,52
Finland	10824,5	10997	10664	12000,2	11841,6	12539,8	12684,4	13074	14109,5	13811,7
Sweden	6860	6975	6904	6840	6670	7040	7050	7000	9278	9424

Data signed in orange are obtained by linear interpolation of the other data, and the other ones highlighted in green were missing and are obtained by adopting Holt method (Appendix II for details).

In table 7, wood residues from NACE activities are defined.

"NACE is the statistical classification of economic activities in the European community and is the subject of legislation at the European Union level, which imposes the use of the classification uniformly within all the Member States"[30]. It represents the globality of industrial activities in Europe.

To include in the right way all the industrial activities, is needed to define the statistical units. From these units all the data collected for the subscription of NACE are taken.

Council Regulation highlights which are the statistical units: "the enterprise group, the enterprise, the kind of activity unit (KAU), the local unit, the kind of activity unit (local KAU), the institutional unit, the unit of homogenous production (UHP), the local unit of homogeneous production"[30]. In figure 6, is described the system of units involved by developing data of NACE. Administrative units manage at legal level the developing of the work of the statistical ones.

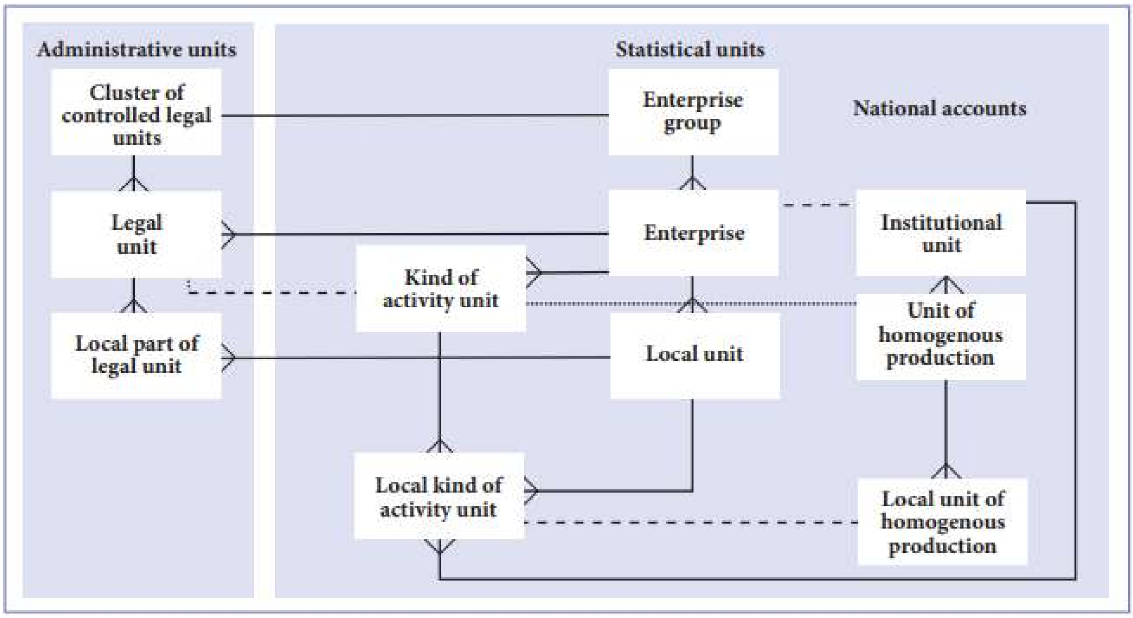


Figure 6: system of administrative and statistical units [30]

In table 7 is reported all the activities included in NACE Rev. 2, that are, in fact, taken into account in this work.

Table 7: complete list of activities included by NACE [31]

Complete list of activities included by NACE Rev. 2
Agriculture, forestry and fishing
Mining and quarrying
Manufacturing
Electricity, gas, steam and air conditioning supply
Water supply; sewerage, waste management and remediation activities
Construction
Wholesale and retail trade; repair of motor vehicles and motorcycles
Transportation and storage
Accommodation and food service activities
Information and communication
Financial and insurance activities
Real estate activities
Professional, scientific and technical activities
Administrative and support service activities
Public administration and defence; compulsory social security
Education
Human health and social work activities
Arts, entertainment and recreation
Other service activities
Activities of households as employers; undifferentiated goods- and services- producing activities of households for own use
Activities of extraterritorial organisations and bodies

Table 8: wood residues from all NACE activities, non-hazardous [tonnes] [29]

GEO/TIME	2004	2006	2008	2010	2012	2014	2016	2018
Belgium	1.798.672	1.721.002	1.530.924	2.729.827	2.850.516	3.280.248	3.623.422	3.882.374
Bulgaria	291.502	159.176	324.749	113.528	200.967	265.720	316.578	333.367
Czechia	902.317	634.130	234.157	288.685	235.057	183.479	237.281	287.604
Denmark	721.091	862.325	891.401	267.993	273.130	807.167	505.444	571.406
Germany	7.064.067	8.261.042	9.473.035	9.729.238	10.404.773	10.863.359	11.697.156	11.674.219
Estonia	3.862.773	1.790.517	1.288.145	871.293	816.028	551.228	434.266	182.245
Ireland	556.402	400.875	147.184	504.393	203.294	318.204	293.755	210.853
Greece	102.073	745.221	829.982	349.809	120.971	91.779	94.996	78.060
Spain	2.910.834	1.904.383	1.922.535	1.621.081	1.245.091	1.069.673	1.068.116	1.114.863
France	8.051.000	7.410.540	8.609.520	8.868.849	5.963.455	6.122.372	6.716.924	7.147.773
Croatia	218.987	133.508	190.236	155.022	97.053	91.021	91.293	95.275
Italy	2.724.534	2.449.793	3.424.526	3.751.288	3.838.139	4.331.845	4.475.395	5.239.390
Cyprus	54.108	32.689	17.181	24.032	6.183	3.882	4.395	6.525
Latvia	169.953	238.946	86.987	86.218	55.632	79.075	70.345	56.670
Lithuania	189.872	219.600	231.363	300.251	180.965	125.273	142.661	156.808
Luxembourg	100.128	62.569	42.803	67.930	48.220	38.151	40.340	27.399
Hungary	384.321	481.504	335.700	286.568	241.071	143.259	159.254	131.839
Malta	753	729	154	8.172	13.339	14.601	10.097	9.738
Netherlands	1.917.227	1.877.834	2.206.478	2.504.472	2.514.371	2.508.480	2.534.898	2.616.516
Austria	5.489.860	6.277.259	6.203.358	1.251.661	856.951	1.130.227	1.627.966	1.348.171
Poland	2.186.762	2.803.384	3.364.628	3.504.032	3.947.318	3.863.632	2.560.395	2.095.240
Portugal	2.660.405	1.168.974	695.598	353.215	274.525	253.614	332.821	399.965
Romania	1.322.533	1.458.316	1.802.153	2.337.485	2.072.090	2.288.879	3.283.172	2.731.800
Slovenia	728.065	1.153.821	469.706	333.720	337.646	275.464	148.160	94.146
Slovakia	349.790	768.101	628.989	238.936	400.697	253.514	414.023	449.431
Finland	13.397.182	13.222.571	12.403.828	12.238.485	11.926.012	4.227.810	4.728.395	4.320.632
Sweden	3.666.292	4.664.627	4.473.610	1.766.454	1.069.587	1.194.355	1.707.575	1.775.392

3.1.2 Amount of bovine and pigs in EU

To start the calculation of dejections from pigs and bovines, the total number of these animals is considered. In the same way for woody biomass, data are taken from Eurostat. It gives statistical data for the calculation of the theoretical potential. Through other values found in literature, equations for the calculation of the dejections are set to obtain the amount of dejections that will be put in the anaerobic digestion plant. In the following tables, data on the number of animals are given based on their age for bovines and weight for pigs.

Table 9: bovine animals [thousand heads] less than 1 year old [32]

GEO/TIME	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
European Un	:	:	:	:	:	:	:	:	:	:	:
Belgium	758,35	758,90	701,42	689,00	744,97	748,56	748,26	699,71	723,99	721,96	710,78
Bulgaria	141,42	141,58	121,44	150,04	120,65	108,81	119,69	109,72	108,15	99,70	111,56
Czechia	388,20	392,39	395,28	390,42	412,50	403,47	397,03	406,69	403,62	411,03	404,71
Denmark	553,00	548,00	545,00	528,00	534,00	538,00	540,00	541,00	534,00	522,00	524,00
Germany	3.867,58	3.851,20	3.868,37	3.878,25	3.908,57	3.836,21	3.794,84	3.704,22	3.583,69	3.485,38	3.404,52
Estonia	62,70	62,60	65,50	70,70	73,00	70,30	67,90	70,00	70,60	70,90	72,00
Ireland	1.694,60	1.868,01	1.986,61	1.893,29	1.885,70	2.025,70	2.076,51	2.086,51	1.999,88	1.962,38	2.056,58
Greece	205,60	191,20	190,90	167,00	175,90	154,00	145,20	151,40	141,00	156,50	153,80
Spain	2.120,90	2.078,04	2.122,07	2.067,77	2.203,37	2.324,64	2.403,64	2.492,05	2.494,13	2.528,83	2.541,32
France	5.589,20	5.525,10	5.541,00	5.453,00	5.529,00	5.597,00	5.138,00	5.266,45	5.231,79	5.085,86	4.865,04
Croatia	130,30	145,80	142,80	144,80	131,60	147,90	155,00	155,80	154,50	151,50	145,70
Italy	1.736,15	1.782,81	1.598,35	1.680,32	1.653,88	1.678,15	1.745,23	1.738,44	1.702,76	1.759,33	1.773,64
Cyprus	20,16	21,07	20,67	21,08	21,93	20,81	21,77	23,44	23,79	24,53	25,38
Latvia	105,57	103,87	108,42	109,28	118,38	113,57	112,97	108,19	105,90	108,24	111,51
Lithuania	180,20	200,70	193,20	186,50	192,20	185,30	179,30	180,20	172,90	166,70	168,70
Luxembourg	51,59	51,92	52,02	55,23	54,47	53,67	54,34	50,46	50,17	49,73	49,84
Hungary	170,00	188,00	213,00	212,00	219,00	220,00	239,00	243,00	251,00	258,00	266,00
Malta	4,37	4,47	4,84	4,30	4,48	4,17	3,88	4,18	4,25	4,00	4,21
Netherlands	1.577,00	1.581,00	1.623,00	1.653,00	1.676,00	1.707,00	1.666,00	1.594,00	1.510,00	1.528,00	1.510,00
Austria	634,05	623,36	628,72	626,97	629,40	624,48	632,15	623,52	618,22	605,32	598,60
Poland	1.386,58	1.361,63	1.387,95	1.408,63	1.450,00	1.616,94	1.717,80	1.713,10	1.709,40	1.747,60	1.734,60
Portugal	437,11	462,17	450,90	425,23	487,29	509,84	499,22	514,71	497,06	531,15	525,57
Romania	420,30	448,40	457,80	454,10	462,80	474,70	446,90	432,40	417,80	400,30	393,50
Slovenia	146,77	146,20	146,56	143,85	147,64	152,42	155,05	153,23	153,20	151,02	153,12
Slovakia	131,93	133,26	135,75	132,52	129,77	130,24	130,48	124,77	123,34	122,26	125,96
Finland	302,50	303,58	300,66	301,84	306,98	307,80	302,10	298,80	295,76	287,31	291,69
Sweden	478,80	479,91	475,46	469,07	473,44	467,19	467,90	473,75	467,52	453,13	464,43

Table 10: bovine animals [thousand heads] from 1 to 2 years old [32]

GEO/TIME	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
European Un	:	:	:	:	:	:	:	:	:	:	:
Belgium	504,92	495,04	498,46	495,30	489,72	493,35	492,00	484,33	464,36	463,56	460,56
Bulgaria	53,09	59,37	64,17	61,68	65,34	63,99	63,20	56,76	58,74	58,49	71,33
Czechia	302,56	299,26	297,94	299,73	311,42	309,16	295,06	299,25	304,27	298,78	295,32
Danmark	317,00	306,00	314,00	319,00	307,00	302,00	298,00	294,00	284,00	280,00	279,00
Germany	3.016,02	2.930,61	2.939,89	3.014,73	3.010,86	2.993,28	2.959,71	2.904,25	2.829,08	2.751,31	2.639,02
Estonia	47,70	47,30	49,50	53,60	54,10	52,60	50,10	49,40	49,20	49,80	49,50
Ireland	1.520,49	1.441,88	1.617,10	1.714,41	1.648,76	1.659,96	1.778,12	1.792,21	1.789,70	1.741,38	1.708,02
Greece	116,60	125,70	128,90	129,40	118,90	103,00	102,30	101,30	95,50	90,70	90,10
Spain	695,90	774,71	713,93	735,10	795,20	786,38	803,88	822,23	846,72	857,05	852,70
France	3.378,40	3.311,33	3.378,00	3.441,00	3.418,00	3.461,00	3.493,00	2.968,72	3.179,80	3.181,76	2.702,45
Croatia	83,80	90,30	101,90	92,30	87,20	88,20	88,90	99,90	95,50	106,70	111,30
Italy	1.392,02	1.393,94	1.420,86	1.456,56	1.365,74	1.379,08	1.448,04	1.500,51	1.537,60	1.588,00	1.595,38
Cyprus	9,72	9,89	9,95	9,11	10,06	9,34	9,74	10,68	12,16	11,53	11,85
Latvia	67,61	66,73	70,02	75,31	74,86	76,20	72,54	69,71	64,90	64,66	65,43
Lithuania	147,80	144,10	144,90	143,60	149,30	151,90	142,50	135,10	133,00	131,70	128,40
Luxembourg	44,07	42,75	43,02	45,24	46,50	44,64	44,42	44,29	41,60	41,20	40,75
Hungary	154,00	137,00	158,00	179,00	176,00	180,00	176,00	179,00	182,00	193,00	195,00
Malta	3,33	3,49	3,67	3,76	3,17	3,65	3,19	3,08	2,90	3,11	2,85
Netherlands	616,00	591,00	603,00	627,00	657,00	660,00	644,00	575,00	465,00	440,00	465,00
Austria	443,65	429,93	423,90	434,55	432,46	439,08	432,04	438,59	428,38	426,43	414,40
Poland	1.226,82	1.256,20	1.323,83	1.371,60	1.444,87	1.531,51	1.637,30	1.668,70	1.731,70	1.756,50	1.800,00
Portugal	204,07	209,55	206,19	211,29	213,70	240,22	266,57	255,72	235,93	240,35	257,02
Romania	214,70	218,60	235,30	237,70	253,70	261,20	250,60	248,40	241,00	223,40	220,40
Slovenia	122,43	119,06	120,02	122,97	122,31	129,34	155,05	153,23	153,20	151,02	153,12
Slovakia	93,94	91,41	95,20	97,56	92,66	91,02	84,38	84,41	83,10	83,32	86,77
Finland	226,20	222,43	225,02	223,62	222,55	221,30	218,49	213,10	209,69	204,62	199,38
Sweden	342,56	330,18	338,15	342,36	334,40	342,20	344,12	341,98	342,92	338,82	323,39

Table 11: bovine animals [thousand heads] 2 or more years old [32]

GEO/TIME	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
European Un	:	:	:	:	:	:	:	:	:	:	:
Belgium	1.329,36	1.306,37	1.284,39	1.248,23	1.242,55	1.261,35	1.261,09	1.201,95	1.209,74	1.187,58	1.162,81
Bulgaria	359,19	366,58	349,72	373,83	376,37	388,24	387,25	386,45	375,23	369,00	405,71
Czechia	628,65	647,83	627,84	641,93	649,15	653,70	647,52	660,43	657,34	657,25	640,01
Denmark	760,00	758,00	748,00	736,00	713,00	726,00	715,00	723,00	712,00	698,00	697,00
Germany	5.823,29	5.746,03	5.698,51	5.793,01	5.822,76	5.805,97	5.712,04	5.672,72	5.536,32	5.402,85	5.258,32
Estonia	125,90	128,40	131,00	137,10	137,60	133,30	130,20	131,50	132,10	133,20	131,80
Ireland	2.702,61	2.615,43	2.649,53	2.701,35	2.708,59	2.736,57	2.758,81	2.794,88	2.803,92	2.855,89	2.764,83
Greece	363,00	363,80	343,30	354,70	364,20	325,20	306,40	303,00	305,30	282,90	295,20
Spain	3.258,20	3.070,37	2.976,61	2.999,35	3.042,45	3.071,89	3.110,12	3.151,47	3.169,74	3.214,46	3.242,41
France	10.631,00	10.292,34	10.133,00	10.235,00	10.306,00	10.328,00	10.372,00	10.740,32	10.151,64	9.883,01	10.023,98
Croatia	230,20	210,50	206,80	205,30	221,80	218,20	200,70	195,00	164,10	162,00	165,70
Italy	2.704,29	2.720,78	3.072,28	3.112,45	3.105,79	3.098,58	3.121,62	3.110,85	3.070,80	3.029,90	3.031,02
Cyprus	24,83	25,96	26,30	26,89	27,55	28,72	31,63	32,91	34,87	37,91	40,27
Latvia	206,31	210,01	214,65	221,90	228,79	229,32	226,80	227,93	224,53	222,43	222,05
Lithuania	420,00	407,60	391,10	383,40	395,10	385,40	373,00	361,60	347,60	336,20	332,40
Luxembourg	98,35	93,43	93,26	97,77	100,18	102,33	103,66	103,33	102,63	101,17	100,10
Hungary	357,00	372,00	389,00	393,00	407,00	421,00	438,00	448,00	451,00	458,00	472,00
Malta	7,25	7,11	7,08	7,16	7,24	7,20	7,28	6,92	6,97	6,88	6,94
Netherlands	1.766,00	1.740,00	1.760,00	1.810,00	1.836,00	1.948,00	1.985,00	1.860,00	1.715,00	1.752,00	1.716,00
Austria	935,58	923,23	903,00	896,76	899,34	894,05	890,20	881,37	866,21	847,77	842,44
Poland	2.948,35	2.883,11	2.808,56	2.809,31	2.765,40	2.614,09	2.615,10	2.653,90	2.742,30	2.757,50	2.744,30
Portugal	861,59	847,39	840,46	833,99	847,62	855,80	869,22	899,59	899,44	903,46	908,73
Romania	1.340,70	1.300,70	1.316,00	1.330,60	1.352,40	1.356,50	1.352,20	1.330,30	1.318,40	1.299,20	1.280,20
Slovenia	200,95	197,04	193,49	193,76	198,30	202,31	202,78	197,90	195,85	196,52	199,23
Slovakia	241,26	238,69	240,13	237,75	243,12	236,33	231,25	230,65	232,42	226,68	229,03
Finland	380,23	376,68	375,72	377,90	377,87	374,30	366,66	362,63	353,93	348,81	344,31
Sweden	648,65	639,64	629,96	632,08	628,69	619,01	624,04	632,86	625,02	612,71	603,14

Table 12: piglets, weight lower than 20 kg [thousand heads] [32]

GEO/TIME	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
European Uni	:	:	:	:	:	:	:	:	:	:	:
Belgium	1.666,96	1.668,60	1.711,94	1.663,53	1.627,46	1.630,64	1.577,09	1.563,80	1.596,52	1.584,68	1.650,21
Bulgaria	130,00	130,21	108,54	100,48	141,47	129,42	121,16	133,23	152,47	91,86	131,01
Czechia	494,39	412,13	404,38	451,89	440,09	415,90	414,94	476,96	465,71	483,39	481,93
Denmark	4.146,00	4.235,00	4.281,00	4.340,00	4.468,00	4.416,00	4.416,00	4.582,00	4.543,00	4.563,00	4.674,00
Germany	7.148,73	7.997,48	8.116,61	8.219,05	8.097,77	8.031,17	7.998,23	8.040,57	7.671,60	7.673,80	7.708,80
Estonia	116,10	113,90	125,60	118,60	111,60	96,70	85,00	98,40	104,70	111,40	103,40
Ireland	405,73	447,90	407,67	427,21	439,05	408,02	426,24	449,92	436,87	451,63	426,93
Greece	303,30	298,30	285,10	298,80	297,70	217,30	194,90	203,90	204,30	196,30	203,00
Spain	6.999,10	6.928,22	7.084,78	7.103,04	7.879,91	7.909,64	8.100,46	8.364,93	8.550,74	8.341,14	8.377,36
France	3.466,00	3.373,00	3.307,00	3.247,00	3.217,00	3.229,00	3.122,00	3.259,00	3.350,00	3.308,00	5.244,00
Croatia	444,80	387,00	329,20	341,50	327,00	324,60	309,10	258,50	273,90	265,20	273,10
Italy	1.732,46	1.748,69	1599,39	1.450,08	1.406,80	1.407,85	1.375,03	1.385,18	1.407,23	1.411,60	1.424,32
Cyprus	158,76	153,38	145,36	126,35	126,46	126,57	123,54	124,38	127,94	124,69	129,14
Latvia	89,84	83,97	79,22	87,07	81,01	74,26	75,61	62,91	57,56	58,61	55,61
Lithuania	171,90	138,60	140,40	126,90	124,50	120,20	124,40	117,20	113,40	103,50	106,20
Luxembourg	8,34	8,05	8,29	8,32	9,76	7,76	11,54	18,41	17,20	16,77	16,78
Hungary	681,00	695,00	682,00	689,00	751,00	712,00	668,00	654,00	690,00	656,00	717,00
Malta	18,03	12,32	11,76	13,18	10,94	10,05	10,00	8,30	8,59	7,38	11,47
Netherlands	4.649,00	4.797,00	4.993,00	4.920,00	5.116,00	5.408,00	4.986,00	5.522,00	5.287,00	5.002,00	4.883,00
Austria	764,54	717,90	718,81	684,61	692,73	683,35	660,56	667,80	652,75	650,93	664,11
Poland	4.284,95	3.556,91	2.950,75	2.892,31	2.833,99	2.575,51	2.789,80	2.723,20	2.278,90	2.288,20	2.376,80
Portugal	588,25	645,41	668,20	658,22	713,84	764,33	709,09	743,42	763,00	806,96	820,80
Romania	704,30	774,20	799,00	811,30	805,30	796,50	785,70	836,70	698,40	735,90	723,10
Slovenia	99,04	81,59	65,98	67,49	63,64	59,50	57,53	58,66	58,01	51,33	50,45
Slovakia	164,30	158,15	152,55	194,00	138,12	147,17	170,63	186,45	169,87	202,33	202,98
Finland	360,90	333,50	327,40	328,40	327,50	345,30	342,30	312,40	273,30	272,40	299,70
Sweden	427,00	428,87	415,29	401,71	375,67	384,00	378,50	379,15	360,55	383,44	367,65

Table 13: pigs from 20 to 50 kg [thousand heads] [32]

GEO/TIME	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
European Uni	:	:	:	:	:	:	:	:	:	:	:
Belgium	1.348,12	1.374,45	1.371,19	1.249,66	1.343,94	1.363,18	1.118,28	1.247,68	1.282,13	1.240,20	1.264,44
Bulgaria	119,00	144,18	150,23	145,36	136,02	155,32	151,30	141,18	154,18	133,71	128,72
Czechia	419,36	319,51	369,93	345,90	380,80	380,64	356,76	345,67	320,55	331,41	361,62
Denmark	3.469,00	3.558,00	3.508,00	3.542,00	3.777,00	3.884,00	3.884,00	3.971,00	3.937,00	3.908,00	4.087,00
Germany	6.185,98	5.394,79	5.611,83	5.449,07	5.759,19	5.551,33	5.189,35	5.363,60	5.048,60	4.851,90	4.700,60
Estonia	100,20	98,40	94,40	86,70	89,90	76,20	60,40	52,30	42,00	59,20	55,60
Ireland	399,31	402,65	412,62	380,63	384,53	396,91	409,91	417,17	417,26	417,78	436,33
Greece	246,50	273,00	230,80	251,40	261,60	201,90	164,20	166,70	172,20	172,80	176,00
Spain	5.943,80	5.887,78	5.735,41	5.811,91	6.009,85	6.595,20	6.397,27	7.058,28	6.897,16	7.020,19	7.560,54
France	3.910,00	3.806,00	3.810,00	3.657,00	3.544,00	3.669,00	3.504,00	3.652,00	3.763,00	3.749,00	2.163,00
Croatia	235,90	267,40	298,90	176,00	267,90	201,00	248,20	252,10	228,40	178,30	188,30
Italy	1.873,00	1.856,94	1701,44	1.545,94	1.629,27	1.633,18	1.602,34	1.623,78	1.610,80	1.621,64	1.619,80
Cyprus	100,14	97,75	78,24	70,06	67,77	63,55	75,18	75,16	71,64	70,73	70,73
Latvia	107,58	111,94	105,91	108,11	88,92	79,58	92,03	96,20	96,84	87,72	92,16
Lithuania	247,70	208,50	220,80	208,00	192,70	183,10	173,90	166,90	151,60	153,00	151,00
Luxembourg	34,96	38,07	34,27	39,46	34,01	35,74	35,76	34,78	26,34	24,00	23,60
Hungary	695,00	696,00	694,00	675,00	722,00	708,00	624,00	601,00	637,00	563,00	565,00
Malta	17,30	11,37	12,33	12,15	11,90	10,40	9,49	8,37	9,08	10,78	11,70
Netherlands	2.031,00	2.011,00	1.835,00	1.783,00	1.748,00	1.765,00	1.730,00	1.731,00	1.616,00	1.704,00	1.692,00
Austria	839,54	804,09	792,97	785,46	762,17	744,00	743,55	736,70	714,94	722,22	739,94
Poland	4.003,09	3.585,35	3.163,02	3.084,72	3.149,46	2.969,95	3.169,80	3.508,00	3.228,70	3.338,70	3.443,70
Portugal	438,66	460,34	465,27	468,09	481,46	503,62	484,70	475,08	454,65	476,60	426,16
Romania	1.058,70	1.094,30	1.104,80	1.093,20	1.098,80	1.140,50	1.016,70	878,10	826,00	727,20	710,10
Slovenia	82,25	69,71	58,93	63,25	55,90	52,01	50,76	46,85	52,98	49,42	43,96
Slovakia	176,61	140,97	168,49	151,71	190,45	173,07	161,16	155,63	167,50	130,53	97,37
Finland	303,90	288,40	276,50	272,70	268,50	274,70	255,50	248,50	246,20	257,70	263,70
Sweden	339,85	352,97	332,375	311,78	315,36	318,40	313,53	340,62	358,04	354,42	338,01

Table 14: pigs with weight more than 50 kg [thousand heads] [32]

GEO/TIME	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
European Uni	:	:	:	:	:	:	:	:	:	:	:
Belgium	2.882,45	2.955,31	3.050,72	3.075,43	2.923,29	2.921,84	3.057,76	2.880,57	2.924,13	2.861,03	2.905,34
Bulgaria	347,00	268,17	212,43	282,23	219,11	254,96	278,39	255,59	276,80	214,64	265,67
Czechia	753,53	611,21	615,05	596,31	640,56	619,43	572,26	570,94	586,22	561,84	566,69
Denmark	3.381,00	3.305,00	3.261,00	3.251,00	3.208,00	3.154,00	3.154,00	3.009,00	2.908,00	3.002,00	3.344,00
Germany	11.301,07	11.791,56	12.458,64	12.382,47	12.407,63	11.957,06	12.255,13	12.220,34	11.870,20	11.721,30	11.946,10
Estonia	119,70	117,20	120,20	119,60	121,80	106,50	94,60	111,90	118,80	105,00	130,10
Ireland	544,55	554,71	527,53	515,45	535,06	529,47	545,06	599,10	575,04	598,91	667,47
Greece	360,90	343,50	329,50	299,70	326,80	309,30	270,10	266,30	248,70	264,90	267,10
Spain	10.302,90	10.370,52	10.142,00	9.523,18	10.284,41	11.357,98	12.285,47	12.062,40	12.826,79	13.280,89	14.136,24
France	5.772,00	5.672,00	5.570,00	5.467,00	5.485,00	5.388,00	5.171,00	5.436,00	5.574,00	5.461,00	5.405,00
Croatia	470,90	449,60	428,30	465,60	442,10	519,10	483,40	482,00	422,60	451,30	454,70
Italy	4.976,58	5.011,35	4976,83	4.942,31	5.027,90	5.022,97	4.913,82	4.971,13	4.894,30	4.897,57	4.907,90
Cyprus	157,82	147,04	134,24	125,94	113,40	102,12	120,97	116,99	128,23	124,84	126,37
Latvia	138,81	131,66	126,53	127,42	139,31	142,16	130,35	125,22	117,44	132,98	123,87
Lithuania	426,30	373,80	381,90	359,90	339,80	330,60	316,10	278,10	261,40	251,40	254,40
Luxembourg	38,44	39,06	40,43	35,88	43,18	39,74	41,46	40,29	33,57	38,49	37,44
Hungary	1.485,00	1.358,00	1.330,00	1.362,00	1.373,00	1.415,00	1.356,00	1.362,00	1.285,00	1.182,00	1.322,00
Malta	27,19	17,57	15,84	18,85	19,80	18,92	17,24	13,67	14,78	13,58	17,45
Netherlands	4.419,00	4.179,00	4.189,00	4.209,00	4.087,00	4.223,00	4.140,00	3.967,00	4.032,00	4.163,00	4.032,00
Austria	1.245,38	1.207,05	1.208,18	1.171,41	1.166,42	1.168,44	1.147,94	1.171,89	1.176,17	1.165,89	1.171,83
Poland	5.125,87	4.760,23	3.982,04	4.039,97	4.307,57	4.214,16	4.271,10	4.751,90	4.761,90	4.817,50	5.077,20
Portugal	642,26	642,47	658,47	658,81	691,34	733,79	719,25	705,38	746,28	729,81	776,30
Romania	3.301,60	3.108,20	2.924,60	2.884,70	2.752,90	2.609,70	2.538,00	2.334,80	2.084,30	2.055,50	1.997,40
Slovenia	179,31	166,16	146,81	133,83	140,46	138,73	137,33	130,42	128,79	122,09	118,73
Slovakia	288,22	227,25	251,91	232,26	246,48	258,62	202,63	214,26	235,57	201,77	185,09
Finland	525,60	530,60	534,30	533,60	506,80	501,10	489,20	446,90	425,00	438,60	450,60
Sweden	597,06	547,93	541,585	535,24	541,21	511,90	521,79	529,62	542,83	588,60	530,79

I start from this data for the calculation of biomass that will enter the plants.

3.2 Calculation for obtaining biomass to put into the process plants

3.2.1 Calculation of woody residues

As can be highlighted in the section of the biomass considered, 24,3 % of wood remains as residues in the forest from roundwood production.

Before considering this percentage, Holt method, defined in Appendix 2, has been implemented to forecast the production of coniferous and non-coniferous roundwood production until 2030.

So, table 15, table 16 and table 17 give the results obtained:

Table 15: coniferous roundwood forecast until 2030 [thousands of cubic metres under bark]

Time	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Belgium	3235,07	3239,78	3244,5	3249,22	3253,94	3258,66	3263,38	3268,1	3272,81	3277,53	3282,25
Bulgaria	3927,48	4177,71	4427,93	4678,16	4928,38	5178,61	5428,83	5679,06	5929,28	6179,51	6429,73
Czechia	37548,8	44072,7	50596,5	57120,4	63644,3	70168,1	76692	83215,9	89739,7	96263,6	102787
Denmark	3120,17	3234,35	3348,53	3462,71	3576,89	3691,06	3805,24	3919,42	4033,6	4147,77	4261,95
Germany	61634,5	66502,4	71370,3	76238,2	81106,1	85974	90841,8	95709,7	100578	105446	110313
Estonia	7701,86	8271,55	8841,25	9410,95	9980,65	10550,3	11120	11689,7	12259,4	12829,1	13398,8
Ireland	3920,98	4172,87	4424,76	4676,65	4928,55	5180,44	5432,33	5684,22	5936,11	6188	6439,89
Greece	310,897	310,513	310,13	309,747	309,363	308,98	308,597	308,213	307,83	307,447	307,063
Spain	10168,2	10373,3	10578,3	10783,4	10988,5	11193,5	11398,6	11603,6	11808,7	12013,7	12218,8
France	19396,2	19432,3	19468,4	19504,4	19540,5	19576,6	19612,7	19648,7	19684,8	19720,9	19757
Croatia	986,888	987,6	988,312	989,025	989,737	990,45	991,162	991,875	992,587	993,3	994,012
Italy	10334	13637,6	16941,3	20244,9	23548,5	26852,2	30155,8	33459,4	36763,1	40066,7	43370,4
Cyprus	5,43735	3,01057	0,58379	7,85	7,85	7,85	7,85	7,85	7,85	7,85	7,85
Latvia	10457,8	10872,9	11287,9	11702,9	12118	12533	12948,1	13363,1	13778,1	14193,2	14608,2
Lithuania	3616,17	3577,79	3539,41	3501,03	3462,65	3424,27	3385,89	3347,51	3309,13	3270,75	3232,37
Luxembourg	258,024	254,773	251,523	248,272	245,022	241,772	238,521	235,271	232,021	228,77	225,52
Hungary	899,958	884,164	868,37	852,576	836,781	820,987	805,193	789,398	773,604	757,81	742,015
Malta	0	0	0	0	0	0	0	0	0	0	0
Netherlands	869,459	855,164	840,869	826,574	812,279	797,984	783,689	769,394	755,099	740,803	726,508
Austria	16518,2	16957,6	17397	17836,3	18275,7	18715,1	19154,5	19593,8	20033,2	20472,6	20912
Poland	32607,5	31495,1	30382,7	29270,3	28157,9	27045,5	25933,1	24820,7	23708,3	22595,9	21483,6
Portugal	5083,74	5491,6	5899,46	6307,32	6715,18	7123,04	7530,9	7938,76	8346,62	8754,48	9162,34
Romania	6805,94	7257	7708,06	8159,12	8610,18	9061,24	9512,3	9963,36	10414,4	10865,5	11316,5
Slovenia	2557,77	2254,35	1950,92	1647,5	1344,07	1040,64	737,219	433,794	130,368	2781,99	2781,99
Slovakia	5265,46	5100,57	4935,68	4770,79	4605,9	4441,01	4276,12	4111,23	3946,34	3781,45	3616,56
Finland	49589,6	48340,2	47090,8	45841,3	44591,9	43342,4	42093	40843,6	39594,1	38344,7	37095,2
Sweden	65704,7	65887,5	66070,2	66253	66435,7	66618,5	66801,2	66984	67166,7	67349,5	67532,2

Values marked in grey boxes, are projections that in 2030 would be represented by negative numbers. This is because, in the historical series of their own states, a negative trend was calculated. So, after a long-time period of forecast, numbers become negative. To solve this problem, the values given by Eurostat in 2019 were put instead of negative numbers. In some case, this happens also in the following tables.

Table 16: non-coniferous roundwood forecasts until 2030 [thousands cubic metres under bark]

Time	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Belgium	2340,76	2410,89	2481,01	2551,13	2621,25	2691,37	2761,49	2831,61	2901,74	2971,86	3041,98
Bulgaria	2879,6	2785,95	2692,29	2598,64	2504,98	2411,33	2317,67	2224,02	2130,36	2036,71	1943,05
Czechia	1096,77	912,867	728,962	545,057	361,152	177,246	1273	1273	1273	1273	1273
Denmark	741,712	717,524	693,337	669,149	644,962	620,774	596,587	572,4	548,212	524,025	499,837
Germany	22696	24923	27150,1	29377,1	31604,2	33831,2	36058,3	38285,3	40512,4	42739,4	44966,4
Estonia	6961,57	7792,65	8623,74	9454,82	10285,9	11117	11948,1	12779,2	13610,2	14441,3	15272,4
Ireland	127,516	138,055	148,595	159,134	169,674	180,213	190,753	201,292	211,832	222,371	232,911
Greece	885,23	900,43	915,63	930,83	946,03	961,23	976,43	991,63	1006,83	1022,03	1037,23
Spain	9249,22	9430,23	9611,24	9792,25	9973,26	10154,3	10335,3	10516,3	10697,3	10878,3	11059,3
France	29654,9	29083,4	28512	27940,6	27369,2	26797,8	26226,4	25654,9	25083,5	24512,1	23940,7
Croatia	4463,81	4506,99	4550,17	4593,35	4636,53	4679,71	4722,89	4766,07	4809,25	4852,43	4895,61
Italy	2050,38	409,701	3883,74	3883,74	3883,74	3883,74	3883,74	3883,74	3883,74	3883,74	3883,74
Cyprus	1,66913	1,86355	2,05796	2,25238	2,44679	2,6412	2,83562	3,03003	3,22445	3,41886	3,61327
Latvia	2393,56	2043,41	1693,26	1343,11	992,959	642,808	292,658	3827,42	3827,42	3827,42	3827,42
Lithuania	3005,52	2933,79	2862,05	2790,31	2718,57	2646,84	2575,1	2503,36	2431,62	2359,88	2288,15
Luxembourg	110,009	85,6205	61,2317	36,8429	12,4541	131,55	131,55	131,55	131,55	131,55	131,55
Hungary	4594,61	4491,01	4387,4	4283,8	4180,2	4076,6	3973	3869,39	3765,79	3662,19	3558,59
Malta	0	0	0	0	0	0	0	0	0	0	0
Netherlands	1847,74	1708,02	1568,29	1428,57	1288,85	1149,12	1009,4	869,679	729,956	590,233	450,51
Austria	2857,17	2755,46	2653,75	2552,04	2450,32	2348,61	2246,9	2145,19	2043,48	1941,77	1840,06
Poland	10059,4	9805,99	9552,62	9299,24	9045,86	8792,49	8539,11	8285,73	8032,36	7778,98	7525,61
Portugal	9590,77	9749,18	9907,58	10066	10224,4	10382,8	10541,2	10699,6	10858	11016,4	11174,8
Romania	9530,56	9432,11	9333,65	9235,19	9136,74	9038,28	8939,82	8841,36	8742,91	8644,45	8545,99
Slovenia	1925,93	2052,1	2178,26	2304,43	2430,6	2556,76	2682,93	2809,09	2935,26	3061,43	3187,59
Slovakia	3446,08	3282,37	3118,66	2954,95	2791,25	2627,54	2463,83	2300,12	2136,41	1972,71	1809
Finland	14058	14203,6	14349,2	14494,8	14640,4	14786,1	14931,7	15077,3	15222,9	15368,5	15514,1
Sweden	10290,8	11052,3	11813,9	12575,5	13337	14098,6	14860,1	15621,7	16383,3	17144,8	17906,4

After obtained the forecasts for coniferous and non-coniferous, values in tables 15 and 16 are summed and then multiplied by a specific factor, taking in consideration the value given by Mantau (24,3 %) in the introduction, to obtain thousands of cubic metres under bark of woody residues from roundwood as it is set in equation 1.

$$Total\ woodie\ residues\ from\ roundwood = (conifers + nonconifers) \cdot \left(\frac{0{,}243}{1-0{,}243}\right) \qquad (1)$$

In table 17, there are the results of the calculation specified above.

Table 17: total woody residues from roundwood [thousands of cubic metres under bark]

Time	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Belgium	1789,86	1813,89	1837,91	1861,94	1885,96	1909,98	1934,01	1958,03	1982,06	2006,08	2030,1
Bulgaria	2185,1	2235,36	2285,62	2335,88	2386,14	2436,4	2486,66	2536,92	2587,18	2637,44	2687,7
Czechia	12405,4	14440,5	16475,7	18510,8	20546	22581,1	24616,3	26651,5	28686,6	30721,8	33403,8
Denmark	1239,68	1268,57	1297,46	1326,34	1355,23	1384,12	1413	1441,89	1470,78	1499,67	1528,55
Germany	27070,4	29347,9	31625,4	33902,9	36180,4	38457,9	40735,4	43012,9	45290,4	47567,9	49845,4
Estonia	4707,02	5156,67	5606,33	6055,99	6505,64	6955,3	7404,96	7854,61	8304,27	8753,93	9203,58
Ireland	1299,58	1383,83	1468,07	1552,31	1636,55	1720,79	1805,03	1889,27	1973,51	2057,75	2141,99
Greece	383,961	388,718	393,474	398,23	402,986	407,742	412,499	417,255	422,011	426,767	431,523
Spain	6233,08	6357,01	6480,94	6604,86	6728,79	6852,72	6976,65	7100,57	7224,5	7348,43	7472,36
France	15745,6	15573,7	15401,9	15230	15058,2	14886,4	14714,5	14542,7	14370,8	14199	14027,1
Croatia	1749,7	1763,79	1777,88	1791,97	1806,06	1820,14	1834,23	1848,32	1862,41	1876,5	1890,59
Italy	3975,43	4509,24	5043,06	5576,88	6110,7	6644,51	7178,33	7712,15	8245,97	8779,78	15168,8
Cyprus	2,28121	1,56461	0,84801	0,13141	-0,5852	-1,3018	-2,0184	0,60189	0,5864	0,5709	3,67976
Latvia	4125,35	4146,17	4167	4187,83	4208,66	4229,49	4250,32	4271,15	4291,98	4312,81	5917,91
Lithuania	2125,59	2090,24	2054,89	2019,55	1984,2	1948,85	1913,5	1878,15	1842,81	1807,46	1772,11
Luxembourg	118,14	109,268	100,395	91,5232	82,6509	73,7786	64,9063	56,0341	47,1618	38,2895	114,621
Hungary	1763,78	1725,45	1687,12	1648,8	1610,47	1572,14	1533,82	1495,49	1457,16	1418,84	1380,51
Malta	0	0	0	0	0	0	0	0	0	0	0
Netherlands	872,232	822,791	773,351	723,91	674,47	625,03	575,589	526,149	476,708	427,268	377,828
Austria	6219,57	6327,96	6436,36	6544,75	6653,14	6761,53	6869,92	6978,31	7086,7	7195,1	7303,49
Poland	13696,2	13257,8	12819,4	12381	11942,6	11504,1	11065,7	10627,3	10188,9	9750,47	9312,06
Portugal	4710,58	4892,35	5074,12	5255,9	5437,67	5619,44	5801,21	5982,99	6164,76	6346,53	6528,31
Romania	5244,08	5357,27	5470,46	5583,64	5696,83	5810,02	5923,2	6036,39	6149,58	6262,76	6375,95
Slovenia	1439,29	1382,39	1325,48	1268,58	1211,68	1154,78	1097,88	1040,98	984,079	927,178	1916,26
Slovakia	2796,44	2690,96	2585,48	2479,99	2374,51	2269,03	2163,55	2058,07	1952,59	1847,11	1741,63
Finland	20431,1	20076,8	19722,5	19368,1	19013,8	18659,5	18305,1	17950,8	17596,5	17242,1	16887,8
Sweden	24394,9	24698	25001,1	25304,2	25607,4	25910,5	26213,6	26516,7	26819,9	27123	27426,1

Hence, because in the inlet flux of the plants considered, I need values in table 17, written in tonnes, I multiplied these values by 500 kg/m^3 [27]. Values obtained are represented in table 18.

Table 18: total residues from roundwood [tonnes]

Time	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Belgium	894931,8	906943,73	918955,7	930967,7	942979,6	954991,61	967003,6	979015,5	991027,5	1003039	1015051
Bulgaria	1092550	1117680	1142810	1167940	1193070	1218199,4	1243329	1268459	1293589	1318719	1343849
Czechia	6202691	7220267,5	8237844	9255420	10272997	11290573	12308150	13325726	14343303	15360879	16701912
Denmark	619840,4	634284,01	648727,6	663171,2	677614,8	692058,42	706502	720945,6	735389,2	749832,8	764276,4
Germany	13535210	14673961	15812713	16951464	18090216	19228967	20367719	21506470	22645222	23783973	24922725
Estonia	2353509	2578337,1	2803165	3027993	3252822	3477649,9	3702478	3927306	4152134	4376963	4601791
Ireland	649792,1	691912,67	734033,2	776153,7	818274,2	860394,76	902515,3	944635,8	986756,3	1028877	1070997
Greece	191980,7	194358,8	196736,9	199115	201493,1	203871,22	206249,3	208627,4	211005,5	213383,6	215761,7
Spain	3116541	3178504,9	3240469	3302432	3364396	3426359,6	3488323	3550287	3612251	3674214	3736178
France	7872791	7786867,9	7700945	7615022	7529100	7443176,8	7357254	7271331	7185408	7099486	7013563
Croatia	874848,3	881893,16	888938	895982,8	903027,6	910072,46	917117,3	924162,1	931206,9	938251,8	945296,6
Italy	1987713	2254622	2521531	2788439	3055348	3322257	3589166	3856074	4122983	4389892	7584377
Cyprus	1140,604	782,30482	424,0055	65,70624	-292,593	-650,8923	-1009,192	300,9444	293,198	285,4515	1839,878
Latvia	2062673	2073087,5	2083502	2093917	2104332	2114746,8	2125162	2135576	2145991	2156406	2958956
Lithuania	1062795	1045121,4	1027447	1009773	992099,1	974425,01	956750,9	939076,8	921402,7	903728,6	886054,5
Luxembourg	59069,99	54633,855	50197,72	45761,58	41325,44	36889,307	32453,17	28017,03	23580,9	19144,76	57310,43
Hungary	881888,7	862725,39	843562,1	824398,8	805235,4	786072,13	766908,8	747745,5	728582,2	709418,9	690255,6
Malta	0	0	0	0	0	0	0	0	0	0	0
Netherlands	436115,8	411395,59	386675,4	361955,2	337235	312514,79	287794,6	263074,4	238354,2	213634	188913,8
Austria	3109786	3163982	3218178	3272373	3326569	3380764,8	3434960	3489156	3543352	3597548	3651743
Poland	6848120	6628910,4	6409701	6190492	5971283	5752073,6	5532864	5313655	5094446	4875237	4656028
Portugal	2355288	2446174,7	2537061	2627948	2718834	2809720,9	2900607	2991494	3082381	3173267	3264154
Romania	2622041	2678634,2	2735228	2791821	2848415	2905008	2961601	3018195	3074788	3131382	3187975
Slovenia	719643,1	691192,65	662742,2	634291,8	605841,4	577390,92	548940,5	520490,1	492039,6	463589,2	958130,1
Slovakia	1398219	1345478,5	1292738	1239997	1187257	1134515,9	1081775	1029035	976293,9	923553,3	870812,6
Finland	10215574	10038407	9861241	9684074	9506907	9329740	9152573	8975406	8798239	8621073	8443906
Sweden	12197430	12348993	12500556	12652119	12803682	12955245	13106808	13258371	13409934	13561497	13713060

As a final operation, values obtained in table 18 are summed with the woody residues from NACE Rev. 2 in table 8. Final values are gained and are represented in table 19:

Table 19: total woody residues in 2030 [tonnes]

Time	2030
Belgium	6667406,09
Bulgaria	1871645,17
Czechia	17077554,5
Denmark	1304527,26
Germany	38261360,1
Estonia	4784035,89
Ireland	1281850,36
Greece	219430,017
Spain	4929456,33
France	16748875,4
Croatia	1050420,65
Italy	16121073,7
Cyprus	15362,6895
Latvia	2961623,85
Lithuania	1091379,92
Luxembourg	70463,0024
Hungary	691099,416
Malta	2949434,37
Netherlands	1661401,64
Austria	5746983,25
Poland	5460045,4
Portugal	5858954,22
Romania	3282121,27
Slovenia	1777194,29
Slovakia	5191444,6
Finland	11504770,2
Sweden	14202444,5

3.2.2 Calculation of manure and sludges from bovines

In this section are presented the calculations to obtain the amount of solid and liquid dejections from bovines and pigs.

In table 20, table 21 and table 22 are presented the forecasts of thousands of heads of bovines of different ages, by using Holt method.

Table 20: forecast of bovines less than 1 year old [thousands of heads]

GEO/TIME	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Belgium	705,93	699,777	693,625	687,472	681,319	675,167	669,014	662,861	656,709	650,556
Bulgaria	114,581	119,373	124,165	128,957	133,749	138,541	143,333	148,125	152,917	157,709
Czechia	403,796	401,872	399,949	398,025	396,101	394,177	392,253	390,329	388,406	386,482
Denmark	520,089	517,245	514,4	511,556	508,712	505,867	503,023	500,179	497,335	494,49
Germany	3312,7	3223,28	3133,86	3044,44	2955,02	2865,6	2776,18	2686,76	2597,34	2507,92
Estonia	72,8024	73,6593	74,5163	75,3732	76,2301	77,0871	77,944	78,801	79,6579	80,5149
Ireland	2083,41	2124,51	2165,61	2206,71	2247,81	2288,9	2330	2371,1	2412,2	2453,29
Greece	156,821	159,054	161,287	163,52	165,753	167,986	170,219	172,452	174,685	176,918
Spain	2561,05	2579,07	2597,1	2615,12	2633,14	2651,17	2669,19	2687,21	2705,24	2723,26
France	4696,52	4514,26	4332	4149,74	3967,48	3785,22	3602,96	3420,7	3238,44	3056,18
Croatia	141,392	136,687	131,983	127,279	122,574	117,87	113,165	108,461	103,757	99,0523
Italy	1796,63	1819,26	1841,89	1864,52	1887,15	1909,78	1932,41	1955,04	1977,67	2000,3
Cyprus	26,1562	26,9457	27,7352	28,5247	29,3142	30,1037	30,8932	31,6827	32,4722	33,2617
Latvia	113,729	116,286	118,844	121,402	123,959	126,517	129,074	131,632	134,189	136,747
Lithuania	166,835	165,753	164,671	163,589	162,507	161,425	160,343	159,261	158,179	157,097
Luxembourg	49,646	49,5383	49,4306	49,3229	49,2153	49,1076	48,9999	48,8922	48,7845	48,6768
Hungary	273,575	281,225	288,875	296,525	304,175	311,825	319,475	327,125	334,775	342,425
Malta	4,24875	4,31638	4,38401	4,45164	4,51927	4,5869	4,65453	4,72217	4,7898	4,85743
Netherlands	1496,16	1483,39	1470,62	1457,85	1445,08	1432,31	1419,54	1406,77	1393,99	1381,22
Austria	589,787	581,252	572,717	564,183	555,648	547,113	538,579	530,044	521,509	512,975
Poland	1739,68	1741,5	1743,32	1745,15	1746,97	1748,8	1750,62	1752,45	1754,27	1756,09
Portugal	532,716	537,983	543,249	548,516	553,783	559,049	564,316	569,583	574,849	580,116
Romania	381,952	371,376	360,8	350,223	339,647	329,071	318,495	307,919	297,343	286,767
Slovenia	153,411	154,046	154,681	155,316	155,951	156,586	157,221	157,856	158,491	159,126
Slovakia	127,288	129,156	131,023	132,89	134,758	136,625	138,492	140,36	142,227	144,095
Finland	290,675	290,7	290,725	290,751	290,776	290,801	290,827	290,852	290,877	290,902
Sweden	464,818	467,25	469,681	472,112	474,543	476,974	479,405	481,836	484,267	486,698

Table 21: forecast of bovines 1 to less than 2 years old [thousands of heads]

GEO/TIME	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Belgium	456,3394	452,645	448,9506	445,2562	441,5618	437,8674	434,173	430,4786	426,7842	423,0898
Bulgaria	78,15963	86,29083	94,42202	102,5532	110,6844	118,8156	126,9468	135,078	143,2092	151,3404
Czechia	292,2345	288,8998	285,565	282,2303	278,8955	275,5608	272,226	268,8913	265,5565	262,2218
Denmark	275,9337	273,3754	270,8171	268,2588	265,7005	263,1423	260,584	258,0257	255,4674	252,9091
Germany	2543,186	2443,546	2343,907	2244,267	2144,627	2044,987	1945,347	1845,707	1746,068	1646,428
Estonia	49,52671	49,51094	49,49518	49,47942	49,46365	49,44789	49,43212	49,41636	49,40059	49,38483
Ireland	1673,1	1637,131	1601,161	1565,192	1529,222	1493,253	1457,284	1421,314	1385,345	1349,375
Greece	87,50921	85,31968	83,13016	80,94064	78,75111	76,56159	74,37206	72,18254	69,99301	67,80349
Spain	856,9412	859,1277	861,3143	863,5008	865,6873	867,8738	870,0603	872,2469	874,4334	876,6199
France	2463,258	2174,445	1885,632	1596,819	1308,006	1019,193	730,3805	441,5676	152,7547	2.702,45
Croatia	117,3528	123,3001	129,2473	135,1946	141,1418	147,0891	153,0363	158,9836	164,9309	170,8781
Italy	1621,765	1644,199	1666,634	1689,069	1711,504	1733,938	1756,373	1778,808	1801,243	1823,678
Cyprus	11,98047	12,11352	12,24657	12,37962	12,51267	12,64572	12,77877	12,91182	13,04487	13,17792
Latvia	65,17704	65,22045	65,26386	65,30726	65,35067	65,39408	65,43749	65,48089	65,5243	65,56771
Lithuania	125,8493	123,2116	120,574	117,9363	115,2987	112,6611	110,0234	107,3858	104,7482	102,1105
Luxembourg	40,07523	39,47251	38,86978	38,26706	37,66434	37,06161	36,45889	35,85617	35,25344	34,65072
Hungary	200,2825	205,0542	209,826	214,5977	219,3694	224,1411	228,9128	233,6845	238,4562	243,2279
Malta	2,764161	2,649465	2,534769	2,420074	2,305378	2,190682	2,075987	1,961291	1,846595	1,7319
Netherlands	456,107	455,6867	455,2664	454,8461	454,4258	454,0055	453,5851	453,1648	452,7445	452,3242
Austria	406,3221	397,4429	388,5637	379,6845	370,8054	361,9262	353,047	344,1678	335,2886	326,4094
Poland	1838,572	1877,504	1916,436	1955,367	1994,299	2033,231	2072,163	2111,095	2150,027	2188,959
Portugal	264,8469	274,8816	284,9162	294,9508	304,9854	315,0201	325,0547	335,0893	345,124	355,1586
Romania	211,7948	204,1315	196,4681	188,8047	181,1414	173,478	165,8146	158,1513	150,4879	142,8245
Slovenia	153,3385	153,8616	154,3847	154,9079	155,431	155,9541	156,4772	157,0003	157,5235	158,0466
Slovakia	88,56032	90,73922	92,91812	95,09703	97,27593	99,45483	101,6337	103,8126	105,9915	108,1704
Finland	194,3746	189,2969	184,2192	179,1414	174,0637	168,986	163,9083	158,8306	153,7529	148,6752
Sweden	313,8259	302,9244	292,0228	281,1212	270,2197	259,3181	248,4165	237,515	226,6134	215,7119

Table 22: forecast of bovines 2 or more years old [thousands of heads]

GEO/TIME	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Belgium	1141,744	1119,761	1097,7773	1075,7938	1053,81022	1031,827	1009,8431	987,85959	965,876	943,8925
Bulgaria	421,6886	442,0774	462,46613	482,8549	503,243678	523,6325	544,02123	564,41001	584,7988	605,1876
Czechia	630,7145	619,6796	608,64467	597,60977	586,574865	575,54	564,50506	553,47016	542,4353	531,4004
Denmark	690,5209	684,993	679,46515	673,93727	668,409385	662,8815	657,35362	651,82574	646,2979	640,77
Germany	5119,565	4978,807	4838,0486	4697,2903	4556,53194	4415,774	4275,0153	4134,257	3993,499	3852,74
Estonia	131,5519	131,0751	130,59836	130,12158	129,644805	129,168	128,69125	128,21448	127,7377	127,2609
Ireland	2736,161	2694,895	2653,6282	2612,3619	2571,09559	2529,829	2488,5629	2447,2966	2406,03	2364,764
Greece	294,2599	295,7193	297,1786	298,63794	300,097268	301,5566	303,01593	304,47526	305,9346	307,3939
Spain	3275,31	3307,494	3339,6793	3371,8642	3404,04899	3436,234	3468,4187	3500,6035	3532,788	3564,973
France	9945,575	9911,926	9878,2775	9844,6288	9810,98013	9777,331	9743,6828	9710,0341	9676,385	9642,737
Croatia	163,4406	162,8387	162,23681	161,63492	161,033024	160,4311	159,82924	159,22735	158,6255	158,0236
Italy	3012,655	2998,057	2983,4584	2968,86	2954,26163	2939,663	2925,0648	2910,4665	2895,868	2881,27
Cyprus	42,80872	45,33527	47,86182	50,388371	52,9149215	55,44147	57,968023	60,494574	63,02112	65,54768
Latvia	220,7536	219,6442	218,53487	217,42552	216,316164	215,2068	214,09745	212,9881	211,8787	210,7694
Lithuania	324,7088	317,8782	311,04753	304,21689	297,386251	290,5556	283,72497	276,89433	270,0637	263,233
Luxembourg	98,92496	97,74804	96,571124	95,394206	94,2172889	93,04037	91,863454	90,686537	89,50962	88,3327
Hungary	482,2588	493,3107	504,36261	515,41453	526,466449	537,5184	548,57029	559,62221	570,6741	581,726
Malta	6,939476	6,95186	6,9642437	6,9766273	6,98901098	7,001395	7,0137783	7,026162	7,038546	7,050929
Netherlands	1691,064	1667,002	1642,94	1618,8778	1594,81563	1570,753	1546,6912	1522,629	1498,567	1474,505
Austria	831,3669	821,3702	811,37348	801,37677	791,380054	781,3833	771,38662	761,38991	751,3932	741,3965
Poland	2753,619	2757,234	2760,8491	2764,4639	2768,07875	2771,694	2775,3084	2778,9233	2782,538	2786,153
Portugal	913,3545	917,9434	922,53235	927,12129	931,710227	936,2992	940,8881	945,47704	950,066	954,6549
Romania	1261,696	1242,986	1224,2762	1205,5663	1186,85635	1168,146	1149,4365	1130,7266	1112,017	1093,307
Slovenia	200,5686	202,2702	203,97175	205,67335	207,374943	209,0765	210,77813	212,47973	214,1813	215,8829
Slovakia	228,4884	228,4392	228,38995	228,3407	228,291449	228,2422	228,19295	228,1437	228,0945	228,0452
Finland	339,1348	334,1419	329,14895	324,15601	319,163066	314,1701	309,17718	304,18424	299,1913	294,1984
Sweden	593,0706	582,8597	572,64879	562,43791	552,227035	542,0162	531,80528	521,5944	511,3835	501,1726

Not all the animal dejections are used for energy purposes, but just a little percentage.

In case of bovine animals, 12% [33] of dejections is used in this calculations for production of energy. To obtain values in table A.26, table A.27 and table A.28 last values are multiplied by 0,12 and 1000.

Liquid and solid dejections are finally calculated with parameters used in table 23.

Table 23: Parameters used for the calculation of dejections (data from ISTAT) [34]

Age class	Average weight [kg]	Liquid dejections [l/(100 kg·day)]	Solid dejections [kg dry/(100 kg·day)]
Bovines			
0 – 12 months	200	5,3	0,66
12 – 24 months	400	6,8	0,82
24 months or more	650	8,2	1,05
Buffaloes			
0 – 24 months	300	5,6	0,74
24 months or more	650	8,2	1,05

By multiplying values in table 23 depending on the age of the animals considered in this way, liquid and solid dejections are obtained:

$$Liq.dej.per\ year\ [l] = n°\ of\ animals\ [n°\ animals] \cdot avg.wt\ \left[\frac{kg}{animal}\right] \cdot spec.liq.dej.\left[\frac{l}{100\ kg \cdot day}\right] \cdot 365\ \left[\frac{days}{year}\right] \quad (2)$$

$$Sol.dej.per\ year\ [kg] = n°\ of\ animals\ [n°\ animals] \cdot avg.wt\ \left[\frac{kg}{animal}\right] \cdot spec.sol.dej.\left[\frac{kg_{dry}}{100\ kg \cdot day}\right] \cdot 365\ \left[\frac{days}{year}\right] \quad (3)$$

In the plant considered, values of all dejections are taken in tonnes. So, I had to find a value of density for the liquid dejections. I found 1030 kg/m^3 [34] and finally multiplied by 0,001 twice: first, to obtain cubic metres from litres and second, to obtain tonnes from kg. For solid dejections, I just multiplied by 0,001 to obtain tonnes.

Values in table A.29, A.30, A.31, A.32, A.33, A.34 are gained.

3.2.3 Calculation of manure and sludges from pigs

In table 24 are given the parameters for the calculation of manure and sludges from pigs.

Table 24: parameters used for the calculations (data from ISTAT) [35]

Cathegories	Average weight [kg]	Liquid dejections [l/(100 kg·day)]	Solid dejections [kg dry/(100 kg·day)]
Piglets < 20 kg	15	2,5	0,73
20 kg < pigs < 50 kg	50	7	0,35
Fattening pigs > 50 kg	100	11	0,44

By adopting values in table 33, a different percentage of pig's manure for energy (16,5% [33]) and the same methods adopted for the case of bovine dejections, values in tables A.35, A.36, A.37, A.38, A.39, A.40 are obtained.

Finally, all the tables obtained for bovines and pigs are summed to obtain the total solid dejections and liquid dejections of pigs and bovines highlighted in tables 25, 26, 27, 28.

Table 25: total liquid dejections of bovines [tonnes]

GEO/TIME	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Belgium	3776890	3713974,6	3651059,3	3588143,9	3525228,58	3462313	3399397,9	3336482,5	3273567,2	3210652
Bulgaria	1214148	1277835,6	1341522,9	1405210,1	1468897,42	1532585	1596272	1659959,2	1723646,5	1787334
Czechia	2142281	2109440,8	2076600,1	2043759,4	2010918,77	1978078	1945237,4	1912396,7	1879556,1	1846715
Danmark	2328715	2310275	2291835	2273394,9	2254954,87	2236515	2218074,8	2199634,7	2181194,7	2162755
Germany	17615798	17095794	16575790	16055785	15535781,2	15015777	14495773	13975769	13455764	12935760
Estonia	427346,1	426534,2	425722,29	424910,38	424098,463	423286,5	422474,63	421662,72	420850,81	420038,9
Ireland	9949618	9821064,7	9692511,5	9563958,2	9435404,95	9306852	9178298,4	9049745,1	8921191,9	8792639
Greece	924462,1	926523,35	928584,64	930645,93	932707,219	934768,5	936829,8	938891,09	940952,38	943013,7
Spain	10536183	10628651	10721119	10813587	10906055,2	10998523	11090991	11183459	11275927	11368395
France	30350052	29823634	29297215	28770797	28244378,8	27717961	27191542	26665124	26138706	29095423
Croatia	623794,7	627325,06	630855,38	634385,7	637916,019	641446,3	644976,66	648506,98	652037,3	655567,6
Italy	10446764	10448301	10449837	10451374	10452910,6	10454447	10455984	10457520	10459057	10460594
Cyprus	135167,5	142079,94	148992,39	155904,84	162817,288	169729,7	176642,19	183554,64	190467,09	197379,5
Latvia	691077,3	689555,98	688034,63	686513,29	684991,946	683470,6	681949,26	680427,92	678906,57	677385,2
Lithuania	1053086	1032106	1011125,9	990145,81	969165,71	948185,6	927205,52	906225,42	885245,33	864265,2
Luxembourg	322393,6	318634,5	314875,36	311116,22	307357,083	303597,9	299838,81	296079,67	292320,53	288561,4
Hungary	1592788	1630172,9	1667558,1	1704943,3	1742328,49	1779714	1817098,9	1854484	1891869,2	1929254
Malta	22924,17	22846,994	22769,823	22692,652	22615,4804	22538,31	22461,138	22383,967	22306,795	22229,62
Netherlands	5539814	5472509,7	5405205,1	5337900,6	5270596	5203291	5135986,9	5068682,3	5001377,7	4934073
Austria	2877241	2837053,2	2796865,7	2756678,2	2716490,79	2676303	2636115,9	2595928,4	2555741	2515554
Poland	10032318	10090080	10147842	10205604	10263365,7	10321128	10378890	10436652	10494414	10552176
Portugal	2883107	2909511,6	2935916,4	2962321,1	2988725,9	3015131	3041535,4	3067940,2	3094344,9	3120750
Romania	3624383	3562737,4	3501092,1	3439446,8	3377801,44	3316156	3254510,8	3192865,4	3131220,1	3069575
Slovenia	652498,3	657343,41	662188,48	667033,56	671878,627	676723,7	681568,77	686413,84	691258,91	696104
Slovakia	745761,5	749204,03	752646,55	756089,08	759531,602	762974,1	766416,65	769859,18	773301,7	776744,2
Finland	1232775	1213964,9	1195154,6	1176344,2	1157533,88	1138724	1119913,2	1101102,9	1082292,5	1063482
Sweden	2103025	2065059,2	2027093,9	1989128,7	1951163,37	1913198	1875232,8	1837267,5	1799302,2	1761337

Table 26: total solid dejections of bovines [tonnes]

GEO/TIME	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Belgium	447681	440223	432765	425307	417848	410390	402932	395474	388016	380558
Bulgaria	143911	151451	158991	166531	174071	181611	189152	196692	204232	211772
Czechia	253872	249983	246094	242205	238316	234427	230538	226649	222760	218871
Danmark	276132	273948	271763	269579	267394	265210	263025	260841	258656	256472
Germany	2087309	2025746	1964184	1902622	1841060	1779498	1717936	1656373	1594811	1533249
Estonia	50649,8	50554,6	50459,3	50364,1	50268,8	50173,6	50078,3	49983,1	49887,9	49792,6
Ireland	1178753	1163626	1148498	1133371	1118244	1103116	1087989	1072862	1057734	1042607
Greece	109603	109854	110105	110356	110606	110857	111108	111359	111610	111860
Spain	1250286	1261263	1272241	1283218	1294195	1305173	1316150	1327127	1338105	1349082
France	3598496	3536407	3474319	3412231	3350142	3288054	3225966	3163878	3101789	3447492
Croatia	73892,2	74294,7	74697,2	75099,7	75502,2	75904,6	76307,1	76709,6	77112,1	77514,6
Italy	1237451	1237619	1237786	1237954	1238121	1238289	1238456	1238624	1238791	1238959
Cyprus	16030,4	16850,5	17670,5	18490,5	19310,6	20130,6	20950,6	21770,7	22590,7	23410,7
Latvia	81929,9	81752,4	81574,9	81397,4	81219,8	81042,3	80864,8	80687,3	80509,7	80332,2
Lithuania	124793	122309	119826	117342	114859	112376	109892	107409	104925	102442
Luxembourg	38199,8	37755,2	37310,6	36865,9	36421,3	35976,6	35532	35087,4	34642,7	34198,1
Hungary	188754	193186	197618	202049	206481	210913	215344	219776	224207	228639
Malta	2717,21	2708,34	2699,48	2690,61	2681,75	2672,88	2664,01	2655,15	2646,28	2637,42
Netherlands	657546	649555	641563	633571	625579	617588	609596	601604	593612	585621
Austria	340998	336240	331483	326725	321968	317210	312453	307696	302938	298181
Poland	1187871	1194650	1201429	1208208	1214988	1221767	1228546	1235325	1242104	1248884
Portugal	341882	345000	348118	351236	354354	357472	360590	363707	366825	369943
Romania	429675	422370	415064	407759	400453	393148	385843	378537	371232	363926
Slovenia	90855,8	91476,3	92096,8	92717,4	93337,9	93958,5	94579	95199,5	95820,1	96440,6
Slovakia	88385,4	88791,7	89198	89604,2	90010,5	90416,8	90823	91229,3	91635,6	92041,9
Finland	146110	143889	141668	139448	137227	135007	132786	130565	128345	126124
Sweden	249249	244771	240293	235815	231337	226859	222381	217903	213425	208947

Table 27: total liquid dejections of pigs [tonnes]

GEO/TIME	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Belgium	2299270	2309271	2319272	2329273	2339274	2349275	2359276	2369277,4	2379278,4	2389279,5
Bulgaria	215360,2	224017,9	232675,7	427457,6	419890,6	412323,6	404756,6	397189,63	389622,64	382055,64
Czechia	477378,7	480000,1	482621,5	485242,9	487864,3	490485,7	493107,1	495728,44	498349,83	500971,21
Denmark	3433962	3618023	3802084	3986145	4170206	4354267	4538328	4722388,8	4906449,9	5090510,9
Germany	9331092	9341246	9351399	9361553	9371707	9381861	9392015	9402168,8	9412322,6	9422476,5
Estonia	110431,8	119332,5	128233,2	137133,9	146034,6	154935,2	163835,9	172736,58	181637,25	190537,93
Ireland	591351,3	626855,3	662359,3	697863,3	733367,3	768871,2	188732,9	194336,19	199939,47	205542,75
Greece	229211,5	233341,3	237471,1	241600,9	245730,7	249860,5	253990,3	258120,07	262249,87	266379,67
Spain	12019393	12591432	13163471	13735510	14307548	14879587	13480342	13980521	14480700	17167742
France	4090314	3865172	3640030	3414888	3189746	2964603	2739461	2514318,9	2289176,7	4185447,5
Croatia	357809,2	359769,7	361730,1	363690,6	365651,1	367611,6	369572	371532,5	549846,58	531464,89
Italy	3733888	3736089	3738290	3740491	3742692	3744892	3747093	3749294,3	3751495,3	3753696,2
Cyprus	105017	105450	105883	106316	106749,1	107182,1	107615,1	108048,08	108481,09	108914,1
Latvia	105397,1	104205,9	103014,6	101823,3	100632	99440,76	98249,49	97058,215	95866,941	94675,668
Lithuania	205337,5	203190,9	201044,4	219608,6	217133,4	214658,3	212183,1	209707,94	207232,78	204757,63
Luxembourg	30894,66	30729,89	30565,12	30400,35	30235,57	30070,8	29906,03	29741,255	46886,378	43605,523
Hungary	1057778	1090164	1122551	1154937	1187324	1219710	1252096	1284482,7	1316869,1	1327839,7
Malta	16163,53	17932,54	19701,56	21470,57	23239,59	25008,6	26777,61	28546,627	30315,641	32084,655
Netherlands	3217224	3188218	3159212	3130206	3101200	3072194	3043188	3014182,1	2985176,1	2956170,1
Austria	978220,6	981784,1	985347,7	988911,3	992474,9	996038,5	999602,1	1003165,7	1006729,2	1010292,8
Poland	4395749	4538703	4681656	4824610	4967563	5110517	5253470	5396423,6	5539377	5682330,5
Portugal	652979,3	666361,2	679743,1	693125	706506,9	719888,8	733270,7	725491,04	113051,55	109137,77
Romania	1473846	1419951	1366055	1312160	1258264	1204368	1150473	1096577,2	1042681,6	988786,04
Slovenia	87894	84052,17	80210,34	76368,5	72526,67	68684,84	64843	61001,17	57159,336	53317,503
Slovakia	133796,7	114598,9	95401,12	76203,32	57005,52	37807,71	18609,91	154226,48	154226,48	154226,48
Finland	378873,4	387376,7	395879,9	404383,2	412886,4	421389,7	429892,9	438396,14	446899,39	455402,63
Sweden	433553,7	416434,2	399314,6	382195,1	365075,6	347956,1	330836,6	313717,03	296597,51	279477,99

Table 28: total solid dejections of pigs [tonnes]

GEO/TIME	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Belgium	101.554,02	102.188,15	102.822,28	103.456,41	104.090,53	104.724,66	105.358,79	105.992,92	106.627,05	107.261,18
Bulgaria	9.373,52	9.739,45	10.105,39	19.506,48	19.084,81	18.663,13	18.241,46	17.819,79	17.398,12	16.976,45
Czechia	22.109,70	22.276,69	22.443,67	22.610,66	22.777,64	22.944,63	23.111,61	23.278,60	23.445,58	23.612,57
Denmark	169.112,38	176.895,42	184.678,47	192.461,51	200.244,55	208.027,60	215.810,64	223.593,69	231.376,73	239.159,78
Germany	415.658,78	415.658,80	415.658,82	415.658,84	415.658,86	415.658,88	415.658,91	415.658,93	415.658,95	415.658,97
Estonia	4.995,41	5.331,90	5.668,39	6.004,88	6.341,37	6.677,86	7.014,35	7.350,84	7.687,33	8.023,82
Ireland	26.284,88	27.619,98	28.955,07	30.290,16	31.625,26	32.960,35	10.387,00	10.560,90	10.734,80	10.908,71
Greece	10.440,97	10.620,52	10.800,07	10.979,61	11.159,16	11.338,71	11.518,25	11.697,80	11.877,35	12.056,89
Spain	530.891,73	553.739,13	576.586,53	599.433,93	622.281,33	645.128,73	572.282,72	591.641,78	611.000,85	736.518,34
France	197.330,39	193.410,85	189.491,30	185.571,75	181.652,21	177.732,66	173.813,11	169.893,57	165.974,02	265.035,69
Croatia	15.827,25	15.900,49	15.973,74	16.046,98	16.120,22	16.193,47	16.266,71	16.339,95	24.974,05	24.059,81
Italy	156.592,59	156.744,78	156.896,98	157.049,17	157.201,37	157.353,56	157.505,76	157.657,95	157.810,15	157.962,34
Cyprus	4.970,23	4.997,97	5.025,71	5.053,45	5.081,18	5.108,92	5.136,66	5.164,40	5.192,14	5.219,87
Latvia	4.590,96	4.533,36	4.475,77	4.418,17	4.360,58	4.302,99	4.245,39	4.187,80	4.130,20	4.072,61
Lithuania	8.877,49	8.781,04	8.684,60	14.459,56	14.269,96	14.080,36	13.890,77	13.701,17	13.511,58	13.321,98
Luxembourg	1.339,91	1.329,10	1.318,29	1.307,48	1.296,67	1.285,87	1.275,06	1.264,25	2.093,73	1.931,66
Hungary	46.445,07	47.843,62	49.242,16	50.640,70	52.039,24	53.437,78	54.836,32	56.234,86	57.633,40	52.960,67
Malta	730,05	813,86	897,68	981,49	1.065,31	1.149,13	1.232,94	1.316,76	1.400,57	1.484,39
Netherlands	155.302,19	153.212,40	151.122,62	149.032,83	146.943,04	144.853,26	142.763,47	140.673,69	138.583,90	136.494,11
Austria	43.376,34	43.578,03	43.779,73	43.981,42	44.183,11	44.384,81	44.586,50	44.788,20	44.989,89	45.191,59
Poland	191.639,10	197.494,18	203.349,27	209.204,36	215.059,45	220.914,53	226.769,62	232.624,71	238.479,79	244.334,88
Portugal	31.027,24	31.624,09	32.220,94	32.817,79	33.414,63	34.011,48	34.608,33	29.205,99	5.378,65	5.183,39
Romania	62.694,22	60.467,23	58.240,24	56.013,25	53.786,27	51.559,28	49.332,29	47.105,30	44.878,32	42.651,33
Slovenia	3.769,67	3.597,45	3.425,24	3.253,03	3.080,81	2.908,60	2.736,39	2.564,17	2.391,96	2.219,74
Slovakia	6.552,16	5.791,36	5.030,56	4.269,77	3.508,97	2.748,17	1.987,38	1.226,58	465,78	7.855,95
Finland	17.042,14	17.465,36	17.888,59	18.311,81	18.735,04	19.158,26	19.581,48	20.004,71	20.427,93	20.851,15
Sweden	19.612,29	18.900,65	18.189,00	17.477,36	16.765,72	16.054,08	15.342,44	14.630,80	13.919,16	13.207,52

3.3 Description of the plants

Plants considered in this work, as described in section 'Objective of the thesis', are three: the first to produce DME, the second for the production of FT-diesel and the third for biomethane through also an adding plant of upgrading biogas. As described in the introduction, biofuels taken into account in this section are considered as Advanced biofuels or second-generation biofuels. For this reason, there are no limitation on the production of these biofuels. On the contrary, there is a minimum amount of consumption of energy that must be produced by the usage of these ones (3,5 % as reported in the introduction by 2030 in transport sector).

The question that now arises is: which is the real quantity of these biofuels that must be produced?

3.3.1 Concept of contribution of biofuels

The answer is in the NECP (National Energy and Climate Plan) of each EU nation.

Each EU member sets its NECP to declare and share which are its objectives to achieve in order to reach the minimum request of RED II (i.e., 40 % domestic reduction in greenhouse gas emissions by 2030 compared to 1990 and, in this case, 14 % of renewable energy consumed in transportation sector by 2030). In these NECPs are also defined the amount of energy that has to be consumed by biofuels more or less in detail, depending on the nation talked about. In table 29 and in table 30, data from each NECP of EU-27 members and own calculations are defined:

Table 29: contribution of advanced biofuels in 2030 except biomethane

Contribution of advanced biofuels 2030 [ktoe] (except biomethane)	
Belgium	13,89
Bulgaria	94,10
Czechia	0,00
Denmark	106,00
Germany	1000,00
Estonia	395,00
Ireland	126,50
Greece	197
Spain	557,90
France	945,65
Croatia	9,36
Italy	264,00
Cyprus	1,09

Latvia	23,88
Lithuania	0
Luxembourg	127,66
Hungary	195,00
Malta	3,75
Netherlands	835,80
Austria	211,34
Poland	418,00
Portugal	155,00
Romania	63,60
Slovenia	89,00
Slovakia	22,00
Finland	859,68
Sweden	1719,36

The details of the calculations that lead to these results are defined in Appendix 1.

In the calculations of the biofuels produced from the plants, I supposed that each biofuel satisfies separately all the contribution of advanced biofuels, except the part of biomethane.

Table 30: contribution of biomethane in 2030

Biomethane contribution [ktoe] from NECP	2030
Belgium	13,89115
Bulgaria	0
Czechia	156,51
Denmark	0
Germany	200
Estonia	395
Ireland	0
Greece	197
Spain	557,9
France	945,648
Croatia	9,36
Italy	793
Cyprus	1,085
Latvia	47,76
Lithuania	0
Luxembourg	127,66
Hungary	195
Malta	3,75
Netherlands	835,8
Austria	211
Poland	418
Portugal	155

Romania	63,6
Slovenia	89
Slovakia	20
Finland	17,136
Sweden	1719,36

3.3.2 Plant for the production of DME

In figure 7, all the components of the DME plant are highlighted:

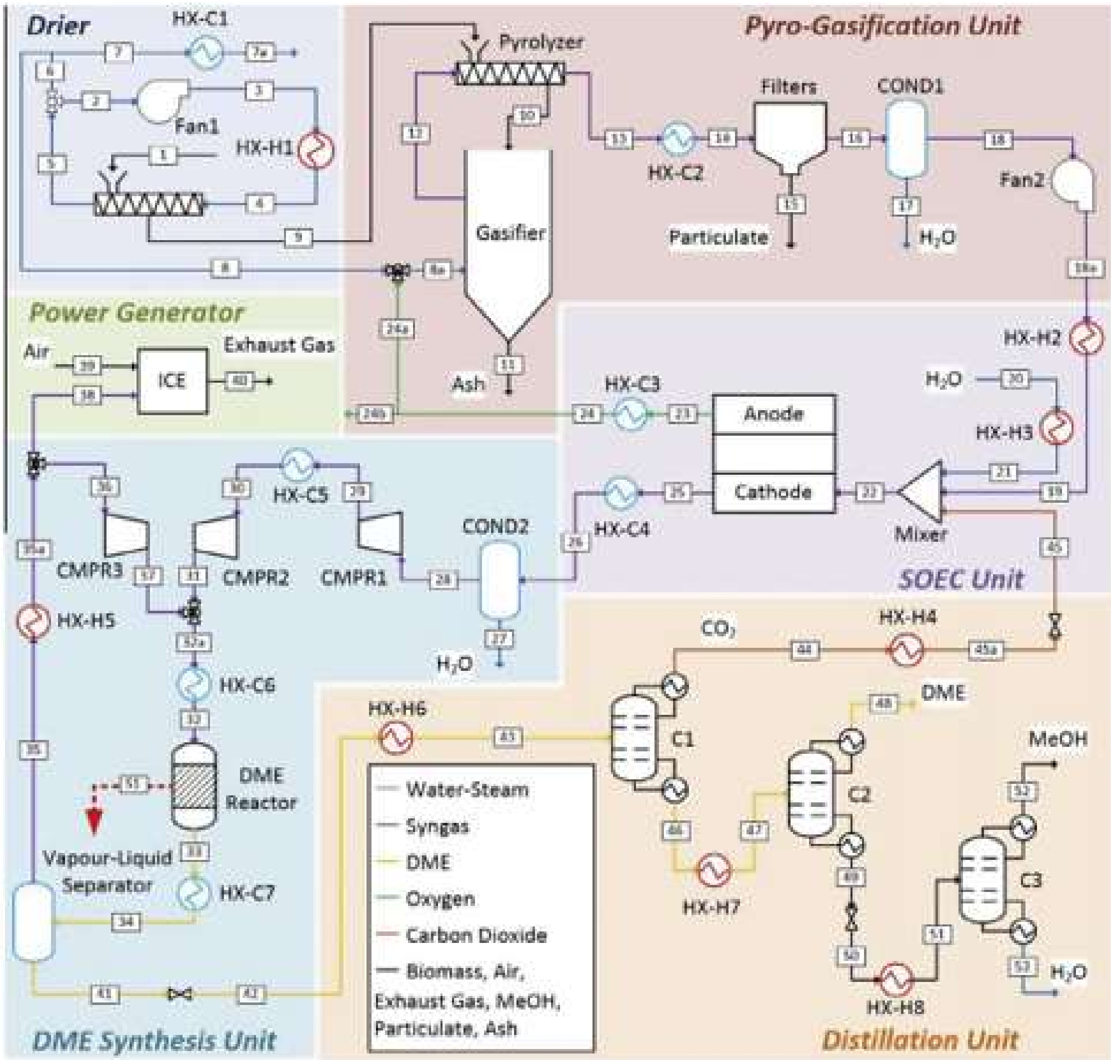


Figure 7: design of DME plant [36]

3.3.2.1 General description of the process

Woody residues from roundwood and NACE Rev. 2 are used for this purpose. Before entering the gasifier, biomass is considered to have 25 % wt. of moisture [37].

Because of this, it undergoes a first process of drying to eliminate moisture content.

Biomass dried enters in a gasifier where is partially combusted. In fact, process of gasification occurs in the condition of sub-stoichiometric amount of oxygen; because of this, not only CO_2 is produced but also CO, H_2 together with other chemical compounds. Blend produced is called syngas. Syngas is full of impurities that must be removed before entering the SOEC. Cleaning of the syngas happens in a mechanism of filters and scrubber to remove particulate, sulphurates and H_2O in excess.

Cleaned syngas enters the cathode of the SOEC, together with an inlet flux of H_2O and CO_2 recovered from the distillation unit where is finally produced DME. SOEC is important to integrate the production of H_2 and CO in the syngas and regulate its chemical proportion. In fact, the ratio of moles H_2/CO must be equal to 1 or very close to 1 to maximize DME production as can be highlighted in figure 8. At the outlet of the anode, oxygen is expelled and is sent to contribute to the combustion of the biomass in the gasifier and, at the cathode side, cleaned syngas enriched of H_2 and CO at the right ratio exits.

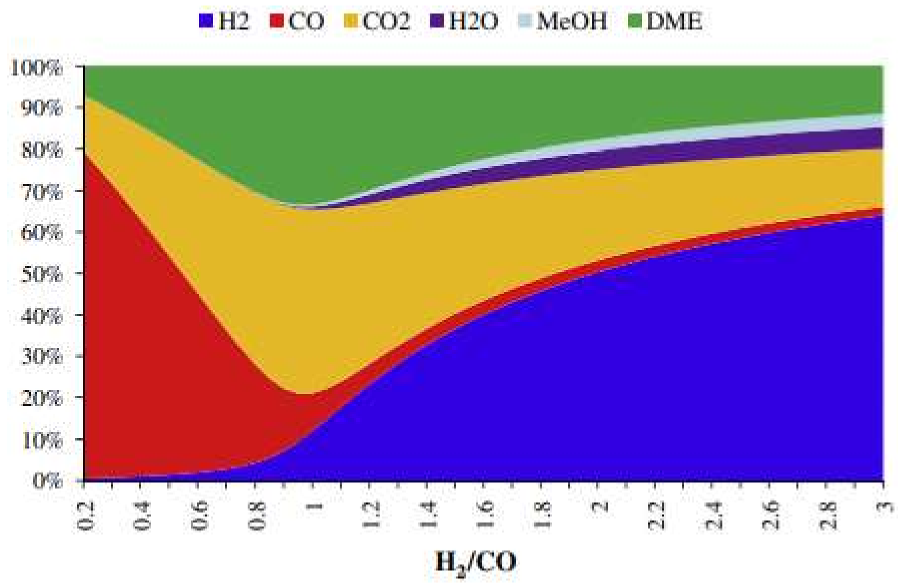


Figure 8: influence of H_2 and CO ratio on the production of DME [36]

Syngas enters in a fixed bed catalytic reactor where a blend of DME (35 % mol) is gained [36]. To obtain pure DME, a distillation unit is needed [36].

The distillation unit "is simulated through three separation columns: the first one is used to separate CO_2, the second one extracts DME and the last one finally separates the water from MeOH" [36].

3.3.2.2 Description of the main components

3.3.2.2.1 Gasifier

The gasifier described in this section is a two-stage gasifier that works at nearly atmospheric pressure [36]. In the first stage (pyrolysis section), dried biomass heats up to 600 °C in a closed screw conveyor, where hot syngas goes through from the gasifier on the outside of the conveyer [36]. In the second stage, oxygen coming from the anode side of the SOEC is added, so the pyrolysis gas is partially oxidized to produce the amount of heat required to sustain the gasification reactions [36]. Syngas produced at a temperature of 860 °C, is cooled to 215 °C by its recirculation in the pyrolizer [36]. In syngas a little percentage of methane is present (1-2%). It can be treated in the SOEC to obtain CO and H_2 (steam reforming) [36]. Using this kind of gasifier let to have a syngas with a very low tar content [36].

3.3.2.2.2 System of cleaning syngas

"The cleaning unit is modelled as a simple black-box having a 100 % efficiency in the removal of contaminants" [36]. This unit includes filters, cyclones, a wet scrubber and a condenser that "drains out condensed water at 15 °C" [36].

3.3.2.2.3 SOEC

Solid oxide electrolytic cells-based modules work at 850 °C and nearly atmospheric pressure [36]. This level of pressure hinders the methanation reaction and carbon deposition [36]. In SOEC following main reactions take place:

$$H_2O \rightarrow H_2 + \frac{1}{2}O_2 \qquad \Delta H_{298K,0.1MPa}=284 \text{ kJ/mol [38]} \qquad (4)$$

$$CO_2 \rightarrow CO + \frac{1}{2}O_2 \qquad \Delta H_{0K,0.1MPa}=19{,}07 \text{ kJ/mol [39]} \qquad (5)$$

$$CH_4 + H_2O \rightarrow 3H_2 + CO \qquad \Delta H_{298K}=206 \text{ kJ/mol [40]} \qquad (6)$$

"The state-of-the-art SOEC technology foresees a porous (Ni-YSZ) fuel electrode (cathode), a dense electrolyte layer based on YSZ and a porous LSM–YSZ oxygen electrode (anode)" [36].

The SOEC operating voltage (V_{op}) is derived from Eq. (7).

$V_{op} = V_{rev} + ASR(t,p) \cdot j$ [36] (7)

Where V_{rev} is the reversible potential, ASR is the Area Specific Resistance calculated through experiments and j is the current per m^2.

$$V_{rev} = -\frac{\Delta g(T,p)}{n^{el} \cdot F}$$ [36] (8)

Eq. (2) represents the reversible voltage of the SOEC stack, where F is the Faraday's constant (96,485 C/mol) and n^{el} is the number of the electrons that are released during the ionization process of one utilized fuel molecule and j the current density [36]. "By applying the Faraday's law, the overall current generated is found by Eq." (9) [36]:

$$I_{op} = \dot{n}_{total\,feed} \cdot RR \cdot n^{el} \cdot RU \cdot F$$ [36] (9)

I_{op} is a function of the overall molar feed to the cathode [36]. To consider the fact that only a part of the inlet feed to the cathode is made up of reactants (i.e., H_2O and CO_2) the Reaction Ratio (RR) parameter is introduced (Eq. (4) being defined as the molar fraction of reactant species) [36]:

$$RR = \frac{\sum_j \dot{n}_{react,j}}{\dot{n}_{total,feed}}$$ (10)

To hinder carbon deposition not all the reactant are converted (called Reactant Utilization) (90 %) [36]. Above this quantity, thermodynamic conditions for carbon build-up are defined. "The higher the RU, more O_2 is pulled out from the cathode side, thus bounding the resulting cathode outlet stream to a composition closer to the carbon boundary limit.

$$RU = \frac{\dot{n}_{react,in} - \dot{n}_{react,out}}{\dot{n}_{react,in}}$$" [36] (11)

Because of high hydrogen content in syngas, partial recirculation of the cathode outlet stream towards the cathode inlet can be impeded, leading to a simplification of the plant design [36].

3.3.2.2.4 DME reactor

To enter in DME reactor, preliminary conditions of temperature and pressure of treated syngas are: $p = 50\ bar$, $T = 250°C$ [36]. "Reactions take place in a fixed bed, multi-tubular, isothermal boiling water reactor (BWR) containing a dual catalyst ($Cu/ZnO/Al_2O_3$ and ϒ- Al_2O_3) for DME and MeOH generation"[36]. These reactions lead a change of the temperature that is kept quite constant by a water-jacketed cooler that provides steam at 240 °C [36]. A blend of 35 % mol of DME exits the reactor and goes through the Vapor-Liquid separator [36]. Following reactions happen in the reactor:

$3H_2 + CO_2 \rightarrow CH_3OH + H_2O$ - $\Delta H_{298K,0.1MPa}$=49.2 kJ/mol [36] (12)

$2H_2 + CO \rightarrow CH_3OH$ - $\Delta H_{298\,K,\,0.1\,MPa}$= 90.4 kJ/mol [36] (13)

$CO + H_2O \rightarrow CO_2 + H_2$ - $\Delta H_{298\,K,\,0.1\,MPa}$= 41.2 kJ/mol [36] (14)

Synthesis of DME is the result of methanol dehydration [36]:

$2CH_3OH \rightarrow CH_3OCH_3 + H_2O$ - $\Delta H_{298\,K,\,0.1\,MPa}$= 24.0 kJ/mol [36] (15)

Production of methanol happens in the optimal condition of high pressure and low temperature [36]. High pressure because many reactant moles are needed to produce few products moles and low temperature because the reactions are exothermic [36].

3.3.2.2.5 Vapour-liquid separator

Vapour-Liquid separator is a cooling unit that decreases the temperature of the blend at – 40°C. It generates two streams: a blend condensate composed of DME, MeOH, water and dissolved CO_2 (stream 41) that will enter the distillation unit, and a gaseous stream (stream 35) made up of incondensable gases such as H_2, CO, undissolved CO_2 and other diluents that are sent to the post-treatment unit [36]. Incondensable gases are partially recirculated and partially sent to an internal combustion engine that produce electricity that is consumed totally in the plant [36].

3.3.2.2.6 Distillation unit

Blend condensate that contains DME enters a distillation unit that is simulated through three separation columns: in the first one CO_2 is separated, in the second one DME is extracted and in the last the H_2O is set apart from MeOH. Separated CO_2 is recirculated to feed the SOEC. This is essential because this step let to have the right amount of CO_2 in the SOEC to obtain the right molar ratio in the syngas (i.e., $H_2/CO = 1$) [36]. “The DME liquid product achieves a purity of 99.3% mol., while the DME plant recovery is 98.9% mol”[36].

3.3.2.2.7 Calculations for the production of DME

Data for calculation of DME	
Available biomass (2030 from Eurostat)	Table 19
LHV wood [MJ/kg]	18,5
LHV DME [MJ/kg] [36]	28,8
Plant efficiency (η) [36]	0,695
Specific productivity (r) [kg_DME/kgdrybiomass] [36]	0,86
Conversion unit for energy [MJ/ktoe] (en_conv)	41876046,9
Percentage of moisture (% wt.) [37]	25
Contribution of advanced biofuels [ktoe] 2030	Table 29

Calculations start with the definition of available dry biomass that will enter the gasifier.

$$available\ dry\ biomass\ [ktons](\dot{m}_{dry\_b}) = (\dot{m}_{biom})[ktons] \cdot \left(1 - \frac{wt_{liq}}{100}\right) \quad (16)$$

It is essential to calculate the energy biomass that will lead to define the necessary RES needed by the plant to operate.

$$Energy\ biomass\ [ktoe]\ (E_{bio}) = \dot{m}_{dry\_b}[ktons] \cdot LHV_{wood}\left[\frac{MJ}{kg}\right] \cdot \frac{10^6\left[\frac{kg}{ktons}\right]}{en\_conv\left[\frac{MJ}{ktoe}\right]} \quad (17)$$

From the available dry biomass by considering specific productivity r, it is found the mass of DME produced:

$$Produced\ DME\ [ktons](m_{DME}) = \dot{m}_{dry_b}[ktons] \cdot r\left[\frac{kg_{DME}}{kg_{dry_{biomass}}}\right] \quad (18)$$

To verify that contributions of advanced biofuels highlighted in NECP are or not satisfied energy that can be produced by the mass of DME must be highlighted.

$$produced\ energy\ [MJ](E_{DME-MJ}) = m_{DME}\ [ktons] \cdot 10^6\left[\frac{kg}{ktons}\right] \cdot LHV_{DME}\left[\frac{MJ}{kg}\right] \quad (19)$$

The contribution of advanced biofuels in NECP are defined in ktoe. So, the energy that can be potentially produced in DME, must be written in ktoe.

$$produced\ energy\ [ktoe](E_{DME-ktoe}) = \frac{E_{DME-MJ}[MJ]}{en\_conv\left[\frac{MJ}{ktoe}\right]} \quad (20)$$

$$Electr.\ required\ [GWh] = \frac{\left(\frac{E_{DME-ktoe}\,[ktoe]}{\eta_{plant}} - E_{bio}\ [ktoe]\right) \cdot en\_conv\left[\frac{MJ}{ktoe}\right]}{3600\left[\frac{s}{h}\right] \cdot 1000\left[\frac{MJ}{GJ}\right]} \quad (21)$$

In case of satisfying the contribution of advanced biofuels, DME that can be exported and the biomass that remains for other purposes are calculated:

$$exportable\ DME\ [kton](Exp_{DME}) = (E_{DME-ktoe} - contribution\ of\ advanced\ biofuels) \cdot \frac{en\_conv\left[\frac{MJ}{ktoe}\right]}{LHV_{DME} \cdot 10^6\left[\frac{kton}{kg}\right]} \quad (22)$$

$$biomass\ for\ other\ purposes\ [kton] = \frac{Exp_{DME}[kton]}{r} \quad (23)$$

Then the potential biomass that should be sufficient to satisfy the internal production of DME to reach the targets defined in NECP is calculated:

$$biomass\ to\ satisfy\ internal\ need(\dot{m}_{int.}) = \dot{m}_{dry\_b} - biomass\ for\ other\ purposes \quad (24)$$

Finally, the necessary renewable energy source in GWh is calculated in order to highlight the energy needed for the functioning of the plant.

$$Electr.required\ \left[\frac{GWh}{yr}\right] = \frac{\frac{contribution\ of\ advanced\ biofuels[ktoe]}{\eta_{plant}} - \dot{m}_{int.}\ [kton]\cdot 10^6[\frac{kg}{kton}]\cdot\frac{LHV\left[\frac{MJ}{kg}\right]}{en\_conv\left[\frac{MJ}{ktoe}\right]}}{\frac{1}{41876046,9}\cdot 1000\left[\frac{MJ}{GJ}\right]\cdot 3600\left[\frac{s}{h}\right]} \quad (25)$$

3.3.3 FT-diesel Plant

Production of FT-diesel is very similar by a chemical point of view, to the production of DME. In fact, it starts with syngas but, finishes with another kind of products. From FT reactions, many products can be obtained, included DME, with a different length of carbon chain. So, it is possible to get a wide variety of fuels from methane to waxes[41].

But in this case a different plant is taken into consideration with respect to the previous plant and FT-diesel must be gained. The processing steps include:

- Feed handling and preparation
- Gasification (and air separation, in directly heated gasifier)
- Tar reforming and scrubbing
- Syngas clean-up and steam reforming
- FT synthesis and product purification - Steam cycle and power generation

3.3.3.1 Feed handling and Preparation

In this stage, wood chips are dried to reduce the amount of heat needed in the gasifier in directly heated rotary driers [41].

3.3.3.2 Gasification in directly heated gasifier

Details of the gasification in the directly heated gasifier and feed preparation are shown in figure 9 [41].

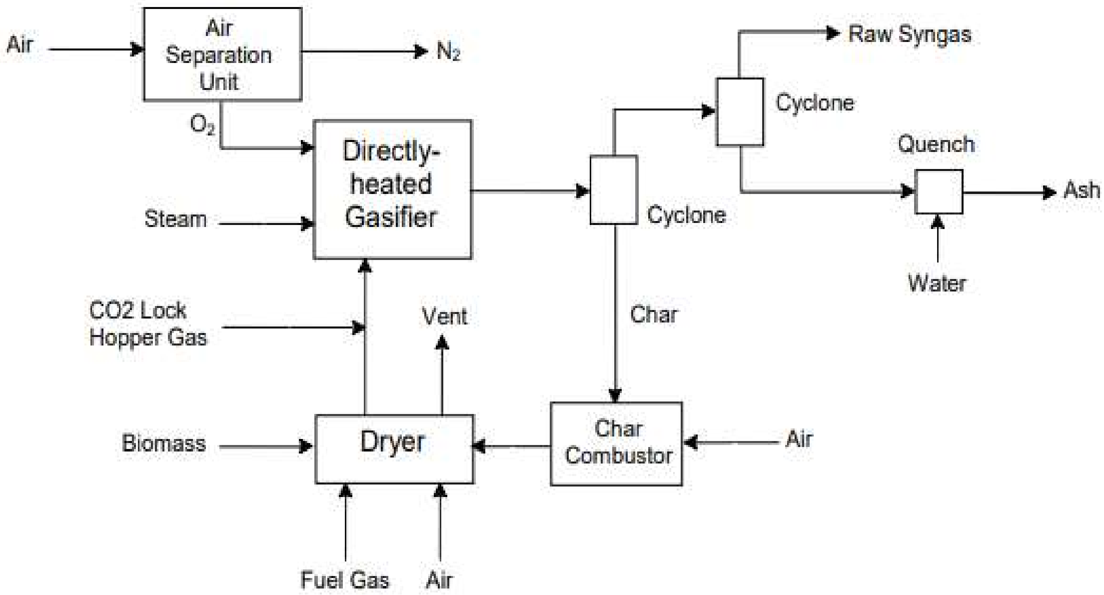


Figure 9: simplified flow diagram of directly heated gasifier and feed preparation [41]

Directly heated gasifier is an oxygen-fired pressurized fluidized bed reactor that works at 20,68 bar and only requires a single-stage compressor [41].

Rate of oxygen is modified to achieve an 871 °C gasifier outlet temperature [41]. The gasifier bed is fluidized by steam that also provides a certain amount of heat. Wood enters in the gasifier by using a lock hopper feeder system in which it is dropped into a chamber, which is closed hermetically, and then filled with pressurized CO_2 recovered from the gas purification and conditioning section of the plant [41]. The chamber is pressurized and wood is sent to the gasifier [41]. “A small amount of MgO is added to the gasifier to react with potassium in the ash to prevent agglomeration in the gasifier bed” [41].

Raw syngas enters the cyclone separator where char is captured and sent to the char combustor and the gas produced from this combustion is sent to the biomass drying unit [41]. Gas from the primary separator passes through a secondary cyclone separator to remove ashes. Ash recovered from the secondary separator is cooled to 149 °C, and then water is added before the mixture is transported to a landfill for disposal. The raw syngas is sent to the tar reformer [41].

3.3.3.3 Tar Reforming and Wet Scrubbing

In figure 10 is highlighted the flow diagram of tar reforming and gas cleaning.

During gasification, a little quantity of tars is produced. They are made up of aromatic and poly-aromatic hydrocarbons [41]. They contain significant quantities of carbon and hydrogen, which are important sources for CO and H_2, therefore, it is better to crack them into small hydrocarbons instead of condensing in the water scrubber and discharging them [41].

Raw gas enters the bubbling fluidized-bed reactor for reforming catalytic tars. A part of the tars reacts with steam and is converted to CO and H_2, and NH_3 is broken into N_2 and H_2. In table 31, compounds whose made up of tars and conversion percentages are highlighted.

Table 31: Design performance of catalytic tar reforming [41]

Compounds	Conversion Percentage
Methane (CH_4)	20%
Ethane (C_2H_6)	90%
Ethylene (C_2H_4)	50%
Tars (C_{10+})	95%
Benzene (C_6H_6)	70%
Ammonia (NH_3)	70% (Converts to N_2 and H_2)
Source: Spath *et al.* 2005	

Gas undergoes to scrubbing and cooling in a venturi scrubber and in a spray quench chamber to remove remaining impurities and residual unconverted tars [41]. Not all the tars are removed by condensation and a little quantity of them passes through the scrubber [41].

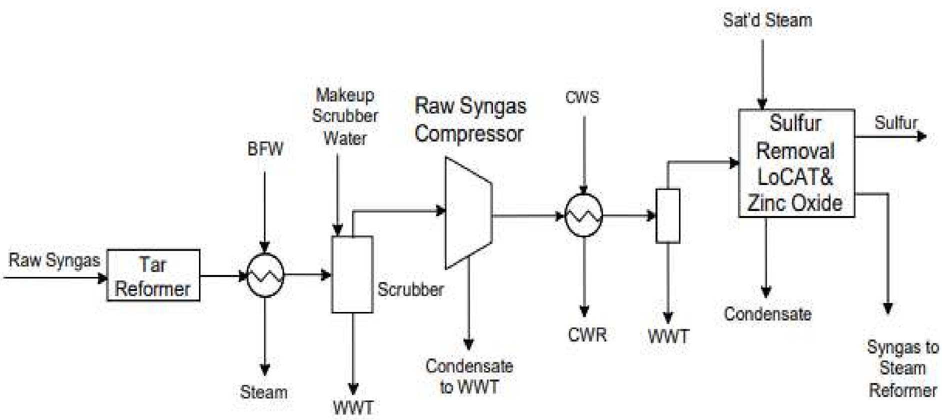


Figure 10: flow diagram of tar reforming and gas cleaning [41]

3.3.3.4 Syngas Compression and Gas Clean-up

As shown in figure 10, cleaned gas is compressed. It still contains traces of methane and other light hydrocarbons, and more or less 100 ppmv H_2S and lower quantities of other sulphur compounds (COS, CS_2, mercaptans) that will poison reforming catalysts [41]. The steam reforming catalysts are sensitive to poisoning by sulphur and chlorides, so these substances must be removed [41]. Hence, a liquid-phase oxidation (Lo-Cat) process followed by a ZnO polishing bed is performed to remove sulphur compounds [41]. The Lo-Cat process removes the sulphur to a concentration of 10 ppm H_2S and the fixed-bed ZnO desulfurization unit cleans gas by reducing the sulfur level to less than 1 ppmv [41]. H_2S is captured by the ZnO sorbent as shown:

$$\mathrm{ZnO} + \mathrm{H_2S} \leftrightarrow \mathrm{ZnS} + \mathrm{H_2O} \quad (26)$$

The ZnO reactor contains a layer of hydrogenation catalyst, where the organic sulphur compounds and other unsaturated hydrocarbons in the raw gas are converted respectively to H_2S and saturated hydrocarbons [41].

3.3.3.5 Steam Reforming and Hydrogen Membrane

In steam reformer, remaining tars are converted to H_2 and CO. The right ratio of CO and H_2 to produce FT diesel is gained through water gas shift reaction, in the presence of the nickel steam reforming catalyst.

The ratio of H_2/CO needed for FT synthesis must be approximately 2,1 to 1 depending on the catalyst used. It is supposed to use a cobalt-type catalyst. So, H_2/CO ratio just over 2.1 is targeted. H_2 in excess can be sent for hydrocracking and hydrotreating [41].

3.3.3.6 Fischer-Tropsch (FT) Synthesis

FT synthesis reactions is represented by the reaction (14)

$$(2n + 1)\mathrm{H_2} + n\mathrm{CO} \leftrightarrow \mathrm{C_nH_{(2n+2)}} + n\mathrm{H_2O} \quad (27)$$

The kind of products obtained depends on the catalyst composition and operating conditions [41]. The waxes can be hydrocracked to yield hydrocarbons in the diesel range [41].

In fact, different carbon length leads to a particular classification:

- "Gas (C_1-C_4)
- Naphtha (C_5-C_8)
- Diesel (C_9-C_{22})

- Wax (C_{23+})" [42]

"The distribution of products may be described using the Anderson-Schulz-Flory (ASF) distribution, as shown in equation" [41] 27:

"$C_n = \alpha^{n-1} (1-\alpha)$ (28)

where n is the length of the hydrocarbon, C is the molar yield of a given carbon number (n), α is the probability of chain growth, and (1-α) is the probability of chain growth termination" [41]. It is assumed that the catalyst produces predominately straight-chained saturated hydrocarbons [41]. Syngas that passes on the catalyst must be sulphur and nitrogen free, because the catalyst poison tolerance is very low [41].

The process flow diagram for the FT synthesis area is shown in figure 11 [41]. Reformed and clean syngas (S461) passes through a hydrogen membrane (M-470). A little amount of hydrogen (S470) is ripped from the clean syngas and will be useful in hydrotreating and hydrocracking process [41]. Before entering the FT reactor, syngas is heated by the fluid exiting the FT reactor itself [41]. The FT reactor is assumed to be a tubular fixed bed reactor with cobalt catalyst in the tubes where synthesis gas is supposed to make a once through pass through the FT reactor, with a CO conversion efficiency of 70% [41]. C_1-C_4 compounds that are used as fuel gas, are removed by a flux of water [41]. Raw product (S520) enters a high pressure (HP) flash tank (V-511) to take away condensate from the gaseous stream [41]. The gas product from the flash tank is further cooled to 4°C by a chiller and enters a medium pressure (MP) flash tank (V-513). The condensate forms a blend with the liquid phase from HP flash tank and enters in a low pressure (LP) flash tank (V-530) [41]. Product is separated in three different flows: gas, water, and waxy oil [41]. The gaseous stream (S532) is combined with the exiting flows from MP flash tank and used as fuel entering the burner [41]. The water stream (S531) from the LP tank is directed to the wastewater treatment [41]. Medium pressure steam heats up the raw oil flux (S534) to 121 °C that is sent to the primary distillation column for the hydrotreating and hydrocracking process [41].

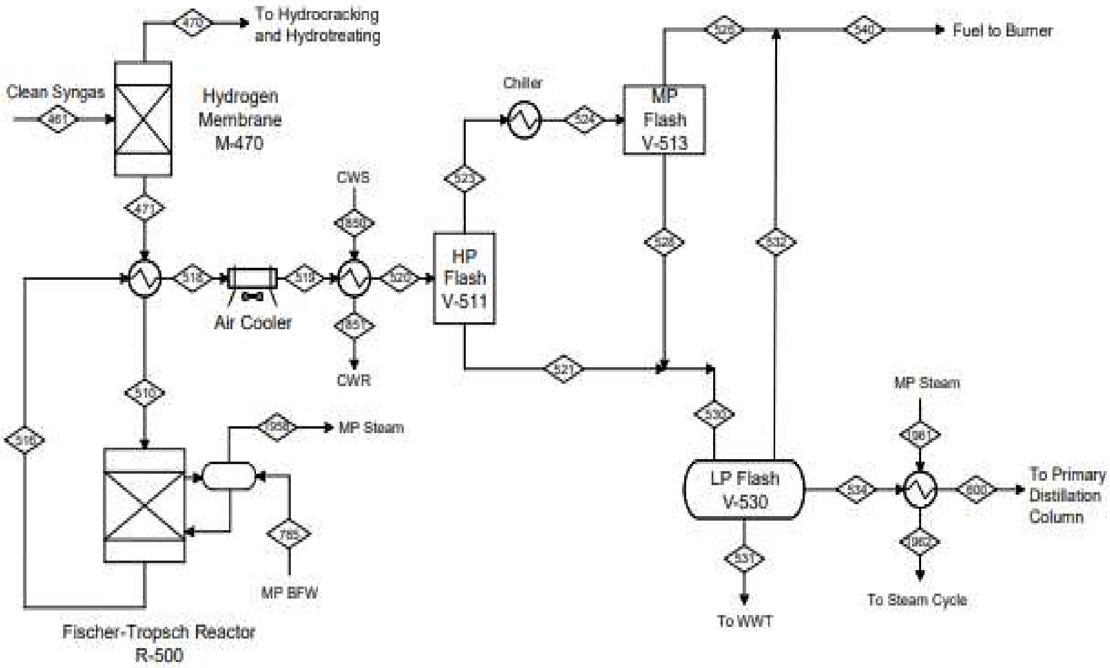


Figure 11: process flow diagram for FT synthesis [41]

3.3.3.7 Hydrocracking and Hydrotreating

In hydrocracking and hydrotreating, FT products are broken to obtain fuel with a proper carbon chain length. A process flow diagram, for the hydrotreating, hydrocracking, and product separation area is given in figure 12. FT products needed are C_{5+}. "These products are mostly linear paraffins and some olefins, with potential for a small amount of oxygenate formation" [41]. Oxygenates, olefins and long chain paraffins (C_{19+}) must be cracked to meet diesel product specifications [41]. The hydrotreater turns any oxygenates present into olefins and then saturates them into paraffins and the hydrocracker breaks C_{19+} hydrocarbons into C_2-C_{19} saturated ones [41]. The hydrocracker (R-610) operates at 70 bar, with an outlet temperature of the substances cracked approximately 399 °C [41]. The hydrotreater (R-615) operates at 68,26 bar and has an outlet temperature of 252 °C [41]. Hydrocracked and hydrotreated FT products are blended (S617) and cooled by high pressure saturated steam and again cooled by an air fin cooler and cooling water [41]. Non-condensable components are taken back as fuel gas [41]. Condensed components are again broken down in distillation columns [41].

3.3.3.8 Product Separation and Purification

This process let to obtain, through two separation columns, FT-diesel and other fuels of different carbon chain length. Fuels until C_3/C_4 formed during hydrotreating and hydrocracking are removed in the first column, referred to as the debutanizer, and sent to the fuel gas system [41]. In the second column, Naphtha is recovered, and middle distillates (Diesel fraction) and some hard distillate remains. This last product is recovered and sent again in the hydrotreating plant [41].

3.3.3.9 Steam Cycle and Power Generation

Steam at different pressures and superheated steam are taken by exothermic reactor, hot reformer and burner offgas [41]. The superheated one is adopted to generate power and the others to fluidize gasifier bed and to provide steam for gasification and reformer/water gas shift reactions [41].

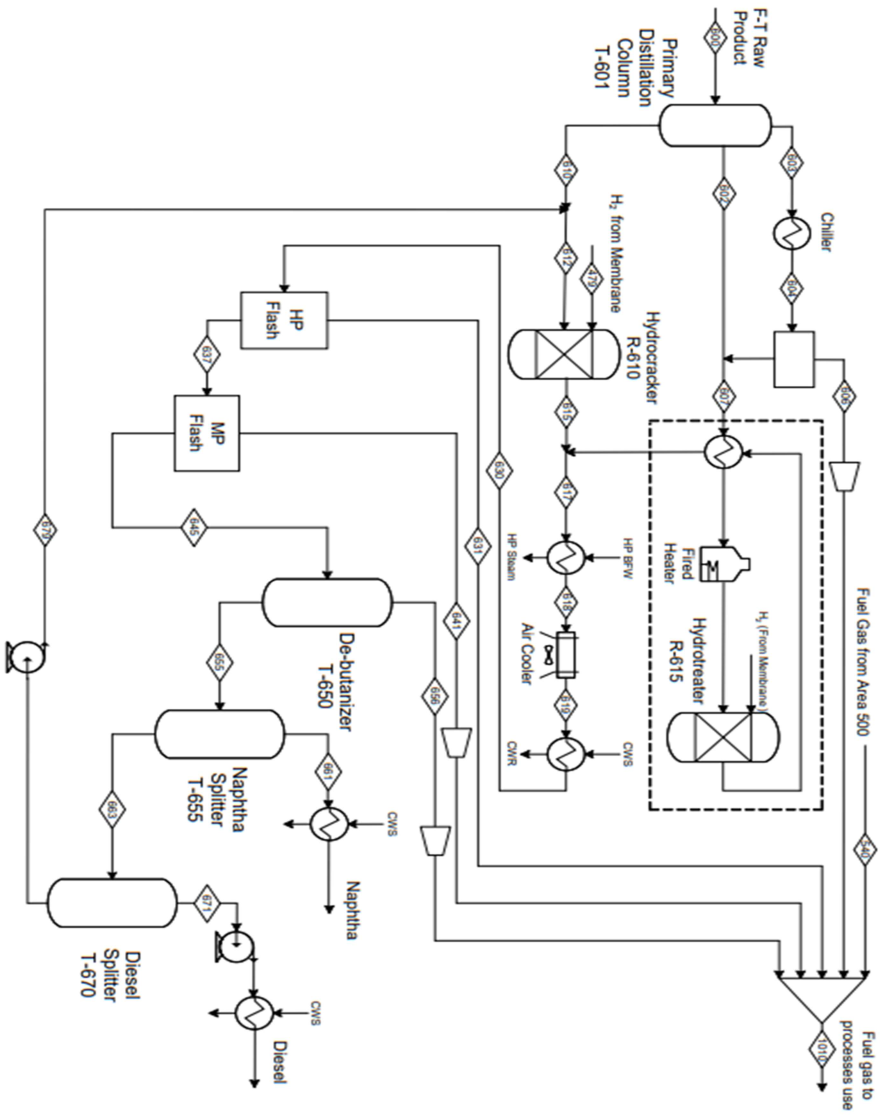


Figure 12: Process flow diagram for hydrocracking and hydrotreating [41]

3.3.3.10 Parameters for calculation of FT-diesel production

Parameters for calculation of FT-diesel are given in figure 13:

Case		Indirectly-heated gasifier	Directly-heated gasifier
Feed			
Dry wood chips, tpd (mtpd)		2200 (2000)	2200 (2000)
Natural gas, scf/hr		-	-
Products			
Diesel, mmgal/y		24	28
By-products			
Naphtha, mmgal/y		8	9
Power consumption, MW			
Air separation unit		-	8.6
Lock hopper gas compressor		-	0.2
Dryer air blower		-	0.1
Char burner air compressor		4.7	0.9
Syngas compressor		16.2	1.9
Reformer air compressor		1.1	2.7
Reformer flue gas blower		0.7	1.0
Clean syngas compressor		0.3	0.5
Hydrogen compressor		0.1	0.1
Fuel gas compressors		0.1	0.01
Boiler air & flue gas blower		0.9	0.1
Steam turbine auxiliaries		0.5	0.6
Power generation, MW			
Steam turbines		46.8	41.2
Net power, MW		**22.2**	**24.5**
Water demand, gpm			
Cooling tower makeup		490	677
Total water demand		901	1167
Wastewater, gpm		536	540
Carbon balance			
Feeds	Biomass	100%	100%
	Natural Gas	0%	0%
	Sum	100%	100%
Fuel products	Diesel	17.9%	20.2%
	Naphtha	5.2%	6.1%
	Sum	**23.1%**	**26.3%**
Wastes	Dryer exhaust	30.4%	11.0%
	Flue gas	20.5%	17.9%
	CO_2	25.8%	44.3%
	Wastewater	0.2%	0.5%
	Sum	76.9%	73.7%
Thermal efficiency, % LHV basis		**39.8%**	**45.6%**

Figure 13: Parameters for calculation of FT diesel [41]

In the calculation section below, only the case of usage in directly heated gasifier is considered, because as can be highlighted in figure 15, the directly heated gasifier leads to a higher production of FT diesel and a higher net power produced.

3.3.3.10.1 Calculations to produce FT-diesel

Data for calculation of FT-diesel production	
Available biomass (2030 from Eurostat)	Table 19
LHV wood [MJ/kg]	18,5
LHV FT-diesel [MJ/kg] [43]	28,8
FT-diesel produced [Mgal/yr] [41]	28
1 gal = 3,785 L	
Conversion unit for energy [MJ/ktoe] (en_conv)	41876046,9
Percentage of moisture (% wt.) [37]	25
Contribution of advanced biofuels [ktoe] 2030	Table 29
Conversion unit for mass (m_conv) [kg/short tonnes] [44]	907,18
Density FT-diesel ($\rho_{FT\text{-}diesel}$) [kg/dm3] [45]	0,78
Net power [MW] (P_{net}) [41]	24,5

Following definitions must be taken in consideration:

$$Efficiency\ of\ production \frac{FT-Diesel}{biomass}\left(\varepsilon_{prod}\right)\left[\frac{L}{kg}\right] = \frac{28\left[\frac{mmgal}{yr}\right]\cdot 3{,}785\left[\frac{ML}{mmgal}\right]\cdot 10^{6}\left[\frac{L}{ML}\right]}{2200\frac{short\ tonn}{day}\cdot 907{,}18\frac{kg}{short\ tonn}\cdot 365\left[\frac{day}{yr}\right]} = 0{,}14548\frac{L_{FTdiesel}}{kg_{dry\ biomass}} \quad (29)$$

the efficiency of production (ε_{prod}) is essential to simplify the calculation of produced FT diesel. As far as the ratio considered in the following equation is concerned, it is worth to define the net electricity delivered to the grid.

$$Ratio_{\frac{electricity\ produced}{energy\ FTdiesel}}(r)\left[\frac{MW}{ktoe}\right] = 24{,}5\ MW\cdot \frac{8760\left[\frac{h}{yr}\right]\cdot en_{conv}\left[\frac{MJ}{ktoe}\right]}{28\left[\frac{mmgal}{yr}\right]\cdot 3{,}785\left[\frac{ML}{mmgal}\right]\cdot 10^{6}\left[\frac{L}{ML}\right]\cdot \rho_{FT-Diesel}\left[\frac{kg}{L}\right]\cdot LHV_{FT-diesel}\left[\frac{MJ}{kg}\right]} = 2470{,}95\left[\frac{MWh}{ktoe}\right] \quad (30)$$

Calculations:

As in the case of DME production, dry biomass as to be calculated:

$$available\ dry\ biomass\ [ktons](\dot{m}_{dry}) = \dot{m}_{bio}[ktons]\cdot\left(1-\frac{\%\ moisture\ in\ weigh}{100}\right) \quad (31)$$

It is important to calculate the energy of FT diesel produced to compare with contribution of advanced biofuels in NECP-

$$produced\ FTdiesel\ \left[\frac{ktoe}{yr}\right](E_{FT-diesel}) = \dot{m}_{dry}\ [ktons] \cdot 10^6 \left[\frac{kg}{ktons}\right] \cdot \varepsilon_{prod} \cdot \rho_{FT-Diesel} \left[\frac{kg}{L}\right] \frac{LHV_{FTdiesel}\left[\frac{MJ}{kg}\right]}{en\_conv\left[\frac{MJ}{ktoe}\right]} \quad (32)$$

As in the case of DME, if the amount of energy produced by FT diesel is sufficient to satisfy values defined in NECP, biomass for other purposes can be calculated:

$$biomass\ for\ other\ purposes\ \left[\frac{kton}{yr}\right] = \frac{(E_{FT-diesel} - contribution\ of\ advanced\ biofuels)\left[\frac{ktoe}{yr}\right] \cdot en\_conv\left[\frac{MJ}{ktoe}\right]}{\varepsilon_{prod} \cdot \rho_{FT-Diesel} \cdot LHV_{diesel}\left[\frac{MJ}{kg}\right] \cdot 10^6 \left[\frac{kg}{ktons}\right]} \quad (33)$$

Finally, this plant can deliver electricity to the grid. It is calculated in this way:

$$net\ electricity\ delivered\ to\ the\ grid[MWh] = contribution\ of\ advanced\ biofuels[ktoe] \cdot r \quad (34)$$

3.3.4 Biogas production: anaerobic digestion

3.3.4.1 Physical and chemical principles of anaerobic digestion

Anaerobic digestion is a process of biological degradation of organic substance in absence of oxygen by means of specific bacteria [46]. Many products are formed in this process, in particular: CH_4 and CO_2 [46].

According to the species of microorganisms used, this process may occur in a wide interval of temperatures: -5 to 70 °C. In fact, microorganisms are classified as: psychrophilic ($T < 20$ °C), mesophilic (20 °C $< T <$ 40 °C) and thermophilic ($T > 45$ °C).

Anaerobic digestion process occurs in 4 steps:

1) hydrolysis of complex substrates in simple monomers;
2) acidogenesis in which, monomers react and form fatty acids, acetic acid and formic acid;
3) acetogenesis, in which is produced acetate, H_2 and CO_2;
4) methanogenesis, where is produced methane and a certain amount of CO_2 [46]

In figure 14, the flow diagram of anaerobic digestion is highlighted.
In the next section, the 4 steps are described in detail.

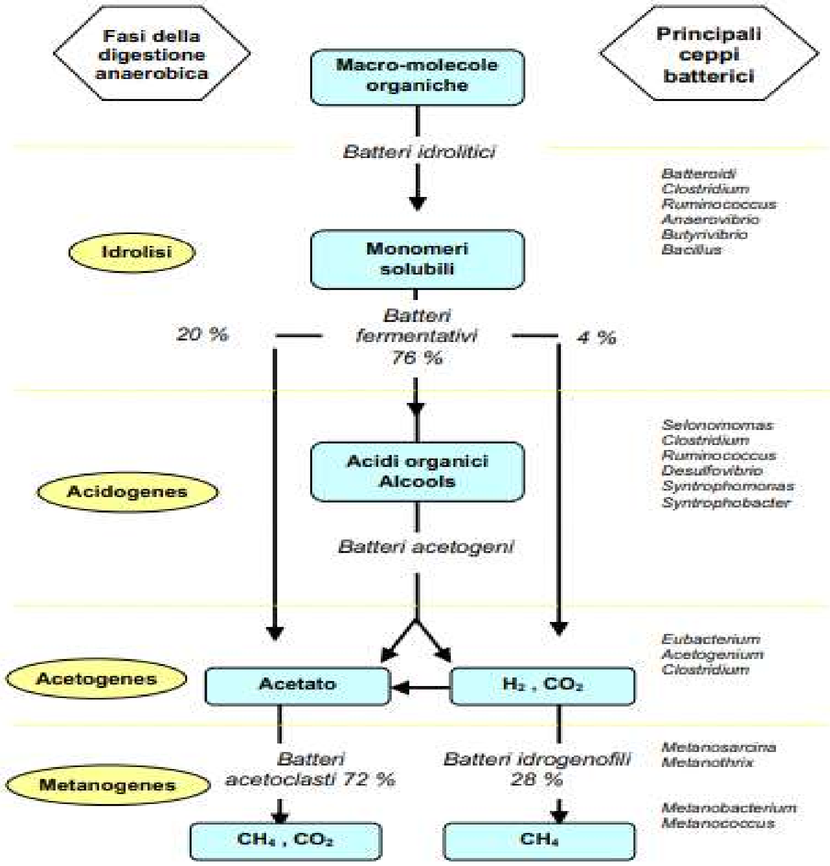


Figure 14: flow diagram of anaerobic digestion [46]

3.3.4.1.1 IDROLYSIS and ACIDOGENESIS

In this step, the intervention of several groups of bacteria provokes the degradation of complex particulate or soluble organic substrates, i.e., proteins, fats and carbohydrates, with the formation of simple compounds as amino acids, fatty acids and monosaccharides in soluble form [46]. Hydrolysing microorganisms can colonize particulate material and degrade it, or produce extracellular enzymes able to divide complex organic molecules in oligomers and monomers that become available for the internal transport of cells of the acidogenic microorganisms fermented [46]. The hydrolytic process can be inhibited from the accumulation of amino acids and sugars because of the interference in the production and activity of hydrolytic enzymes[46].

In acidogenesis process, monomers produced by hydrolytic bacteria, turn into fatty acids, acetic acid and formic acid [46].

3.3.4.1.2 ACETOGENESIS

Starting from the substrates formed during hydrolysis and acidification (volatile acids, essentially propionate and butyrate, but also alcohols), acetogenic bacteria produce acetic acid, formic acid, CO_2 and H_2 [46]. It is reported that two different mechanisms must be considered depending on the fact that the degradation happens starting from long chain fatty acids (LCFA) or short chain fatty acids (SCFA). Generically, fatty acids are defined long chained if they have more than 5 carbon atoms. During the production of acetic acid, the presence of molecular hydrogen in the mean, can determine problem of inhibition. But if H_2 is maintained at low concentrations, thanks to the activity of methanogenic bacteria H_2 oxidants, the degradation of the H_2 fatty acids caused by acetogenic bacteria is more probable, despite the formation of H_2 is energetically underdog [46].

3.3.4.1.3 METHANOGENESIS

The production of CH_4 represents the conclusion of anaerobic trophic chain [46]. Methane, in fact, is the only non-reactive compound in the entire process of anaerobic digestion and can, thus, be considered the final product of the whole process [46]. The production of methane can happen through two different ways of reactions: one way includes methanogenesis caused by hydrogenotrophic bacteria that operate anaerobic digestion of hydrogen, and the second way, acetoclastic way, includes anaerobic dismutation of the acetic acid with formation of methane and carbon dioxide [46]. Most of the methane production happens through this last way. Figure 15 quantifies percentage the distribution in different metabolic pathways involved in the digestion process [46].

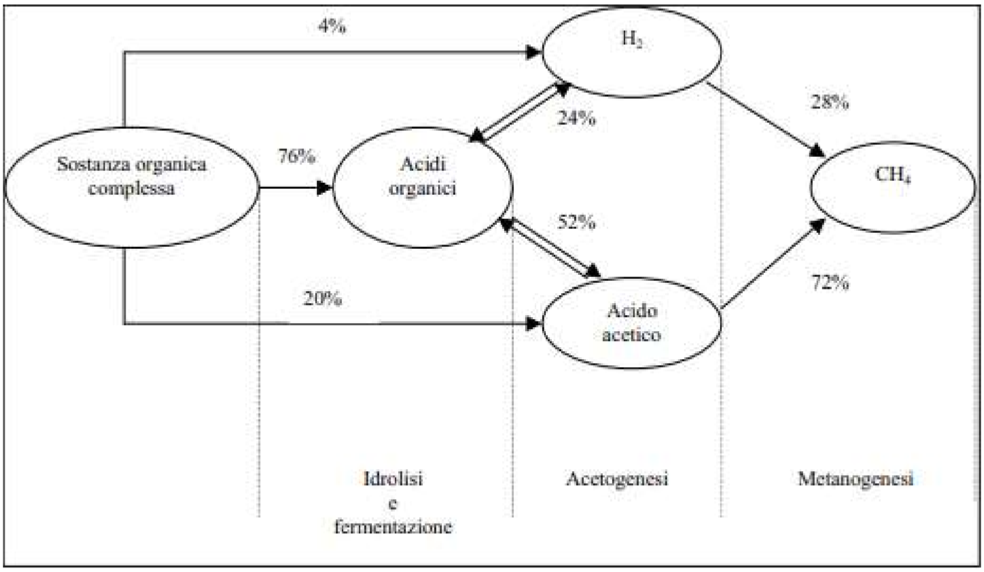


Figure 15: flow diagram of different pathways of anaerobic digestion process [46]

With their own activity, the two strains of methanogenic bacteria play two important functions in the anaerobic trophic chain: on one hand, they degrade acetic and formic acid to CH_4 deleting acids from the mean and keeping, thus, the inhibition of the phenomena of degradation of organic substrates for excess of acidity and on the other hand, maintain the concentration of H_2 at low levels, to let the conversion of long chain fatty acids and of the alcohols to acetate and H_2 [46]. In fact, if the hydrogenotrophic way is slowed down, can be observed an accumulation of H_2 in the mean that inhibits production of methane, while the acetoclastic way can undergo phenomena of inhibition by substrate in presence of elevated concentrations of acetic acid [46]. Table 32 shows, as an example, the main acetotrophic microorganisms involved in biodegradation.

Table 32: acetotrophic microorganisms insulated in pure colture [46]

Microorganism	Used substrate
Methanosarcina barkeri	Acetate, methanol, methylated amines, molecular hydrogen and carbon dioxide
Methanosarcina strain TM-1	Acetate, methanol, methylated amines
Methanococcus mazei	Acetate, methanol, methylated amines
Methanotrix soehngenii	Acetate

The most important factor that control the possibility of using acetate by methanogenic bacteria is represented by the chemical form with which this substrate is present in the mean [46]. In particular, if it is present in non-dissociated form (CH_3COOH), acetic acid can pass through the bacterial membrane and then become available (this phenomenon happens preferably with pH values between 6 and 8) [46]. With more elevated pH values in the mean, acetic acid is present mostly in the dissociated form (CH_3COO-): it follows that the concentration of the non-dissociated form is not sufficient to guarantee such a gradient of concentration to allow the trans-membrane transport of the metabolite [46]. In case of environments characterised by a pH quite slow (lower than 5), an elevated concentration of non-dissociated acid that pass-through cell membrane happens, and the concentration of acetic acid can result higher than the capacities of metabolization of the cells with a consequent inhibition for excess of substrate [46].

3.3.4.2 Anaerobic digestion plant

To conclude the simulation of production of advanced biofuels, the anaerobic digester at AFBI-Hillsborough is considered. The digester is filled with cow slurry, which was then heated up to 37 °C in a mesophilic process [47].

Figure 16: photograph of AD plant at AFBI [47]

Details of AFBI plant are given in table 33 and in figure 16:

Table 33: details of AD plant at AFBI [47]

Digester tank	660 m^3 above ground sealed epoxy coated steel tank with 100 mm mineral wool insulation and 1mm plastic coated steel outer protection. Continuously stirred tank reactor (CSTR) operating at mesophilic temperature (37^{0}C).
Secondary digester tank	660m^3 above ground epoxy coated sealed steel tank, continuously stirred, but not insulated
Feedstock tank	200 m^3 above ground epoxy coated open top steel tank
Digestate stores	2 of 1,500 m^3 above ground open top steel tanks (1 glass coated and 1 epoxy coated)
Digester feed	Fed hourly with a positive displacement lobe pump
Digester and secondary digester discharge	Discharged hourly with positive displacement lobe pumps
Digester mixing	Biogas recirculation 3 x 5 minutes per hour
Digester heating	External 100kW heat exchanger with circulation of digestate by positive displacement lobe pump. Hot water supplied by district heating system
Digester feed macerator	All digester inputs macerated to a nominal particle size of 12mm
Biogas boiler	Hoval 100kW nominal heat output
CHP	Tedom 23kW nominal electrical output
System control	Programmable logic controller (PLC)
Design and construction	Greenfinch Ltd (now BiogenGreenfinch), Ludlow, Shropshire to AFBI specifications

3.3.4.2.1 PERFORMANCE OF THE AFBI ON-FARM DIGESTER

Table 34 gives the values that characterize AFBI digester performance. Digestion required 32 kWh of heat per tonne of slurry fed to maintain average digester temperature at 37.1°C, plus an average demand of 5.4 kWh of electricity per tonne of slurry input for pumps, mixing etc" [47].

Table 34: performance of AFBI AD plant over 117 weeks (24 January 2009 - 22 April 2011) [47]

Inputs	Mean	Minimum	Maximum	Standard deviation
Slurry (tonnes/day)	20.0	17.6	24.4	1.06
Dry matter (total solids) (tonnes/day)	1.38	0.83	1.79	0.19
Organic matter (tonnes/day)	1.07	0.65	1.40	0.15
Organic matter (kg/m^3 digester per day)	2.02	1.19	2.49	0.29
Retention time (days)	27	23	30	1.29
Temperature (^{0}C)	37.1	36.3	42.0	0.30
Outputs				
Digestate	19.8	17.0	25.4	1.17
Biogas (m^3/day)	303	158	455	50.6
Methane (m^3/day)	169	90	266	27.6
Methane content of biogas (%)	56	52	61	1.6
Hydrogen sulphide content of biogas (ppm)	1670	496	2959	523
Gross biogas energy/tonne slurry (kWh)	85	45	132	14.9
Efficiency measures				
m^3 biogas/tonne slurry	15.2	8.0	22.6	2.73
m^3 biogas/m^3 digester/day	0.57	0.30	0.81	0.09
m^3 biogas/kg dry matter (total solids)	0.22	0.14	0.31	0.034
m^3 biogas/kg organic matter	0.28	0.18	0.40	0.045
m^3 methane/kg organic matter	0.16	0.10	0.23	0.025
Digester heating (kWh/tonne slurry input)	32	22	41	5.1
Energy required for digester heating (% gross biogas energy)	39	21	68	9.9
Slurry				
Dry matter (g/kg fresh)	69.0	35.3	86.5	9.69
Organic matter (g/kg fresh)	53.9	27.5	67.5	7.75
Organic matter (% of dry matter)	78.0	74.0	80.1	1.2
Nitrogen (g/kg fresh)	3.33	1.84	4.37	0.50
Ammonia nitrogen (g/kg fresh)	1.78	1.26	3.11	0.32
pH	7.23	5.90	8.63	0.50
Volatile fatty acids (g/kg fresh)	5.79	1.30	8.74	1.62
Chemical oxygen demand (g/l)[b]	81	47	103	10.8
Digestate				
Dry matter (g/kg fresh)	54.8	38.8	66.3	6.00
Organic matter (g/kg fresh)	40.0	28.4	50.0	4.64
Organic matter % of dry matter)	73.3	70.7	76.5	0.90
Nitrogen (g/kg fresh)	3.36	2.28	4.29	0.487
Ammonia nitrogen (g/kg fresh)	2.10	1.59	2.91	0.319
pH	7.92	7.15	8.93	0.381
Volatile fatty acids (g/kg fresh)[a]	1.16	0.08	3.35	0.811
Chemical oxygen demand (g/l)[b]	58	47	70	5.2
Dry matter digested (%)	24	15	34	3.8
Organic matter digested (%)	31	19	43	4.9
Chemical oxygen demand digested (%)	29	11	46	7.9
Volatile fatty acids digested (%)	76	23	99	16.7

[a] January 2009 to January 2010; [b] May 2009 to April 2010

3.3.5 Plant for upgrading biogas to biomethane

Bright biomethane technology is used.

Bright biomethane uses a membrane technology. In the membrane unit, the gas is separated by means of an imposed pressure difference over the membrane. Two gas streams will be obtained from the plant: a product gas with a high methane value and a CO_2 rich gas. Using membranes with high separation efficiency allows recovery of the highest possible methane yield. Depending on the grid or user requirements, the gas can be upgraded to the preferred methane concentration. Upgrading plant considered is in figure 19 [48]:

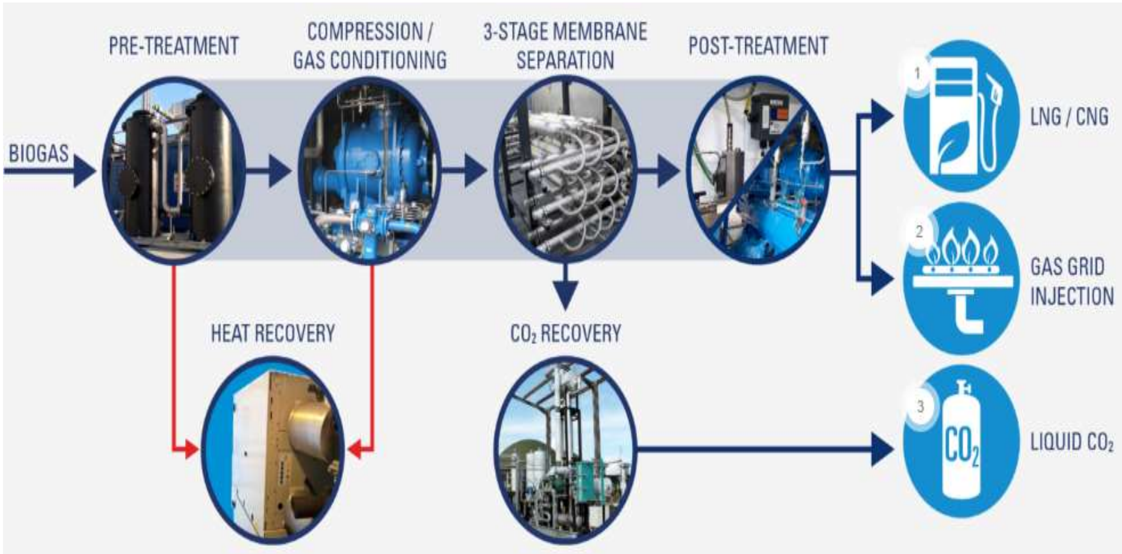


Figure 17: components of upgrading plant [48]

3.3.5.1 Pre-treatment of biogas

Biogas is dried and, H_2S and other contaminants are removed from it by using a double active carbon filter [48]. Water is removed by cooling the biogas to approximately 5°C with a chiller [48].

3.3.5.2 Compression and heat recovery

After pre-treatment, biogas is compressed to the necessary pressure for upgrading by membranes [48]. The heat of the drying of the biogas, the heat from the compressor and the heat from cooling the gas after the compressor may be recovered by using a patented heat recovery system, this option makes it possible to recover the optimal amount of heat, so less energy is needed [48].

3.3.5.3 Separation by 3 stage membrane arrangement

For the separation of CO_2, Bright Biomethane uses membranes with very high selectivity [48]. The membrane modules in the system are arranged in 3 stages [48]. In this design, the permeate gas from the different stages is recirculated to obtain the highest efficiency (> 99.5%) and lowest methane loss (< 0.5%) [48].

3.3.5.4 CO_2 recovery

CO_2 can be recovered and liquefied [48]. The liquefaction process lets to reach zero methane slip, because the small amount of methane still present in the CO_2 is recovered [48]. Recovery system can be put in a stand-by mode that requires no additional energy if CO_2 condensate is not necessary [48].

The CO_2 is compressed in a non-lubricated two stage process compressor [48]. From the compressor the CO_2 goes to the activated carbon filter to remove any remaining odour compounds/impurities [48]. The filtered gas passes through an automatic molecular sieve dryer to completely remove the moisture [48]. The purified gas is sent to the CO_2 liquefier; traces of non-condensable gases still contained in the CO_2 remain gaseous while the CO_2 condenses in the liquefier [48]. Any entrained non-condensables such as oxygen, methane and nitrogen are effectively removed in the stripping tower [48]. The pure liquid CO_2 flows to an insulated storage tank [48].

The global "process of separation has a very low electric consumption, (0,22 kWh/Nm^3 biogas) and no heat required for the process of upgrading biogas. Heat recovery (> 0,25 kWt/Nm^3 biogas) can cover most of the energetic consumption of biogas plant" [48].

3.3.5.5 Calculations for the production of biomethane

In the plant considered, only cow slurry is used. As far as the calculations in case of pig dejections are concerned, they are done hypothesizing that they are threated in the same plant. I assumed the same amount of heat required because liquid percentage in pig manure is almost the same to that of cow slurry taken in consideration, with the same power electricity because of absence of data.

Table 35: characteristic of pig manure [49]

Sample	pH	Total solids %	Volatile solids %	Total Kjeldahl nitrogen %	Total ammonium nitrogen %	Protein %	Lipids %	Crude fibre %	Lignin %	Volatile fatty acids %
Liquid manure	7.43 ± 0.45	3.46 ± 2.91	11.41 ± 2.38	0.68 ± 0.13	0.30 ± 0.09	2.34 ± 0.47	0.35 ± 0.09	2.80 ± 0.75	0.94 ± 0.25	0.34 ± 0.26
Solid fraction of manure	7.65 ± 0.01	20.28 ± 0.03	16.00 ± 0.01	0.61 ± 0.05	0.07 ± 0.00	3.34 ± 0.31	0.05 ± 0.00	4.48 ± 0.16	3.31 ± 0.83	0.06 ± 0.04
Liquid fraction of manure	7.60 ± 0.27	0.88 ± 0.57	0.53 ± 0.46	0.06 ± 0.01	0.04 ± 0.02	0.13 ± 0.09	0.00 ± 0.00	0.02 ± 0.03	0.02 ± 0.03	0.25 ± 0.28

Data for the calculations on the production of biomethane are given in the table below:

Data for calculations of production of biomethane	
Total liquid dejections of bovines	Table 25
Total solid dejections of bovines	Table 26
Total liquid dejections of pigs	Table 27
Total solid dejections of pigs	Table 28
Electricity required for upgrading [kWh/Nm3 biogas] [48]	0,22
Conversion unit for energy [MJ/ktoe] (en_conv)	41876046,9
No heat required for upgrading because of heat recovery [48]	
Contribution of biomethane [ktoe] 2030	Table 30
Total Volatile solids in liquid dejections (pigs) (% weight) (TVS_l) [35]	4,68
Total volatile solids in solid dejections (pigs) (% weight)(TVSs) [35]	18,04
Ratio biogas (Nm3/t_TVSl) (pigs) [35]	355
Ratio biogas (Nm3/t_TVSs)(pigs) [35]	450
% methane in biogas [47]	56
Gross biogas energy [kWh energy/tonn slurry] [47]	85
Volume of biogas produced (V) [m3/tonn slurry] [47]	15,2
Heat required per kWh biogas [kWhheat/kWhbiogas] [47]	0,39
Electricity required [kWh/tonn_slurry] [47]	5,4
LHVmethane at 25 °C [MJ/m3] [50]	36
Ratio of methane gained by upgrading biogas [48]	0,995

Table 36: Parameters for the calculation of biogas available from pigs breeding [35]

	Liquid dejections	Solid dejections
Total solids (% as it is)	6	22
Total volatile solids, TVS, (% ST)	78	82
TVS (% as it is)	4,68	18,04
Nm^3 biogas/t_TVS	355	450
Nm^3 biogas/(t as it is)	16,614	81,18

First, biogas from bovine dejections is defined:

$$biogas\ from\ liquid\ dejections\ (bovine)\ (m^3) = liquid\ dejections\ [tonns] \cdot V \left[\frac{m^3}{tonns\ cow\ slurry}\right] \tag{35}$$

$$biogas\ from\ solid\ dejections\ (bovine)(m^3) = solid\ dejections\ [tonns] \cdot V \left[\frac{m^3}{tonns\ cow\ slurry}\right] \tag{36}$$

Unlikely bovines, pigs' dejections are calculated using data in table 36 that are given in Nm^3:

$$biogas\ from\ liq.dej.(pigs)(m^3\ at\ 37°C) = liq.dej.(pigs)\ [tonns] \cdot \frac{TVS_l}{100} \cdot ratio\ biogas \left(\frac{Nm^3}{t_{TVS_l}}\right) \cdot \frac{310}{273} \tag{37}$$

$$biogas\ from\ sol.dej.(pigs)(m^3 at\ 37\ °C) = sol.dej.(pigs)\ [tonns] \cdot \frac{TVS_s}{100} \cdot ratio\ biogas \left(\frac{Nm^3}{t_{TVS_l}}\right) \cdot \frac{310}{273} \tag{38}$$

Then, total biogas produced can be counted:

$$Total\ biogas\ produced = Biogas\ produced\ by\ dejections\ of\ bovines\ and\ pigs$$

Finally, biomethane is obtained considering the operation of upgrading biogas plant:

$$\text{biometh. obt.} = \text{biogas prod.} \cdot \text{\% meth. in biogas} \cdot \text{Ratio of biometh. obt. by upgrading biogas}$$

$$Biomethane\ produced \left[\frac{MJ}{year}\right] = biometh.obt \cdot LHV at\ 37°C \tag{39}$$

$$Biomethane\ produced \left[\frac{ktoe}{year}\right] = biomethane\ produced \frac{\left[\frac{MJ}{year}\right]}{en_{conv}\left[\frac{MJ}{ktoe}\right]} \tag{40}$$

Following definitions are considered to calculate electricity and heat required:

$$Ratio\ of\ \frac{electricity\ required}{Gross\ biogas\ energy} = \frac{5{,}4}{85} = 0{,}063529 \left[\frac{kWh_{el}}{kWh_{biogas}}\right] \tag{41}$$

$$HV\ of\ biogas = \frac{Gross\ biogas\ energy}{Volume\ of\ biogas\ produced} = \frac{85}{15{,}2} = 5{,}592105 \left[\frac{kWh}{m^3}\right] \tag{42}$$

Heating value of biomethane is calculated considering that it exits the upgrading biogas at the same temperature of work of anaerobic digestor:

$$LHV\ of\ biomethane\ at\ 37°C = LHV_{biomethane} \cdot \frac{298{,}15}{310{,}15} = 34{,}607 \left[\frac{MJ}{m^3}\right] \tag{43}$$

Energy of biogas is calculated in order to define the electricity and heat required by the anaerobic digestor.

$$Energy\ biogas = Total\ biogas\ produced\ [m^3] \cdot HV_{biogas} \left[\frac{kWh}{m^3}\right] \tag{44}$$

$$Heat\ required = heat\ required\ per\ kWh\ biogas \cdot Energy\ biogas \tag{45}$$

Because for the upgrading plant, electricity required is defined for Nm^3 of biogas, volume of biogas must be referred to a 0 °C, instead of 37 °C (exiting digester).

$$electricity\ required = Energy\ biogas\ [kWh] \cdot Ratio\ of\ \frac{el.\ required}{gross\ biogas\ energy}\left[\frac{kWhel}{kWh_{biogas}}\right] + total\ biogas\ produced\ [m^3] \cdot electr.required\ for\ upgrading\ \left[\frac{kWh_{el}}{Nm^3}\right] \cdot \frac{273{,}15}{310} \tag{46}$$

3.4 Calculations of GHG emissions

Calculations of GHG emissions are done starting with data found in each EU-27 member NECP.

Table 37: Projections of GHG emissions in transportation sector [$ktCO_{2eq}$]

GEO/TIME	2020	2025	2030	2035	2040	Reference
Belgium	26.900	27.500	28.300	:	:	(Trend in total GHG emissions by IPCC sector (WAM scenario)) table 13 [51]
Bulgaria	9096,34	9.282,43	8.989,77	:	:	Table 5 [52]
Czech Republic	17.600,00	17.010,00	15.730,00	13.930,00	11.920,00	Projection of total greenhouse gas emissions from the Energy sector for WEM and WAM scenarios [53]
Denmark	13.000,00	13.000,00	12.500,00	12.300,00	11.700,00	From graphical rappresentation figure 25 [54]
Germany	:	152.000	125.000	:	63.000	Table B25 [55]
Estonia	2.100,00	2.200,00	2.300,00	2.400,00	2.480,00	Figure 25 [56]
Ireland	12.383,34	10.935,35	7.600,41	5.812,06	4.407,39	Table 3 WAM projection [57]
Greece	18.100	18.100	17.200	16100	15.300	Table 35 [58]
Spain	87.058	77.651	59.875	:	:	Table A.9 [59]
France	130000,00	120000,00	110000,00	70000	50000	Figure 13 [60]
Croatia	6200,00	6200,00	6200,00	6000	5200	Figure 4-8 [61]
Italy	95000,00	92000,00	79000,00	:	:	Table 7 INECP scenario [62]
Cyprus	:	:	1681,00	:	:	Table 5.36 [63]
Latvia	2800,00	2600,00	2200,00	:	:	Figure 54 [64]
Lithuania	6161,00	5168,00	3655,00	3159	2748	Table 5.1.1.1 [65]
Luxembourg	5077,00	4004,00	3289,00	2548	1865	Table 20 [66]
Hungary	12000,00	12000,00	12000,00	10000	9500	Figure 83 [67]
Malta	550,00	530,00	600,00	630	530	Figure 57 ESR [68]
Netherlands	34800,00	34400,00	33100,00	:	:	Table 4.4 [69]
Austria	24500,00	:	23700,00	:	22000	Table 14 [70]
Poland	62849,34	60362,78	56327,76	54598,87	52365,71	Table 21 [71]
Portugal	:	:	10703	:	3171,36	Table 40, 41 my own calculations [72]
Romania	:	:	:	:	:	
Slovenia	6000	5800	5000	4000	2300	Figure 29 [73]
Slovakia	6878	7070	7097	6907	6152	Table 72 [55]
Finland	11000	10000	10000	9900	9600	Figure 10 [74]
Sweden	14800	13900	13400	13200	13300	Table 26 [75]

Most of these projections considers emissions from transportation sector. But in this work are highlighted only emissions by road transport. In order to consider only them, historical series from Eurostat in table 38 and table 39 are taken.

Table 38: Historical series of GHG emissions of fuels in road transport [$ktCO_{2eq}$] [76]

GEO/TIME	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Belgium	26.535,63	25.651,3	25.298,37	24.563,99	24.061,09	24.408,46	26.061,51	25.811,92	25.214,79	25.345,83
Bulgaria	7.770,06	7.561,96	7.586,11	7.936,86	6.944,78	7.968,39	8.785,34	8.909,33	8.982,42	9.282,96
Czechia	17.336,53	16.329,79	16.180,56	15.960,71	15.844,1	16.358,11	17.138,04	17.864,2	18.337,68	18.694,61
Denmark	12.410,51	12.340,44	12.049,53	11.511,54	11.324,46	11.544,62	11.771	11.973,58	12.151,82	12.448,54
Germany (u	146.958	148.107,23	150.110,44	148.857,9	153.160,47	154.354,32	157.019,22	160.233,38	163.357,62	157.707,09
Estonia	1.995,09	2.067,62	2.140,62	2.184,24	2.144,51	2.173,62	2.229,6	2.285,06	2.350,34	2.357,32
Ireland	11.907,91	10.996,34	10.747,58	10.375,78	10.606,57	10.855,59	11.330,05	11.764,58	11.517,86	11.677,52
Greece	21.620,09	19.484,83	17.768,99	14.410,22	14.640,78	14.497,2	14.740,4	14.973,4	14.723,67	14.782,34
Spain	87.550,61	84.366,33	80.021,98	73.379,26	75.654,12	76.553,31	79.275,03	81.374,3	82.754,34	83.658,7
France	124.846,68	127.893,6	127.767,75	126.014,59	125.576,85	125.702,05	126.795,1	127.320,37	127.531,49	124.794,62
Croatia	5.898,56	5.704,75	5.565,44	5.398,63	5.480,35	5.421,29	5.748,44	5.965,2	6.426,68	6.193,38
Italy	108.178,85	105.910,5	105.822,33	98.892,27	96.793,55	101.857,28	99.476,23	97.976,71	93.831,21	96.865,93
Cyprus	2.268,81	2.318,79	2.250,9	2.077,42	1.870,93	1.821,83	1.891,21	2.023,15	2.095,75	2.064,33
Latvia	2.933,45	3.026,5	2.635,1	2.516,83	2.566,12	2.714,27	2.909,98	2.960,83	3.122,3	3.140,38
Lithuania	4.058,78	4.165,11	4.131,15	4.144,87	4.157,15	4.627,89	4.899,41	5.286,16	5.494,04	5.845,83
Luxembou	6.145,46	6.507,51	6.883,5	6.581,38	6.442,25	6.133,47	5.695,4	5.526,29	5.639,73	6.019,93
Hungary	12.649,42	11.382,46	10.789,32	10.463,05	9.776,23	10.909,87	11.982,98	12.241,44	12.855,4	13.599,86
Malta	497,28	526,43	511,9	508,21	510,02	522,92	549,1	549,35	563,26	568,78
Netherland	32.546,47	33.187,21	33.169,38	31.683,04	30.841,91	28.898,33	29.059,24	29.254,84	30.038,45	30.295,66
Austria	21.084,94	21.884,1	21.147,68	21.081,64	22.126,17	21.529,94	21.941,32	22.819,36	23.500,02	23.682,71
Poland	45.747,14	48.395,13	48.961,34	46.910,21	43.861,72	44.232,14	46.814,57	53.481,77	61.965,39	63.847,34
Portugal	18.494,94	18.290,61	17.004,77	15.592,11	15.244,36	15.566,92	15.706,59	16.108,29	16.374,55	16.445,71
Romania	14.173,99	13.181,77	13.258,23	14.327,97	14.219,07	15.039,58	15.093,54	16.214,83	17.280,33	17.824,86
Slovenia	5.280,21	5.222,82	5.659,16	5.737,64	5.434,06	5.346,15	5.321,52	5.698,28	5.508,84	5.791,8
Slovakia	6.039,64	6.502,59	6.053,4	6.448,64	6.214,72	6.262,26	6.944,71	7.078,24	7.180,88	7.343,66
Finland	11.363,98	11.812,21	11.630,71	11.390,86	11.232,89	10.163,44	10.177,39	11.405,18	10.776,59	10.942,74
Sweden	18.768,4	18.895,81	18.458,77	17.385,14	16.931,05	16.567,38	16.536,61	15.818,11	15.390,97	14.980,26

Table 39: Historical series of GHG emissions of fuels in whole transportation sector [$ktCO_{2eq}$] [76]

GEO/TIME	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Belgium	27.487,56	26.688,4	26.302,72	25.513,28	24.997,33	25.244,55	26.929,69	26.645,52	26.067,34	26.251,18
Bulgaria	8.246,2	8.013,46	8.195,75	8.527,46	7.463,14	8.437,07	9.233,65	9.358,25	9.495,52	9.700,62
Czechia	17.852,92	16.832,27	16.662,02	16.384,24	16.254,09	16.768,69	17.531,63	18.205,97	18.706,61	19.055,34
Denmark	13.515,09	13.388,25	13.083,99	12.510,76	12.325,34	12.443,68	12.716,65	12.994,42	13.173,53	13.436,52
Germany	153.472,87	154.375,77	156.513,81	155.083,88	159.445,86	160.439,48	163.056,39	166.410,62	169.181,18	163.620,06
Estonia	2.141,64	2.267,96	2.278,1	2.303,63	2.251,95	2.278	2.340,23	2.385,81	2.427,47	2.404,7
Ireland	12.460,76	11.545,68	11.234,36	10.845,81	11.078,52	11.361,42	11.827,32	12.308,05	12.026,49	12.224,73
Greece	25.293,33	22.476,45	20.117,75	16.737,32	16.513,74	16.547,59	17.100,38	17.438,47	17.215,75	17.448,44
Spain	94.918,1	91.590,68	86.416,34	79.280,72	80.061,38	80.358,49	83.482,65	86.347,47	89.025,85	90.268,87
France	131.989,38	134.956,63	135.015,4	133.331,34	132.775,52	132.590,51	133.671,3	134.240,64	134.615,74	132.178,92
Croatia	6.185,61	5.954,67	5.812,39	5.631,01	5.717,8	5.664,73	5.973,06	6.194,88	6.662,2	6.428,25
Italy	117.050,33	115.539,5	114.476,46	106.756,41	104.061,36	108.875,48	106.247,41	104.815,72	100.917,89	104.263,14
Cyprus	2.280,9	2.329,58	2.256,12	2.080,95	1.873,43	1.824,25	1.894,17	2.025,24	2.098,67	2.067,41
Latvia	3.206,84	3.278,99	2.916,64	2.813,95	2.850,23	2.973,84	3.153,89	3.173,13	3.325,87	3.353,9
Lithuania	4.310,85	4.428,29	4.398,52	4.412,21	4.404,83	4.879,8	5.129,54	5.514,02	5.745,18	6.111,4
Luxembourg	6.157,53	6.520,5	6.896,47	6.593,22	6.452,51	6.145,01	5.703,77	5.534,15	5.648,16	6.028,73
Hungary	12.997,76	11.666,55	11.093,28	10.764,2	10.041,67	11.203,16	12.222,27	12.496,64	13.158,74	13.930,49
Malta	540,83	557,57	557,37	578,98	603,27	631,95	659,63	631,08	634,82	662,75
Netherlands	33.942,46	34.756,06	34.654,67	33.064,13	32.328,04	30.143,02	30.389,47	30.482,69	31.249,59	31.486,16
Austria	21.763,01	22.577,14	21.922,83	21.743,05	22.925,72	22.224,37	22.700,5	23.553,59	24.312,05	24.425,87
Poland	46.900,9	49.420,49	50.012,62	48.066,18	45.209,08	45.548,94	48.049,51	54.777,53	63.285,87	65.303,45
Portugal	19.192,52	18.982,96	17.632,07	16.237,88	15.870,92	16.214,95	16.397,7	16.856,69	17.186,48	17.247,62
Romania	15.182,05	14.236,47	14.370,05	15.249,12	15.064,96	15.599,33	15.713,69	16.828,15	17.975,64	18.435,22
Slovenia	5.316,8	5.262,58	5.697,87	5.774,34	5.470,51	5.394,75	5.367,74	5.737,67	5.547,4	5.824,01
Slovakia	7.006,34	7.425,74	7.057,79	6.934,07	6.795,56	6.534,31	7.234,12	7.482,67	7.603,39	7.738,65
Finland	12.205,29	12.711,45	12.518,04	12.209,38	12.002,03	10.859,81	10.862,16	12.077,71	11.465,25	11.656,19
Sweden	20.204,59	20.365,84	19.975,79	18.836,12	18.394,4	17.995,6	17.948,83	17.280,98	16.855,86	16.472,29

Table 38 represents the historical series of GHG emissions of fuels in road transport and table 39 the historical series of GHG emissions of fuels in the whole transportation sector.

So, ratio between values in table 38 and table 39 are given in table 40.

Table 40: Ratio of contribution of road transport to the whole transportation sector

GEO/TIME	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Belgium	0,97	0,96	0,96	0,96	0,96	0,97	0,97	0,97	0,97	0,97
Bulgaria	0,94	0,94	0,93	0,93	0,93	0,94	0,95	0,95	0,95	0,96
Czechia	0,97	0,97	0,97	0,97	0,97	0,98	0,98	0,98	0,98	0,98
Denmark	0,92	0,92	0,92	0,92	0,92	0,93	0,93	0,92	0,92	0,93
Germany	0,96	0,96	0,96	0,96	0,96	0,96	0,96	0,96	0,97	0,96
Estonia	0,93	0,91	0,94	0,95	0,95	0,95	0,95	0,96	0,97	0,98
Ireland	0,96	0,95	0,96	0,96	0,96	0,96	0,96	0,96	0,96	0,96
Greece	0,85	0,87	0,88	0,86	0,89	0,88	0,86	0,86	0,86	0,85
Spain	0,92	0,92	0,93	0,93	0,94	0,95	0,95	0,94	0,93	0,93
France	0,95	0,95	0,95	0,95	0,95	0,95	0,95	0,95	0,95	0,94
Croatia	0,95	0,96	0,96	0,96	0,96	0,96	0,96	0,96	0,96	0,96
Italy	0,92	0,92	0,92	0,93	0,93	0,94	0,94	0,93	0,93	0,93
Cyprus	0,99	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00
Latvia	0,91	0,92	0,90	0,89	0,90	0,91	0,92	0,93	0,94	0,94
Lithuania	0,94	0,94	0,94	0,94	0,94	0,95	0,96	0,96	0,96	0,96
Luxembourg	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00
Hungary	0,97	0,98	0,97	0,97	0,97	0,97	0,98	0,98	0,98	0,98
Malta	0,92	0,94	0,92	0,88	0,85	0,83	0,83	0,87	0,89	0,86
Netherlands	0,96	0,95	0,96	0,96	0,95	0,96	0,96	0,96	0,96	0,96
Austria	0,97	0,97	0,96	0,97	0,97	0,97	0,97	0,97	0,97	0,97
Poland	0,98	0,98	0,98	0,98	0,97	0,97	0,97	0,98	0,98	0,98
Portugal	0,96	0,96	0,96	0,96	0,96	0,96	0,96	0,96	0,95	0,95
Romania	0,93	0,93	0,92	0,94	0,94	0,96	0,96	0,96	0,96	0,97
Slovenia	0,99	0,99	0,99	0,99	0,99	0,99	0,99	0,99	0,99	0,99
Slovakia	0,86	0,88	0,86	0,93	0,91	0,96	0,96	0,95	0,94	0,95
Finland	0,93	0,93	0,93	0,93	0,94	0,94	0,94	0,94	0,94	0,94
Sweden	0,93	0,93	0,92	0,92	0,92	0,92	0,92	0,92	0,91	0,91

By doing the average of the values in table 40 for each nation over the years, is obtained the average contribution of GHG emissions from road transport sector.

Finally in table 41 are defined the results of multiplication of values in table 37 and the average contribution gained.

Table 41: final values of CO2 emissions from road transportation sector [ktonCO$_{2eq}$]

GEO/TIME	2020	2025	2030	2035	2040
Belgium	25958,03	26537,02	27309,01	:	:
Bulgaria	8572,076	8957,384	8674,972	:	:
Czechia	17172,13	16596,48	15347,59	:	:
Denmark	11990,69	11990,69	11529,51	11345,04	10791,62
Germany (u	:	146130,2	120172,9	:	60567,14
Estonia	2100	2200	2300	2400	2480
Ireland	11839,72	10455,3	7266,759	5556,916	4213,91
Greece	15659,47	15659,47	14880,82	13929,14	13237,01
Spain	81320,89	72533,81	55929,24	:	:
France	123075,4	113608,1	104140,7	66271,37	47336,69
Croatia	5950,013	5950,013	5950,013	5758,077	4990,334
Italy	88227,99	85441,84	73368,54	:	:
Cyprus	:	:	1681	:	:
Latvia	2570,274	2386,683	2019,501	:	:
Lithuania	5840,326	4899,011	3464,761	2994,577	2604,969
Luxembou	5077	4004	3289	2548	1865
Hungary	11704,89	11704,89	11704,89	9754,072	9266,369
Malta	550	530	600	630	530
Netherland	33342,65	32959,4	31713,84	:	:
Austria	23710,62	:	22936,4	:	21291,17
Poland	61330,59	58904,12	54966,6	53279,49	51100,3
Portugal	:	:	10266,44	:	3042,004
Romania	:	:	:	:	:
Slovenia	5957,271	5758,695	4964,392	3971,514	2283,62
Slovakia	6326,122	6502,717	6527,55	6352,795	5658,375
Finland	10289,62	9354,197	9354,197	9260,655	8980,029
Sweden	13621,96	12793,6	12333,39	12149,31	12241,35

The results and the confrontations between advanced biofuels that can be potentially produced, and contribution of the advanced biofuels required in 2030 is finally done in the next section.

3.4.1 Calculation of CO$_{2eq}$ emissions from advanced biofuels

As it is highlighted in European normative, an LCA should be carried out to count CO_2 emissions for any fuel. In this work, is impossible to write an exhaustive life cycle assessment because precise place where is extracted the biomass should be known; must be taken into account which are the emissions during harvesting and the transport to the plant, the emissions of the plants and own many plants are working. So, for simplicity, advanced biofuels considered are CO_2 neutral. In fact, CO_2 emitted by DME and FT-diesel can be absorbed by the trees from which woody residues are taken, and process of anaerobic digestion avoids the natural emissions of CH_4 from manure and slurries by storing it into the digester and then used as a fuel.

Having set this, values for the GHG emissions from fossil fuels are given in table 42:

Table 42: standard CO_2 emission factors (from IPCC, 2006) and CO_2-equivalent LCA emission factors (from ELCD) for most common fuel types [77]

Type	Standard emission factor [t CO_2/MWh]	LCA emission factor [t CO_2-eq/MWh]
Motor Gasoline	0.249	0.299
Gas oil, diesel	0.267	0.305
Residual Fuel Oil	0.279	0.310
Anthracite	0.354	0.393
Other Bituminous Coal	0.341	0.380
Sub-Bituminous Coal	0.346	0.385
Lignite	0.364	0.375
Natural Gas	0.202	0.237
Municipal Wastes (non-biomass fraction)	0.330	0.330
Wood[a]	0 – 0.403	0.002[b] – 0.405
Plant oil	0[c]	0.182[d]
Biodiesel	0[c]	0.156[e]
Bioethanol	0[c]	0.206[f]
Solar thermal	0	-[h]
Geothermal	0	-[h]

Then the calculation of CO_2 saved by using biofuels is simply done considering as fuel fossil diesel and natural gas. In fact, as set in the introduction, DME and FT-diesel can substitute completely fossil diesel and biomethane can substitute fossil natural gas.

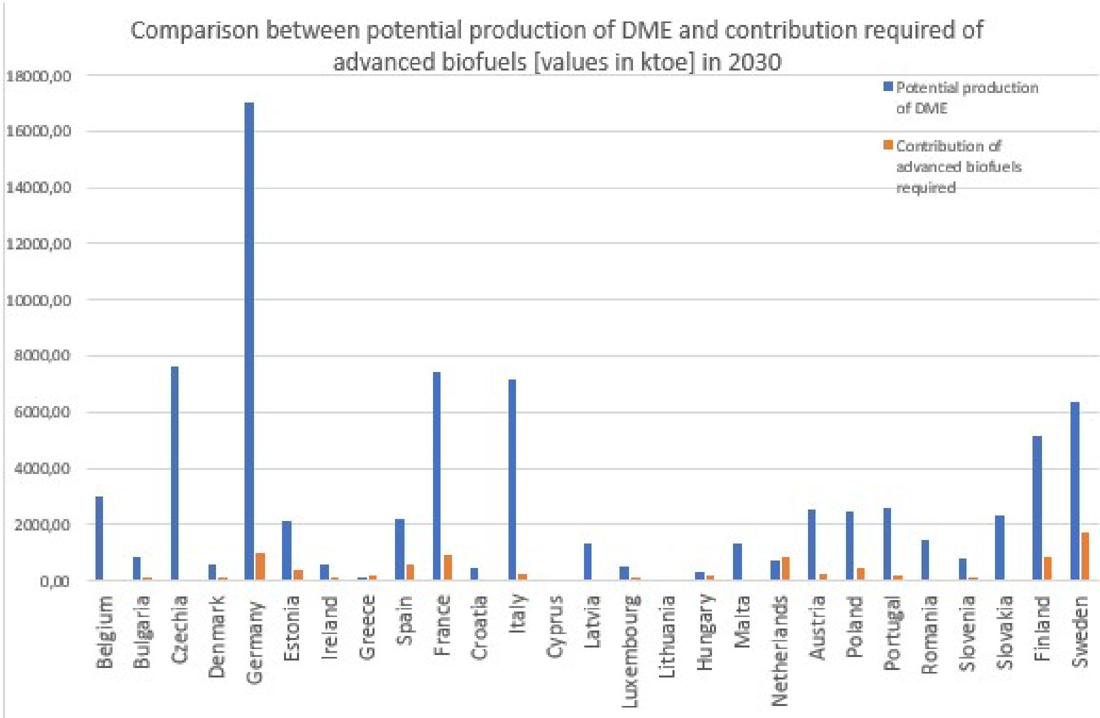
So:

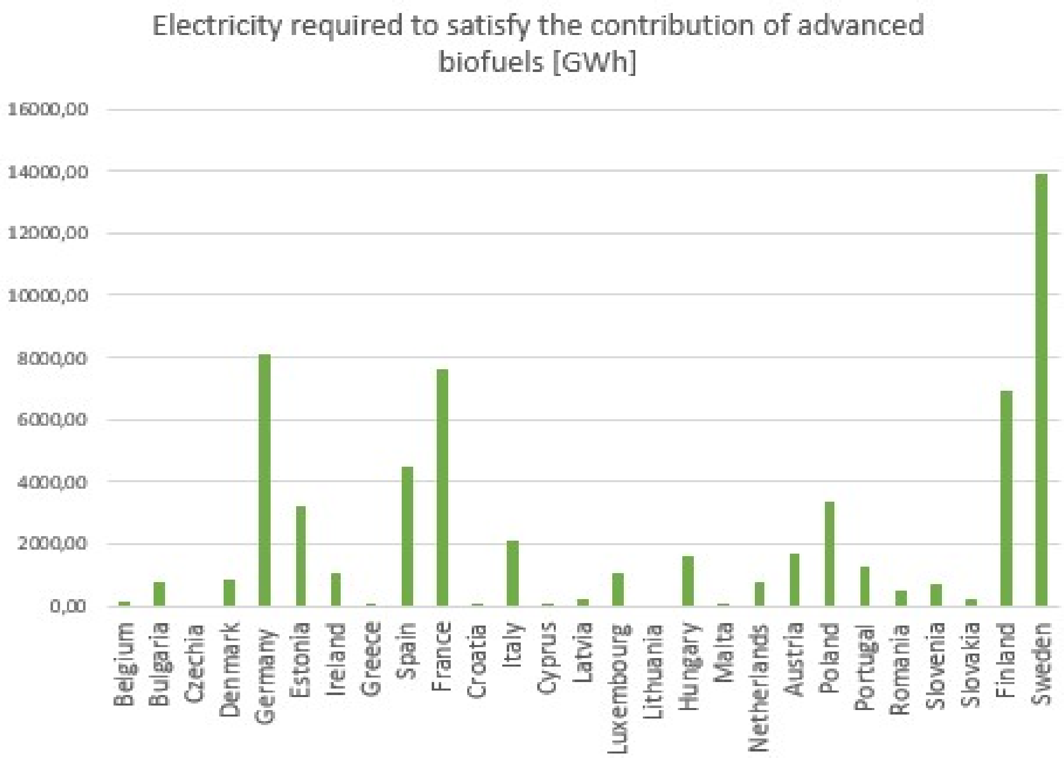
$$GHG_{emissions\ saved} = contribution\ of\ advanced\ biofuels\ [MWh] \cdot LCA_{emission\ factor} \left[\frac{tCO_{2e}}{MWh}\right] \quad (47)$$

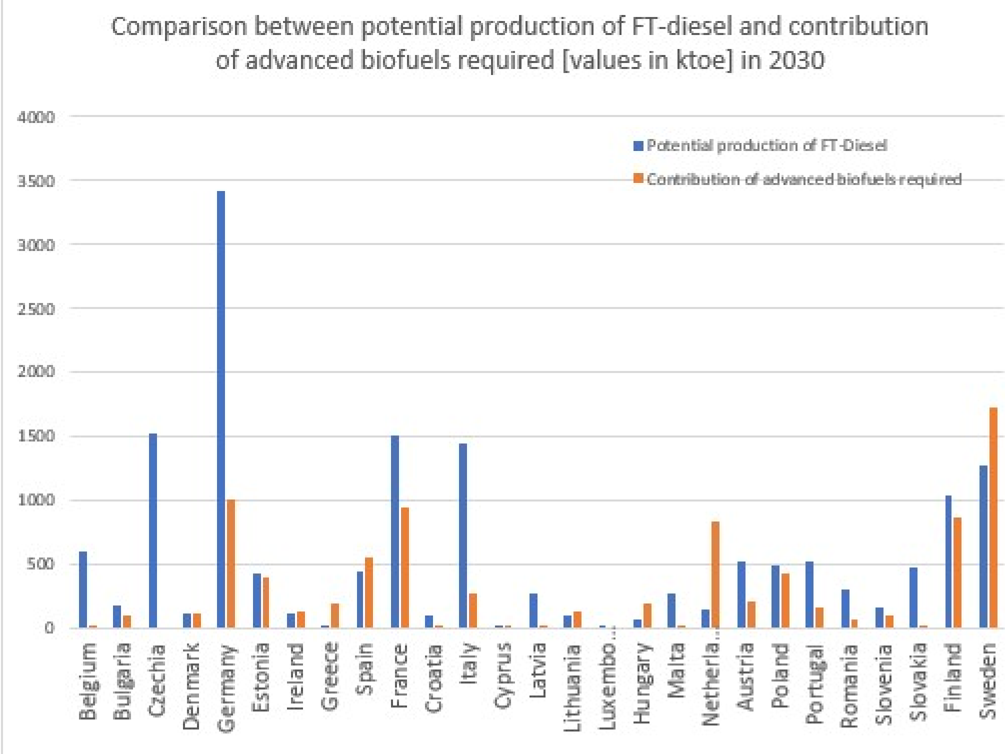
In case, nation does not satisfy the contribution of advanced biofuels, the maximum energy produced from biofuels is considered.

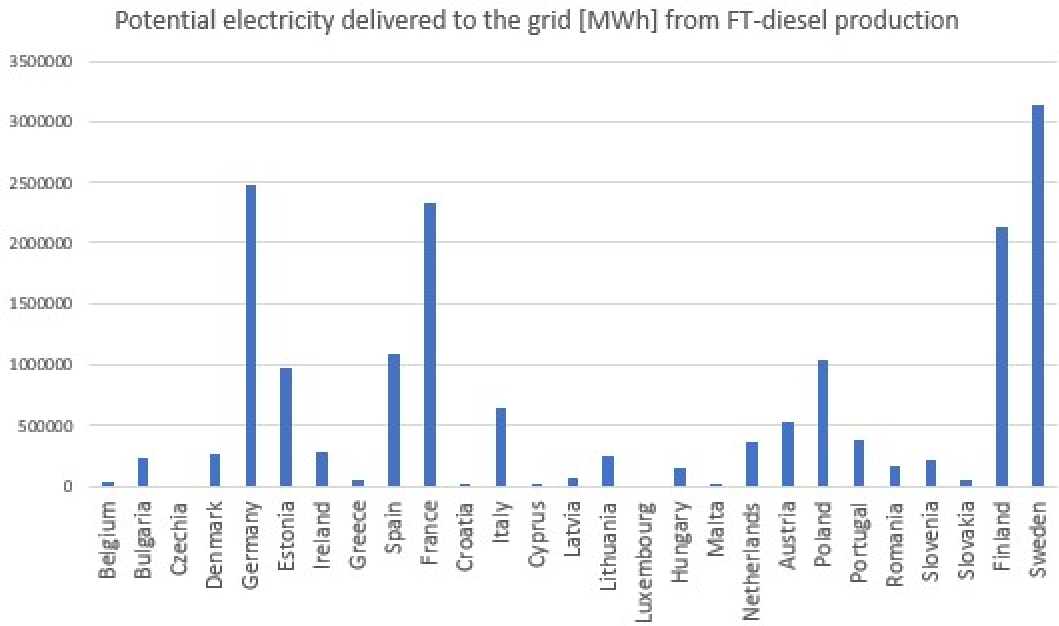
4. Main results

In the following figures are given the results:

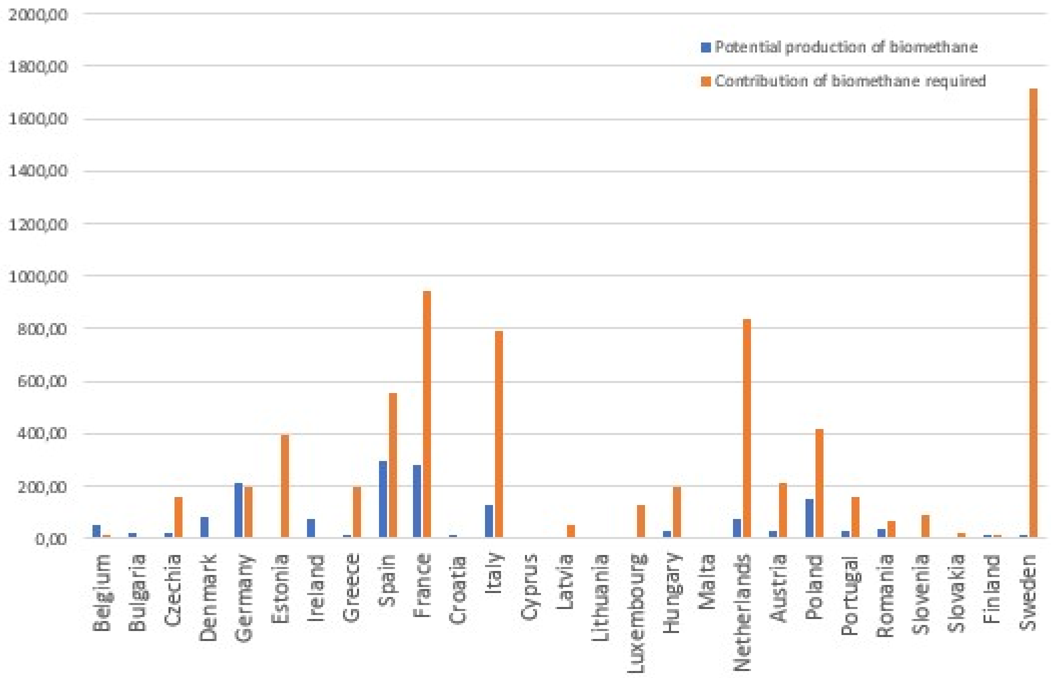




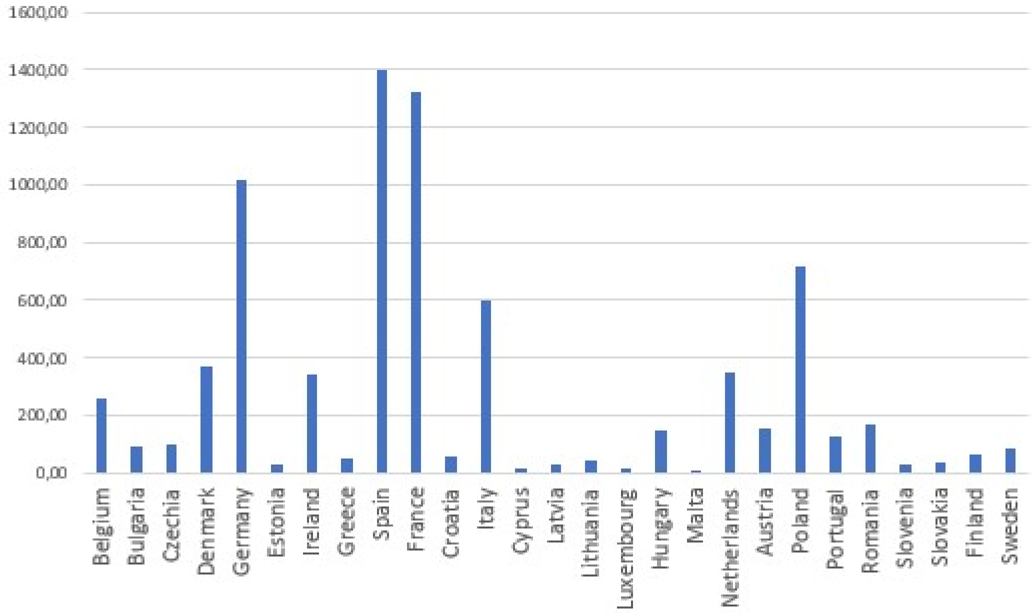

Comparison between potential production of FT-diesel and contribution of advanced biofuels required [values in ktoe] in 2030
4000
3500
3000
2500
2000
1500
1000
500
0
Potential production of FT-Diesel
Contribution of advanced biofuels required
Belgium
Bulgaria
Czechia
Denmark
Germany
Estonia
Ireland
Greece
Spain
France
Croatia
Italy
Cyprus
Latvia
Lithuania
Luxembo...
Hungary
Malta
Netherla...
Austria
Poland
Portugal
Romania
Slovenia
Slovakia
Finland
Sweden

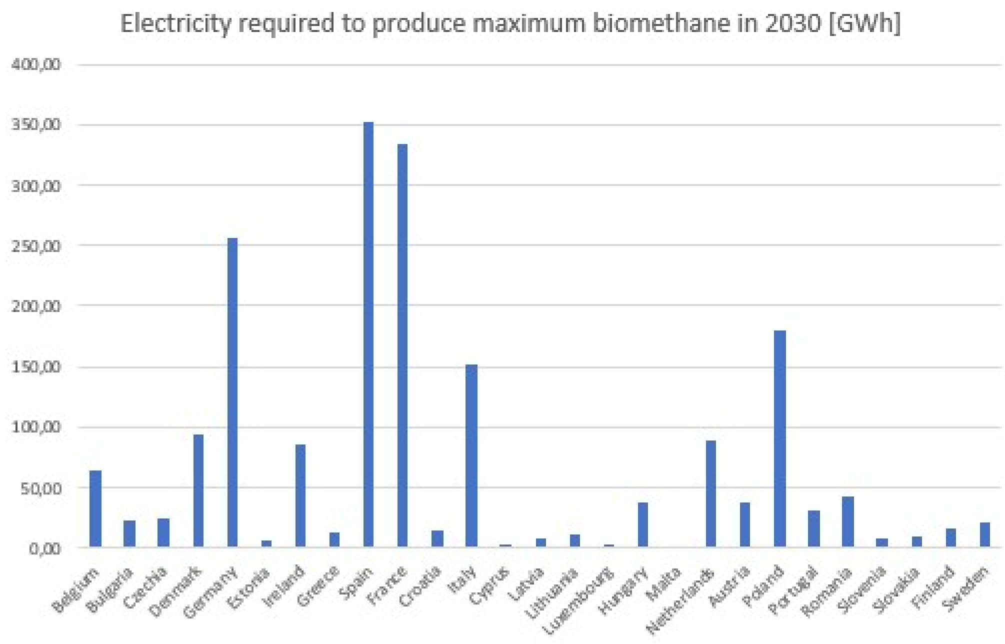

Potential electricity delivered to the grid [MWh] from FT-diesel production
3500000
3000000
2500000
2000000
1500000
1000000
500000
0
Belgium
Bulgaria
Czechia
Denmark
Germany
Estonia
Ireland
Greece
Spain
France
Croatia
Italy
Cyprus
Latvia
Lithuania
Luxembourg
Hungary
Malta
Netherlands
Austria
Poland
Portugal
Romania
Slovenia
Slovakia
Finland
Sweden

Comparison between potential production of biomethane and contribution of biomethane required in 2030 [values in ktoe]



Heat required to produce maximum potential of biomethane in 2030 [GWh]





From the previous figures, can be highlighted that the theoretical biomass that can be used for these purposes is enough to satisfy the request of contribution of advanced biofuels in case of DME for each nation, except Greece and Netherlands. In case of FT-diesel production, the question is a little bit complicated: in fact, in Ireland, Greece, France, Lithuania, Hungary, Netherlands and Sweden, theoretical biomass is not enough to satisfy the internal need in 2030.

The most critical situation is considered in the case of production of biomethane. In fact, with this kind of biomass, only few nations can satisfy their internal energy need. Only dejections from pigs and manure are considered, so, there is a lot of organic biomasses not considered that can be put in the anaerobic digester and therefore increase internal biomethane production.

As far as the energy required by the plants to work is concerned, in case of production of just DME, electricity theoretically needed for the plant is partially recovered from the internal combustion engine fed by incondensable gases, however SOEC needs electrical power from the grid to make sure that reactions happen [36]. From a thermal energy point of view, DME plant is “thermally self-sustaining”[36] and does not require any external thermal source. To ensure this, a pinch analysis of the plant is performed where the pinch point is found in the SOEC with a $\Delta T_{pinch} = 100\ °C$. In fact, in figure 18, can be highlighted that there is a good connection between hot and cold fluids that let to not require heat.

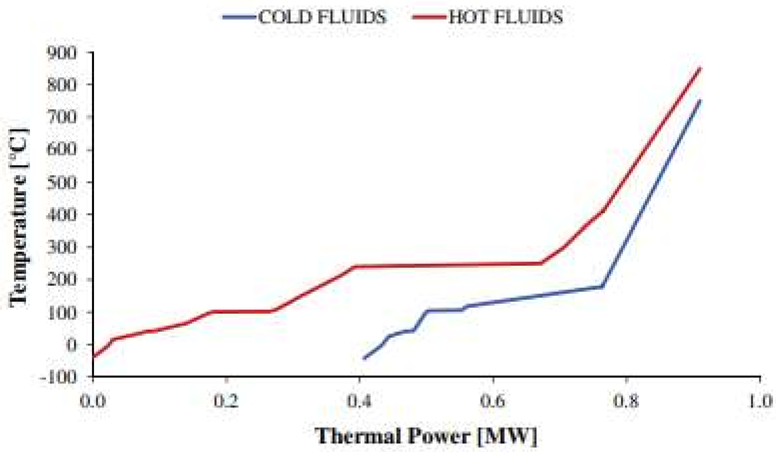


Figure 18: Pinch point analysis of DME plant considered [36]

Also in the case of FT-diesel plant considered, there is a system of heat exchangers to recover thermal energy required. However, in this paper is not defined a pinch analysis to better analyse the match of hot and cold fluids.

Another important aspect characterises FT-diesel plant from the others described: is that electric energy is produced from the plant by a system of turbines in which superheated steam with very high-pressure passes. So, even if there is a certain amount of electricity required, globally, the plant produces renewable electricity that can be delivered to the grid.

In the case of biomethane production, heat required is adopted in the anaerobic digestor to maintain the internal temperature at 37.1 °C and, in the section of the upgrading biogas plant, heat is not needed because of an efficient heat recovery system. Electricity is required to feed pumps, compressors and other appliances of the plant.

In the tables below are defined the equivalent tonnes of CO_2 saved by replacing fossil fuels with the advanced biofuels.

Table 43: t_{CO2eq} saved using DME instead of using fossil diesel

	2030 with DME [tCO2eq saved]
Belgium	49,29112334
Bulgaria	333,8509678
Czechia	0
Denmark	376,0701656
Germany	3547,831751
Estonia	1401,393542
Ireland	448,8007165
Greece	346,5380538
Spain	1979,335334
France	3355
Croatia	33,20770519
Italy	936,6275824
Cyprus	3,84939745
Latvia	84,72222222
Lithuania	452,925
Luxembourg	0
Hungary	691,8271915
Malta	13,30436907
Netherlands	2623,792776
Austria	749,7916667
Poland	1482,993672
Portugal	549,9139215
Romania	225,6420994
Slovenia	315,7570259
Slovakia	78,05229853
Finland	3050
Sweden	6100

Table 44:t_{CO2eq} saved using FT-diesel instead of using fossil diesel

	2030 with FT-diesel [tCO2eq saved]
Belgium	49,29112334
Bulgaria	333,8509678
Czechia	0
Denmark	376,0701656
Germany	3547,831751
Estonia	1401,393542
Ireland	406,6828564
Greece	69,61688229
Spain	1563,930891
France	3355
Croatia	33,20770519
Italy	936,6275824
Cyprus	3,84939745
Latvia	84,72222222
Lithuania	346,2537551
Luxembourg	0
Hungary	219,2598233
Malta	13,30436907
Netherlands	527,1001866
Austria	749,7916667
Poland	1482,993672
Portugal	549,9139215
Romania	225,6420994
Slovenia	315,7570259
Slovakia	78,05229853
Finland	3050
Sweden	4505,900902

Table 45: t_{CO2eq} saved by using biomethane instead of using natural gas

	2030 with biomethane tCO2eq saved
Belgium	38,29567455
Bulgaria	0
Czechia	56,5124143
Denmark	0
Germany	551,3679509
Estonia	15,35317435
Ireland	0
Greece	29,18609929
Spain	812,5642292
France	770,4340044
Croatia	25,8040201
Italy	349,6119638
Cyprus	2,991171133
Latvia	17,74915209
Lithuania	0
Luxembourg	7,671523945
Hungary	85,30863238
Malta	1,545132066
Netherlands	204,6470438
Austria	87,76161235
Poland	415,4658837
Portugal	70,98627484
Romania	98,93025314
Slovenia	17,05095189
Slovakia	21,92028604
Finland	38,06439714
Sweden	47,31149674

5. Conclusions

From the results obtained in the last section, can be noted that advanced biofuels help a lot in reducing GHG emissions, even if a low utilisation is still foreseen. This work could be an interesting beginning to continue to investigate other types of plants and biomasses.

5.1 Critical issues

Obviously, this work has important critical issues.

In fact, Holt method is used to foreseen values until 2030. This type of method generates higher error as it went far from the last year of historical series.

These ones represent the theoretical potential considered in statistical data defined by Eurostat. The steps to pass from theoretical potential to implementation potential as considered in figure 4, are not considered. This lack overestimates the quantity of biomass that can be used because the restrictions highlighted in figure 4 are not applied.

As far as dejections of animal for energy purpose are concerned, two simple percentage are used to quantify them. These values are very difficult to find out and depend on the agricultural organisation in each EU-27 member.

Plants considered, work 365 days per year. It is very difficult to see plants with $CF = 1$. Further, values taken as data for the calculations are always constant, without considering any possible variation.

Biofuels are considered at energy level, without considering any eventual transformation to make them suitable for engines.

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Appendixes

Appendix I

Contribution of advanced biofuels. Data taken from EU-27 NECP and own calculations.

BELGIUM

Table A. 1: Contribution of various types of biofuels [%] [78]

Biofuels	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Actual value	8.95	8.95	9.25	9.55	9.8	10	10.2	10.45	10.45	10.45	10.45
1G	7	7	7	7	7	7	7	7	7	7	7
Part A	0.1	0.1	0.1	0.1	0.1	0.5	0.5	1	1.5	1.75	1.75
Part B	1.85	1.85	2.15	2.45	2.7	2.5	2.7	2.45	1.95	1.7	1.7
Double counting	0.6	0.6	0.95	0.95	0.95	2.2	2.2	2.7	3.2	3.45	3.45
Nominal value	9.55	9.55	10.2	10.5	10.75	12.2	12.4	13.15	13.65	13.9	13.9

Table A. 2: forecast to 2030 of generation of biofuels in Flemish Region [78]

Generation (ktoe)	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Green heat	738.7	744.5	751.0	758.1	765.8	774.3	784.4	795.4	807.2	819.7	833.1
Green electricity	833.8	858.9	884.0	909.2	934.3	959.4	987.4	1,015.3	1,043.2	1,071.2	1,099.1
Biofuels in transport	444.4	435.1	425.7	416.4	407.1	568.3	543.8	519.2	494.6	470.1	519.8
Total	2,016.8	2,038.5	2,060.7	2,083.7	2,107.2	2,302.0	2,315.6	2,329.9	2,345.0	2,361.0	2,452.0

Table A. 3: Renewable energy targets in Walloon region [78]

GWh	Achieved in 2015	Achieved in 2016	2020 target	2030 target	
				WEM (29)	WAM (29)
Electricity	4,060	4,463	5,555	5,691	10,081
Heating	8,108	8,706	8,900	9,170	14,233
Transport*	906	1,596	2,382	2,263	3,187
Final consumption of renewables	13,073	14,765	16,837	17,124	27,501
Gross final consumption	121,700	124,194	120,770	131,955	117,032
Share of RES in final consumption	10.74%	11.89%	13.94%	12.98%	23.50%

* Biofuels (incorporation rate of 14% set by the Federal Government) and biogas only (renewable electricity for transport included in 'electricity').

Definition of advanced biofuels targets [ktoe] 2030 (Annex IX part A RED II):

$$Contr.adv.biofuels = \left(519{,}8[ktoe] + 3187[GWh] * 3600\left[\frac{s}{h}\right] * 1000\left[\frac{MJ}{GJ}\right] * 2{,}38 * 10^{-8}\right) * 0{,}0175 = 13{,}89115\ ktoe$$

BULGARIA

Table A. 4: Projection curve by renewable energy technology for the period 2020-2030 [ktoe] transport [52]

	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Biofuels (content of up to 7%)	187.6	189.0	190.3	191.7	193.0	194.4	181.5	168.2	155.0	141.7	128.4
New generation biofuels	27.7	28.0	28.2	28.5	28.7	29.0	42.0	55.0	68.1	81.1	94.1
New generation biofuels, multiplied by 2 or 2*1.2	55.4	55.9	56.5	57.0	57.5	58.0	84.1	110.1	136.2	162.3	188.4
Biogas	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Biogas, multiplied by 2 or 2*1.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.0
E-RS in road transport	1.3	1.7	2.1	2.4	2.8	3.2	5.3	7.5	9.7	11.9	14(1)
E-RS in transport (for 2020, multiplied by 5 in accordance with Directive 2009/28/EC, for the period 2021—2030, multiplied by 4 in accordance with Directive (EU) 2018/2001)	6.6	7.8	9.0	10.2	11.4	12.6	21.4	30.1	38.9	47.6	56.4
E-RS in rail transport	6.0	6.3	6.6	6.9	7.2	7.4	7.9	8.5	9.0	9.5	10.0
E-RS in rail transport (for 2020, multiplied by 2.5 in accordance with Directive 2009/28/EC, for the period 2021—2030, multiplied by 1.5 in accordance with Directive (EU) 2018/2001)	15.0	14.2	13.5	12.7	11.9	11.2	11.9	12.7	13.4	14.2	15.0
E-RS in other transport sectors	0.4	0.5	0.5	0.5	0.5	0.5	0.6	0.6	0.7	0.7	0.8
Hydrogen	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.7
Gross final consumption of energy from renewable sources in transport	223.1	225.4	227.7	229.9	232.2	234.5	237.4	239.9	242.4	244.9	250.2
Final consumption of energy from renewable sources in transport calculated for the purpose of defining the sectoral target	265.2	267.5	269.8	272.1	274.4	276.7	299.5	321.9	344.3	366.6	391.7
Final energy consumption in transport	2 680.6	2 699.8	2 719.0	2 738.2	2 757.3	2 776.5	2 773.0	2 769.4	2 765.8	2 762.2	2 758.6
RS-T, %	9.89	9.91	9.92	9.94	9.95	9.97	10.80	11.62	12.45	13.27	14.20

Source: (B)EST model, E3-Modelling, Deloitte analysis

$$Contr.advanced\ biofuels = New\ generation\ biofuels\ (2030) = 94{,}1\ ktoe$$

$$Biogas\ contribution = 0\ ktoe$$

CZECH REPUBLIC

Table A. 5: Expected consumption of bioenergy broken down by sectors in [TJ] [53]

Bioenergy consumption	2016	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Electricity	17 119.2	17 802.0	18 433.7	18 593.5	18 898.8	18 857.5	18 982.0	18 587.6	17 958.1	17 596.5	16 921.6	16 605.7
Biomass	7 443.9	7 899.7	8 026.5	8 085.4	8 525.0	8 532.0	8 607.8	8 607.0	8 635.3	8 639.7	8 637.2	8 988.4
Biodegradable component of MSW	354.8	432.8	991.4	1 104.8	1 241.0	1 354.4	1 354.4	1 354.4	1 354.4	1 603.8	1 603.8	1 603.8
Biogas	9 320.5	9 469.5	9 415.9	9 403.3	9 132.8	8 971.1	9 019.8	8 626.2	7 968.4	7 353.0	6 680.6	6 013.5
Heating	111 992.0	112 242.2	119 695.8	122 526.1	127 167.5	129 981.8	133 162.1	135 895.9	138 879.2	142 496.4	145 226.4	149 313.9
Biomass (excl. households)	26 631.0	27 561.3	31 284.3	31 676.4	33 614.4	33 900.9	34 836.0	35 097.3	35 220.6	35 269.5	35 318.5	36 723.2
Biomass (households)	75 454.0	74 395.0	76 198.9	78 002.8	79 806.7	81 610.6	83 414.6	85 218.5	87 022.4	88 826.3	90 630.2	92 434.1
Biodegradable component of MSW	2 418.0	2 690.9	4 701.7	5 110.2	5 600.2	6 008.7	6 008.7	6 008.7	6 008.7	6 906.5	6 906.5	6 906.5
Biogas	7 489.0	7 595.0	7 510.9	7 736.7	8 146.1	8 461.6	8 902.9	9 571.5	10 627.5	11 494.1	12 371.2	13 250.1
Transport	12 580.0	18 557.9	19 743.0	20 234.5	21 021.8	21 692.8	22 491.6	23 534.9	25 048.8	26 452.7	27 962.6	29 421.2
Bioethanol	1 998.0	2 836.5	2 842.9	2 823.8	2 802.3	2 780.0	2 756.9	2 728.7	2 700.5	2 674.5	2 653.4	2 629.8
Biodiesel	10 582.0	15 721.4	16 761.9	17 132.7	17 520.4	17 927.4	18 318.6	18 673.8	19 060.7	19 463.0	19 877.0	20 237.2
Biogas	0.0	0.0	138.2	278.0	699.0	985.4	1 416.1	2 132.4	3 287.6	4 315.2	5 432.2	6 554.2
Total	141 691.2	148 602.2	157 872.5	161 354.1	167 088.1	170 532.1	174 635.7	178 018.3	181 886.1	186 545.6	190 110.6	195 340.8

$$Contr.adv.biofuels\ excluded\ biogas = 0\ ktoe$$

$$Contr.biogas\ [ktoe] = 6554{,}2\ [TJ] * 10^6 \left[\frac{MJ}{TJ}\right] * 2{,}38 * 10^{-8} \left[\frac{ktoe}{MJ}\right] = 156{,}51\ ktoe$$

DENMARK

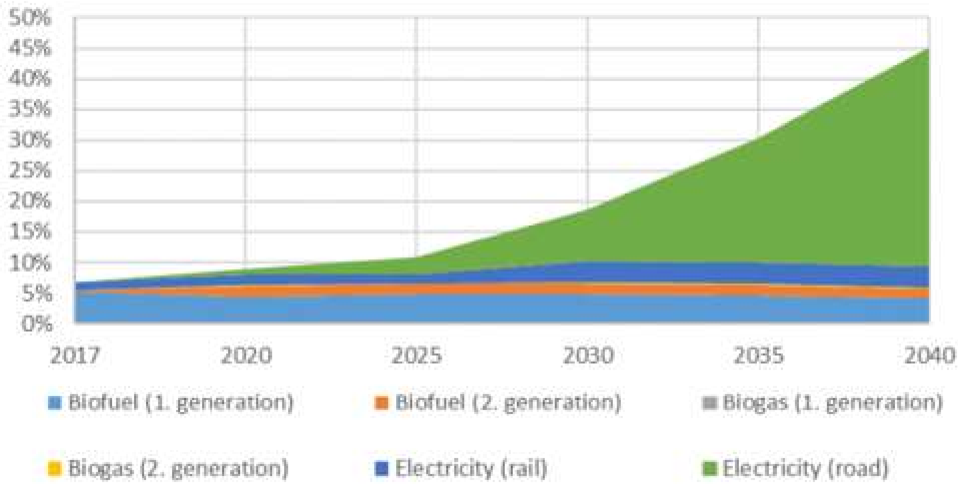


Figure 19: RES-T by technology 2017 - 2040 [%] [54]

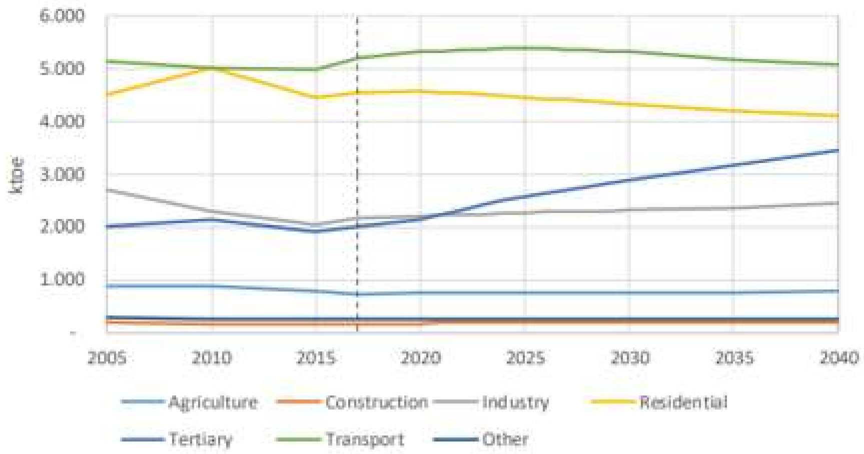


Figure 20: Final energy consumption by sector 2017-2040 [ktoe]. Tertiary sector includes HSDC [54]

“At the time of the submission of the National Energy and Climate Plan, these initiatives, however, have not yet been proposed or developed to an extent, where they can be defined as “planned policies and measures” as defined by the Governance Regulation, i.e., being “(…) options that are under discussion and that have a realistic chance of being adopted and implemented after the date of submission of the integrated national energy and climate plan (…)”. Consequently, no analysis has been made of the impacts of planned policies. Impact assessments of planned policies will be provided in progress reports, as appropriate, and as requested by the Governance Regulation.” [54]

WEM scenario

From the second graph, I take:

$$Final\ energy\ consumption\ in\ transport\ (2030) = 5300\ ktoe$$

From the first graph:

% biofuel second generation in 2030: 2 %

$Contrib. adv\ biofuels\ excluded\ biogas\ (2030) = 0{,}02 * 5300 = 106\ ktoe$

$Contribution\ of\ biogas\ (2030) = 0\ ktoe$

GERMANY

Table A. 6: Indicative technology-specific shares for renewable energies, specifying the expected total gross final energy consumption per technology and sector [Mtoe] [55]

Mtoe	2020	2025	2030
Electricity			
Onshore wind	9	10	12
Offshore wind	1	3	6
Photovoltaics	4	6	8
Hydropower	2	2	2
Biomass	4	4	3
Biogenic fraction of waste	1	1	1
Transport			
Biodiesel (including HVO and vegetable oil)	2	2	2
Biogenic petrol	1	1	1
Biogenic jet fuels	0	0	0
Biogases (biomethane)	0.0	0.1	0.2
Renewable energies – electricity	1	1	3
PtX	0.0	0.2	0.3
Heating and cooling			
Biomass and renewable waste	13	14	14
Other renewable energies	2	4	6

From this graph is taken in consideration:

$Contr. adv. biofuels\ except\ biomethane\ (2030) = 1000\ ktoe\ (Biogenic\ petrol)$

$Contr\ biomethane\ (2030) = 200\ ktoe$

ESTONIA

Figure 21: Contribution of different types of energy and biofuels towards meeting the renewable target in the transport sector [GWh] [56]

$$Contr.adv.biofuels\ (2030) = 395\ ktoe$$

IRELAND

Table A. 7: Projections of Electricity and transport from renewable [ktoe] [57]

Renewable Electricity-Generation by Source (ktoe)												
	2018	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2040
Hydro	60	63	61	61	61	61	62	60	59	57	56	57
Biodegradable Municipal Solid Waste	28	23	23	23	23	23	23	23	23	23	23	23
Biogas	16	5	5	5	5	4	12	19	26	34	41	51
Biomass (CHP and Co-Firing)	29	60	60	60	33	33	33	33	33	33	33	33
Onshore Wind	740	959	1060	1149	1217	1231	1218	1200	1241	1334	1462	1542
Offshore Wind	6	6	6	6	6	228	522	765	893	896	889	1698
Solar PV	1	6	8	10	12	14	17	19	22	27	31	49
Ocean	0	0	0	1	2	2	3	4	4	5	6	21
Renewable Transport Consumption by Source (ktoe)												
	2018	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2040
Ethanol - Total	27.3	32.7	32.4	32.1	64.8	64.1	60.6	57.1	52.4	47.2	41.1	11.8
Part A, Annex IX Ethanol	0.0	0.3	0.3	0.3	0.6	0.6	0.6	0.6	0.5	0.5	0.4	0.1
Part B, Annex IX Ethanol	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Food or Feed Ethanol	27.3	32.4	32.1	31.8	64.2	63.5	60.0	56.6	51.9	46.7	40.7	11.7
Biodiesel - Total	127.0	201.9	229.0	223.8	246.3	240.5	254.0	241.1	249.5	231.0	234.2	151.1
Part A, Annex IX Biodiesel	0.0	7.3	16.5	24.2	35.5	43.3	64.0	78.1	98.8	108.1	126.5	81.6
Part B, Annex IX Biodiesel	127.0	192.6	208.0	192.9	201.0	185.2	173.5	143.7	127.0	97.5	78.5	50.6
Food or Feed	0.0	2.0	4.6	6.7	9.9	12.0	16.5	19.3	23.7	25.4	29.3	18.9
Biofuels - Total	154.2	234.7	261.5	256.0	311.2	304.7	314.6	298.3	301.9	278.2	275.3	163.0

$$Contr.adv.biofuels\ (2030) = 126{,}5\ ktoe$$

$$Contr.of\ biogas\ (2030) = 0\ ktoe$$

GREECE

Table A. 8: Evolution of the contribution of advanced biofuels to the target of RES penetration in transport [58]

Advanced biofuels (in accordance with Part A of Annex IX to Directive (EU) 2018/2001)	2020	2022	2025	2027	2030
Consumption (ktoe)	81	94	127	127	197
Contribution to the target of RES penetration in transport	3.3%	3.8%	5.1%	5.2%	8.2%

$$Contr.adv.biofuels = 197\ ktoe$$

SPAIN

Table A. 9: Compliance with limits set in Directive 2018/2001 in the transport sector [59]

Compliance with limits set in Directive 2018/2001						
	Component	2015*	2020	2025	2030	2030 Objective
Article 27(1)(b)	Biogas and biofuels Annex IX, part B	0%	0.5%	1.7%	1.7%	Maximum 1.7%
Article 25.1	Advanced biogas and biofuels Annex IX, part A	0%	0.9%	1.6%	3.7%	Minimum 3.5%
Article 26. 1	Biofuels produced from food and feed crops	0%	6.9%	6.8%	6.8%	Maximum 7%

** The 2015 data are real; the rest are projections prepared by MITECO*

Source: Ministry for Ecological Transition and Demographic Challenge, 2019

Table A. 10: Percentage of renewable energy in final energy consumption in the Target Scenario [59]

Percentage of renewable energy in final energy consumption in the Target Scenario							
Years		2015*	2020	2022	2025	2027	2030
End-use renewable energy consumption (excluding renewable electricity consumption)	Agriculture (ktoe)	4,310	119	148	192	203	220
	Industry (ktoe)		1,596	1,624	1,667	1,711	1,779
	Residential (ktoe)		2,640	2,623	2,598	2,709	2,876
	Services & Other (ktoe)		241	279	337	376	435
	Transport (ktoe)	176	2,348	2,369	2,401	2,285	2,111
Energy supplied by heat pumps (ktoe)		353	629	1,339	2,404	2,851	3,523
Renewable electricity generation (ktoe)		8,642	10,208	12,438	15,784	18,187	21,792
Total renewable energy (ktoe)		13,481	17,780	20,821	25,383	28,324	32,736
Final energy corrected with electricity system losses, aviation consumption and energy supplied by heat pumps (ktoe)		83,361	88,548	86,081	85,023	82,050	77,589
Percentage of renewable energy in final energy consumption		**16%**	**20%**	**24%**	**30%**	**34%**	**42%**

** The 2015 data are real; the rest are projections prepared by MITECO*

Source: Ministry for Ecological Transition and Demographic Challenge, 2019

From the second table:

$$Contribution\ of\ RES-T\ (2030) = 2111\ ktoe$$

$$Advanced\ biofuels\ (2030)\ percentage\ (first\ table) = 3{,}7\ \%$$

$$Contr.adv.biofuels\ (2030) = 2111 * \frac{3{,}7}{14} = 557{,}90\ ktoe$$

FRANCE

Table A. 11: Projections of fuels consumption to 2028 [60]

		2023	2028
Petrol	Fossil	84	79
	1G Renewable	6	6
	2G Renewable	2	3
Diesel	Fossil	294	233
	1G Renewable	22	18
	2G Renewable	3	8
TOTAL		412	347

$$Contribution\ of\ 2^{nd} generation\ biofuels = 3 + 8 = 11\ TWh$$

Values are taken from the table above in 2028.

I assume that these values are in good approximation equal in year 2030.

Because of missing data, I also assume that these biofuels are only from Annex IX part A.

$$Contr.adv.biofuels\ [ktoe] = 11[TWh] * 3600 \left[\frac{s}{h}\right] * 10^6 \left[\frac{MJ}{TJ}\right] * 2{,}38 * 10^{-8} \left[\frac{ktoe}{MJ}\right] = 945{,}65\ [ktoe]$$

CROATIA

Table A. 12: Estimated contribution of RES technologies in transport [61]

ktoe	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Final RES-t	68,4	70,9	74,5	78,6	83,9	91,1	98,5	107,7	119,6	135,2	156,0
Biofuels	56,9	58,3	60,6	63,6	67,8	73,8	79,9	88,0	98,7	113,1	132,7
Electricity from RES	11,4	12,6	13,8	15,0	16,2	17,4	18,6	19,7	20,9	22,1	23,3

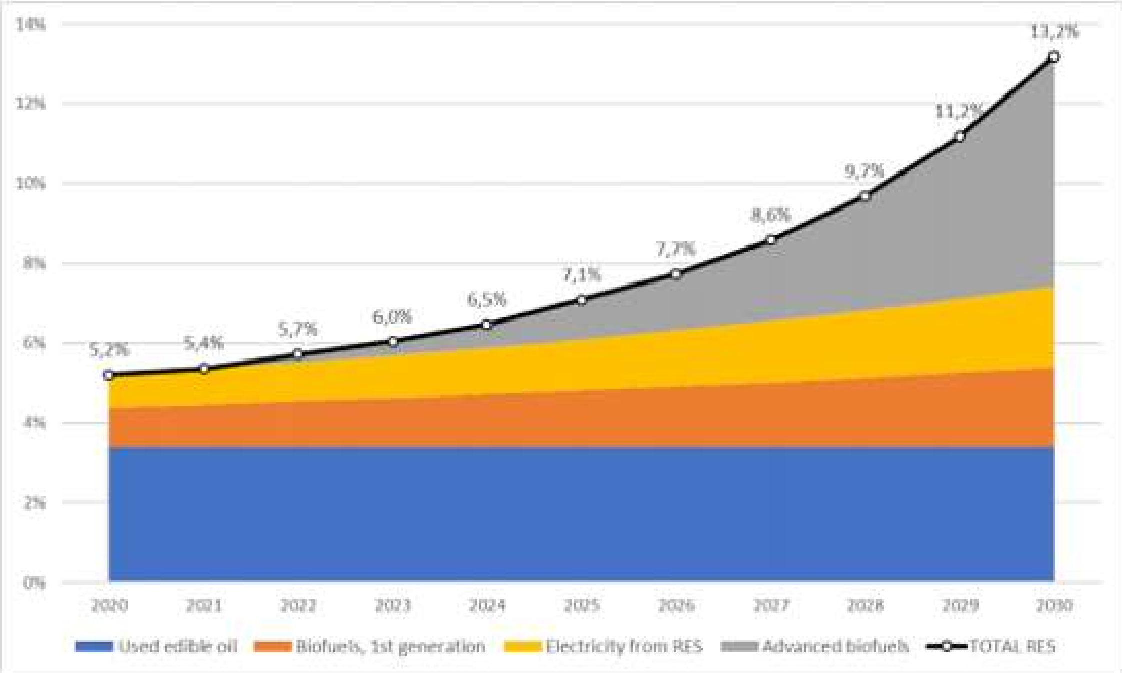


Figure 22: Indicative trajectories of RES share in transport [61]

From the first table:

$$Contribution\ of\ RES - T\ (2030) = 156\ ktoe$$

From the second figure, I assume that in 2030 6 % of RES-T are advanced biofuels:

$$Contr.adv.biofuels\ [ktoe] = 156 * 0{,}06 = 9{,}36\ ktoe$$

ITALY

Table A. 13: Projected contribution of renewables in the transport sector by 2030, according to the criteria defined in RED II for calculating the obligations for fuel and electricity suppliers [ktoe] [62]

	Multiplication factor*	2016	2017	2022	2025	2030
Numerator		**2,056**	**1,665**	3,365	**4,152**	**6,051**
Advanced biofuels	X 2	9	7	394	695	1,057
of which biomethane	X 2	0	0	277	511	793
of which other biofuels	X 2	9	7	117	184	264
Non-advanced double-counted biofuels	X 2	765	350	672	630	570
Single-counted biofuels		265	703	710	655	710
Renewable share of electricity for road transport	X 4	2	2	55	126	404
Renewable share of electricity for rail transport	X 1.5	156	159	203	228	313
Denominator – Gross final consumption in the transport sector		**31,719**	**30,352**	30,655	**28,851**	**27,472**
RES-T share (%)– RED II		**6.5%**	**5.5%**	11,0%	**14.4%**	**22.0%**

$$Contr.adv.biofuels\ except\ biomethane = 264\ ktoe$$

$$Contr.methane = 793\ ktoe$$

CYPRUS

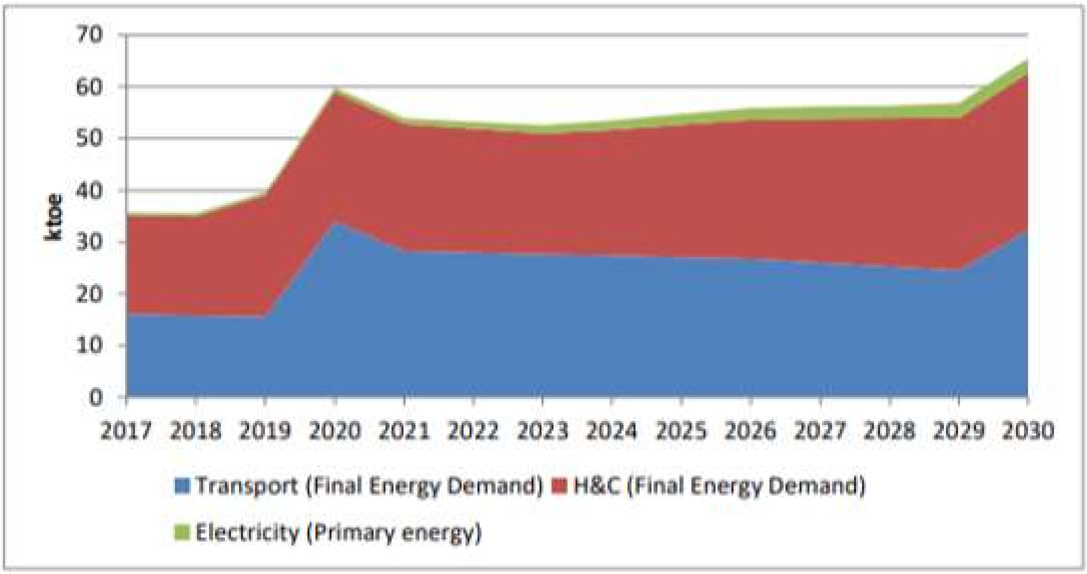


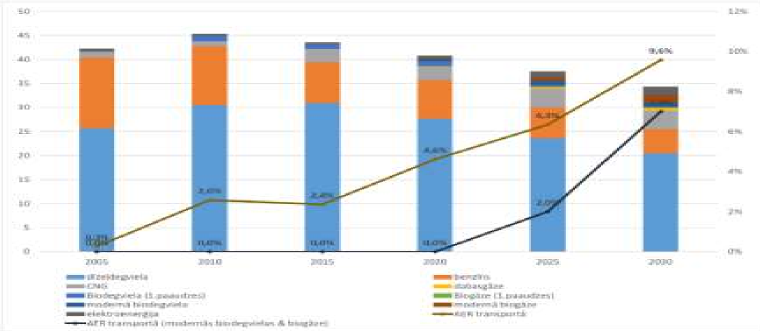
Figure 23: Trajectories for bioenergy demand, disaggregated between heat, electricity and transport [63]

From graphical observation, I assume that final energy demand for transportation sector is: 31 ktoe.

From assumptions taken in RED II, Annex IX Part A, 3,5 % of this demand is covered by advanced biofuels; so:

$$Contr.adv\ biofuels = 0{,}035 * 31 = 1{,}085\ ktoe$$

LATVIA



Key reads, top to bottom, left to right:

Diesel

CNG

Biofuel (1^{st} generation)

Advanced biofuel

Electrical energy

RES in transport (advanced bio and biogas)

Petrol

Natural gas

Biogas (1^{st} generation)

Advanced biogas

RES in transport

Figure 24: Final energy consumption [64]

From the graph above, I assume that:

$$Contr. adv. biofuels\ (except\ biogas) = 1\ PJ$$

$$Contr. of\ biogas = 2\ PJ$$

$$Contr. adv. biofuels\ (except\ biogas)[ktoe] = 1\ [PJ] * 10^9 \left[\frac{MJ}{PJ}\right] * 2{,}38 * 10^{-8} \left[\frac{ktoe}{MJ}\right] = 23{,}88\ ktoe$$

$$Contr. of\ biogas\ [ktoe] = 2[PJ] * 10^9 \left[\frac{MJ}{PJ}\right] * 2{,}38 * 10^{-8} \left[\frac{ktoe}{MJ}\right] = 47{,}76\ ktoe$$

LITHUANIA

Table A. 14: Estimated trajectories of energy production from RES by technology in the transport sector, without applying the multipliers laid down in Directive 2018/2001 [ktoe] [65]

	2020	2022	2025	2027	2030
Projected consumption in road transport, ktoe	1932	1791	1621	1488	1253
Bioethanol, ktoe	17.5	17.1	15.7	14.2	10.9
Biodiesel, ktoe	70.5	68.8	54.9	43.9	25.6
Biogas, ktoe	–	–	14.6	41.7	81.5
Electricity RES, ktoe	1.6	3	14.7	28.5	56.9
RES-T, ktoe	89.6	88.9	99.9	128.3	174.9

$$Contribution\ of\ biogas\ (ktoe) = 81{,}5\ ktoe$$

$Contr.adv.biofuels\ (ktoe) = 0\ ktoe$

LUXEMBOURG

Table A. 15: Energy production, technological details [GWh] [66]

Energy production, technological details		2017	2020	2025	2030	2035	2040
Electricity sector							
Biogas*	GWh	72	56	70	93	96	97
Biomass**	GWh	101	192	228	271	268	338
Hydroelectric power	GWh	104	93	97	100	104	107
Photovoltaics	GWh	108	197	786	1,112	1,257	1,442
Wind energy	GWh	185	211	382	674	956	1,166
Renewable energy electricity, total	**GWh**	570	**748**	**1,563**	**2,251**	**2,680**	**3,150**
Heat sector							
Biomass & biogas, grid-connected	GWh	302	589	625	676	669	728
Biomass, decentralised	GWh	672	883	1,084	1,263	1,083	1,083
Solar thermal energy	GWh	25	58	115	190	236	290
Heat pumps	GWh	52	95	207	422	507	507
Renewable energy heat, total	**GWh**	1,052	**1,626**	**2,030**	**2,551**	**2,495**	**2,609**
Transport sector							
Biofuels, total	**GWh**	1,282	**1,632**	**1,563**	**1,485**	**1,738**	**1,749**
Renewable energy use, total (national)	**GWh**	2,904	**4,006**	**5,156**	**6,287**	**6,914**	**7,508**
Renewable energy cooperation							
Renewable energy cooperation energy	**GWh**	0	**1,000**	**1,374**	**1,748**	**1,748**	**1,748**

$Contribution\ of\ biofuels = 1485\ [GWh]$

I assume that 95 % of these biofuels are advanced biofuels, because in this NECP is written that “that the biofuel mix up to and including 2030 will consist of a maximum of 5% of first-generation fuels, measured by total road transport fuel demand.” [66]

$$Contribution\ of\ advanced\ biofuels = 0{,}95 * 1485[GWh] * 3600\left[\frac{s}{h}\right] * 10^3\left[\frac{MJ}{GJ}\right] * 2{,}38 * 10^{-8}\left[\frac{ktoe}{MJ}\right] = 127{,}66\ ktoe$$

HUNGARY

Table A. 16: Consumption of renewable energy in transport by fuels, with multipliers [ktoe] [67]

	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Bioethanol	47	90	133	176	219	262	253	244	235	226	217
- Annex IX, part 'A'	0	42	84	126	168	210	207	204	201	198	195
- Annex IX, part 'B'	0	0	0	0	0	0	0	0	0	0	0
Biodiesel	220	272.8	325.6	378.4	431.2	484	456.6	429.2	401.8	374.4	347
- Annex IX, part 'A'	0	42	84	126	168	210	207	204	201	198	195
- Annex IX, part 'B'	147	157.2	167.4	177.6	187.8	198	183.8	169.6	155.4	141.2	127
Renewable electricity	37	48.4	59.8	71.2	82.6	94	127	160	193	226	259
- Road	20	29	38	47	56	65	96	127	158	189	220
- Rail	17	19.2	21.4	23.6	25.8	28	30	32	34	36	38
Hydrogen from renewables	0	0	0	0	0	0	10.2	20.4	30.6	40.8	51

$$Contribution\ of\ advanced\ biofuels\ (2030) = 195\ ktoe$$

MALTA

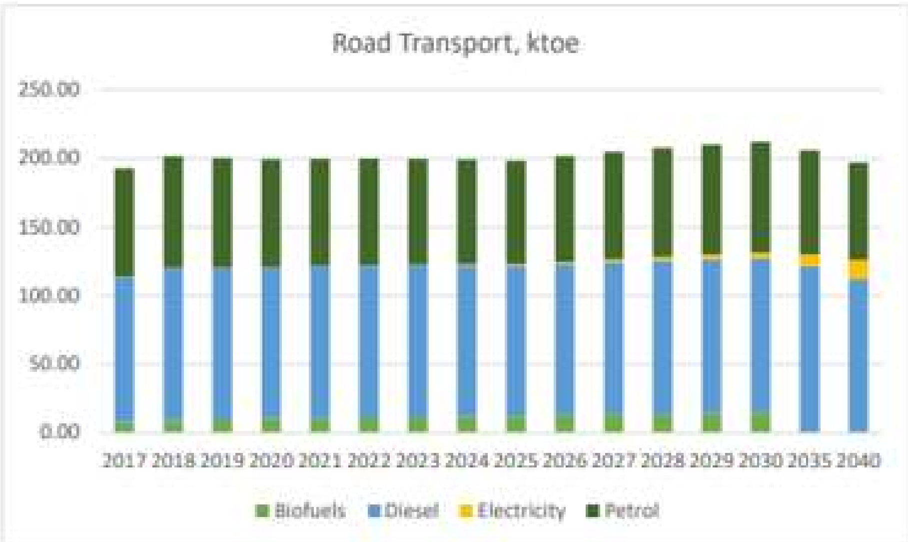


Figure 25: Projections for final energy consumption for transport sector, split by fuel, under the WPM scenario [ktoe] [68]

From the graph above, I assume that final energy consumption using biofuels is 15 ktoe.

In the NECP is defined that "advanced biofuels are expected to contribute to 25 % of the total consumption of biofuels by 2030" [68][69].

So:

$$Contr.adv.biofuels = 0,25 * 15 = 3,75\ ktoe$$

NETHERLANDS

In Netherlands' NECP, is assessed that "the use of biofuels for domestic mobility is expected to grow from 23 PJ in 2018 to 37 PJ in 2020. The use of biofuels between 2021 to 2030 is estimated at around 35 PJ per year." [69]

Because of no other specifications, I assume that all 35 PJ are covered by advanced biofuels.

$$Contr. adv. biofuels = 35\ [PJ] * 10^9 \left[\frac{MJ}{PJ}\right] * 2{,}38 * 10^{-8} \left[\frac{ktoe}{MJ}\right] = 835{,}80\ ktoe$$

AUSTRIA

Table A. 17: Developments in renewable energy and share, expressed as total [70]

	2016	2020	2030	2040
Final energy consumption (PJ)	1,121	1,155	1,180	1,203
Gross inland consumption (PJ)	1,435	1,464	1,474	1,498
Renewable share	33.5%	34.3%	35.8%	37.1%

Table A. 18: Sector-specific shares of energy from renewable sources, measured in terms of gross final consumption of renewable energy (model-based development paths according to the 'with additional measures' scenario [70]

Sector	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
	Share in relation to gross final consumption of renewable energy									
Electricity	18%	18%	19%	19%	20%	21%	21%	22%	22%	23%
Heating and cooling	17%	17%	17%	17%	18%	18%	18%	19%	19%	20%
Transport	2%	2%	2%	2%	3%	3%	3%	3%	3%	3%
Total	**37%**	**38%**	**38%**	**39%**	**40%**	**42%**	**43%**	**43%**	**44%**	**46%**

Austria will have to update its directive to reach European targets.

Actual directive is a little contradictory: it develops a lot the part on the reaching target in WAM scenario, but consumptions are mostly valued with WEM scenario.

I suppose that 3% of 1180 PJ are consumed in transport sector, and these represent the 14% of renewable energy sources and among this 3,5 % are given by advanced biofuels.

$$Contr.adv.biofuels = 1180\ [PJ] * 0{,}03 * \frac{3{,}5}{14} * 10^9 \left[\frac{MJ}{PJ}\right] * 2{,}38 * 10^{-8} \left[\frac{ktoe}{MJ}\right] = 211{,}34\ ktoe$$

POLAND

Table A. 19: Projected gross final renewable energy consumption in the transport sector by technology [ktoe] and the share of the technology in renewable energy consumption in transport [%] - ECP scenario [71]

Gross final renewable energy consumption in the transport sector by technologies [ktoe]	**2005**	**2010**	**2015**	**2020**	**2025**	**2030**	**2035**	**2040**
gross final energy consumption in transport (RES-T denominator)	**10178.7**	**14951.0**	**14488.0**	**20295**	**19804**	**18884**	**18673**	**18356**
electricity	49.1	48.8	67.8	118	142	291	488	703
first-generation biofuels/first-generation HVO/CHVO	46.1	867.4	653.4	1274	1198	999	889	832
second-generation biofuels or second-generation HVO/COHVO	0.0	0.0	0.0	221	338	418	479	489
consumption of electricity for road transport purposes classified as renewable energy	0.3	0.34	0.48	13	53	150	295	473
consumption of electricity for rail transport purposes classified as RES	43.7	43.30	61.06	96	82	132	182	218
consumption of electricity in pipeline transport classified as RES	5.2	5.13	6.26	9	7	9	11	12
total consumption of electricity in transport	343.0	287.0	267.2	355	627	1004	1356	1769
including: for road transport purposes	1.8	2.0	1.9	39	234	517	819	1190
for rail transport purposes	305.2	254.9	240.6	290	363	457	507	550
in pipeline transport	36.0	30.2	24.7	26	29	31	31	30
[%]	**2005**	**2010**	**2015**	**2020**	**2025**	**2030**	**2035**	**2040**
share of electricity in renewable energy consumption in transport	51.6%	5.3%	9.4%	7.3%	8.4%	17.0%	26.3%	34.7%
share of biofuels in renewable energy consumption in transport	48.4%	94.7%	90.6%	92.7%	91.6%	83.0%	73.7%	65.3%
share of electricity used for road transport purposes	0.5%	0.7%	0.7%	11.0%	37.3%	51.4%	60.4%	67.3%
share of electricity used for rail transport purposes	89.0%	88.8%	90.1%	81.6%	58.0%	45.5%	37.4%	31.1%
share of electricity used in other types of	10.5%	10.5%	9.2%	7.4%	4.7%	3.1%	2.3%	1.7%

$Contr.adv.biofuels\ 2030 = 418\ ktoe$

PORTUGAL

Table A. 20: Perspectives for the evolution of renewable energy consumption in the transport sector by technology in Portugal for the 2030 horizon [72]

(ktoe)	**2020**	**2025**	**2030**
1st Generation biofuels	393	255	136
Advanced biofuels	-	94	155
Renewable hydrogen	-	9	65
Electricity	44	208	543
GRAND TOTAL	**437**	**566**	**900**

$$Contr.adv.biofuels = 155\ ktoe$$

ROMANIA

Table A. 21: Indicative trajectory, as broken down by technology, for renewable energy in gross final energy consumption in the transport sector, 2021 - 2030 [ktoe] [79]

ktoe	2020	2025	2030
Renewable energy in road transport	2.2	10.5	55.7
Renewable energy in the rail transport	46.9	72.2	97.6
Renewable energy in other types of transport	1.3	5.3	16.2
Biofuels of Generation I[16]	505.7	490.5	474.3
Biofuels of Generation II[17]	-	40.5	63.6
Total gross final renewable energy consumption in the transport sector	**635.4**	**728.4**	**989.9**

Source: Deloitte calculation based on the information submitted by the INECP Interinstitutional Working Group and of the Commission's recommendations

$$Contr.adv.biofuels = 63{,}6\ ktoe$$

SLOVENIA

Table A. 22: Estimated development scenarios by renewable energy technologies that Slovenia intends to use in order to achieve joint and sectoral development scenarios for renewable energy from 2020 to 2030 in the transport sector [73]

ktoe	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Gross final use of RES in transport	**133**	**140**	**147**	**153**	**160**	**167**	**177**	**187**	**198**	**209**	**220**
Biofuels	126	131	137	142	148	154	159	165	171	177	182
of which advanced biofuels	63	67	72	76	80	85	86	87	88	89	89
Electricity from RES	8	8	10	11	12	13	18	22	27	32	38

$$Contr.adv.biofuels(2030) = 89\ ktoe$$

SLOVAKIA

Table A. 23: Estimation of total contribution anticipated from each renewable energy technology in Slovak Republic in transport [55]

	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Bioethanol/bio-ETBE	50.0	50.0	50.0	50.0	50.0	55.0	55.0	55.0	55.0	55.0
of which advanced biofuels according to Annex IX.A	3.0	6.0	10.0	10.0	13.0	13.0	15.0	15.0	18.0	18.0
Biodiesel	125.0	125.0	125.0	125.0	125.0	125.0	125.0	125.0	125.0	130.0
of which advanced biofuels according to Annex IX.A	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.0	15.0	22.0
of which biofuels according to Annex IX.B	35.0	35.0	35.0	35.0	34.0	33.0	31.0	25.0	23.0	21.0
Hydrogen from renewable sources	0.0	0.0	0.0	0.1	0.2	0.3	0.4	0.6	1.0	2.0
Electricity from renewable sources	12.3	13.2	13.8	14.6	15.4	16.8	17.9	19.2	20.2	22.0
of which road transport	0.7	0.8	1.0	1.2	1.5	1.8	2.4	2.9	3.8	5.2
of which rail transport	10.3	11.0	11.4	12.0	12.4	13.2	13.7	14.1	14.6	15.0
Biomethane/RCF*	0.0	0.0	0.0	0.0	0.5	1.0	2.0	5.0	10.0	20.0
Total	**187.3**	**188.3**	**188.8**	**189.7**	**191.1**	**198.1**	**200.3**	**204.8**	**211.2**	**229.0**

Source: ME SR
*RCF - recycled carbon fuels

From the table above, I considered advanced biofuels according to annex IX, part A only in the section of biodiesel, because fuels considered in this work can be substituted to fossil diesel. So:

$$Contr.\,adv.\,biofuels\ except\ biomethane = 22\ ktoe$$

$$Contr.\,biomethane = 20\ ktoe$$

FINLAND

Table A. 24: Renewable energy per sector and technology in the with additional measure projection [TWh of gross final consumption] [74]

	2020	2022	2025	2027	2030
RES					
Hydropower	14	14	15	15	15
Wind power	8	11	13	15	18
Solar energy	0.2	0.3	0.5	0.7	1.1
Bioenergy	106	113	119	122	124
Heat pumps	6	7	7	7	7
Total	135	145	154	159	165
RES-E					
Hydropower	14	14	15	15	15
Wind power	8	11	13	15	18
Solar energy	0.2	0.3	0.4	0.7	1.1
Biomass	14	14	15	16	16
Total	36	40	43	46	50
RES-H&C					
Solar energy	0.0	0.0	0.0	0.0	0.0
Biomass	87	90	94	95	97
Heat pumps	6	7	7	7	7
Total	93	97	101	102	104
RES-T (excl. coefficients)					
Liquid biofuels	6	9	10	10	10
Biogas	0.0	0.0	0.1	0.1	0.2
Renewable electricity	0.3	0.4	0.5	0.6	0.8
Total	6	9	10	11	11

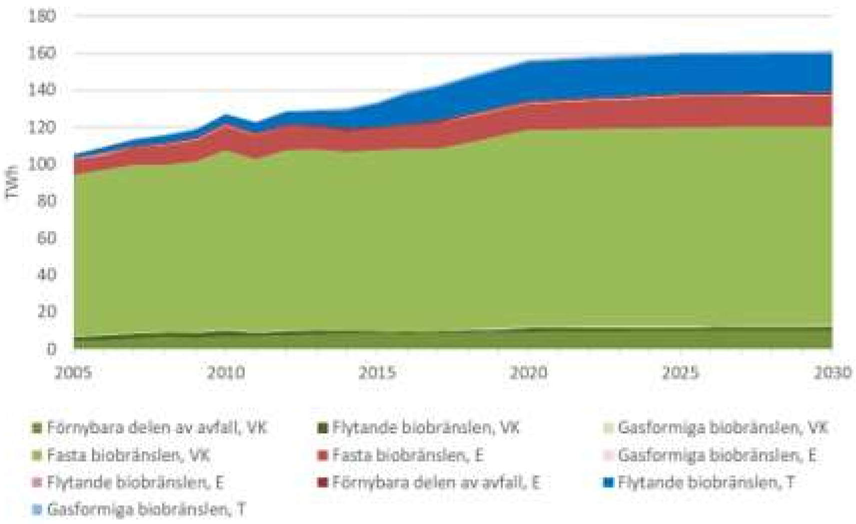
I assume that liquid biofuels are only advanced biofuels. So:

$$Contr.adv.biofuels\ except\ biomethane = 10\ [TWh] * 3600 \left[\frac{s}{h}\right] * 10^6 \left[\frac{MJ}{TJ}\right] * 2{,}38 * 10^{-8} \left[\frac{ktoe}{MJ}\right] = 859{,}68\ ktoe$$

$$Contr.of\ biogas = 0{,}2\ [TWh] * 3600 \left[\frac{s}{h}\right] * 10^6 \left[\frac{MJ}{TJ}\right] * 2{,}38 * 10^{-8} \left[\frac{ktoe}{MJ}\right] = 17{,}136\ ktoe$$

SWEDEN

Table A. 25: Bioenergy consumption in the Heating and Cooling, Electricity and Transport sectors from 2005 to 2017 by type of biomass, and assessment in the EU Reference Scenario up to 2030, TWh. [75]



Source	Target
Förnybara delen av avfall, VK	Renewable share of waste, HC
Fasta biobränslen, VK	Solid biofuels, HC
Flytande biobränslen, E	Liquid biofuels, E
Gasformiga biobränslen	Gaseous biofuels
Flytande biobränslen, VK	Liquid biofuels, HC
Fasta biobränslen E	Solid biofuels, E
Förnybara delen av avfall, E	Renewable share of waste, E
Gasformiga biobränslen, VK	Gaseous biofuels, HC
Gasformiga biobränslen, E	Gaseous biofuels, E
Flytande biobränslen, T	Liquid biofuels, T

From graph above, I assume that:

$$Contr.adv.biofuels(2030) = 20\,[TWh] * 3600\left[\frac{s}{h}\right] * 10^{6}\left[\frac{MJ}{TJ}\right] * 2{,}38 * 10^{-8}\left[\frac{ktoe}{MJ}\right] = 1719{,}36\ ktoe$$

Appendix II

HOLT METHOD

Holt method is used to create a forecast, in this case, on the biomass production for each EU nation, considering historical data taken by Eurostat. It is one of the double exponential smoothing methods, in particular, it is used in cases in which a clear trend is present but not a seasonal component [15].

Starting from a combination of the previous years' production, it is possible to identify the trend in demand; the prediction (P) for the (n + k) year is then fulfilled using the trend (T) and the data's smoothed value (S) [15].

"To evaluate the trend and the smoothed value at time n, the previous n-1 data are used considering two different smoothing factors: the data smoothing factor (alpha) (Eq. (2)) and the trend smoothing factor (beta).

$$P_{n+k} = S_n + T_n \cdot k$$

$$S_n = \alpha \cdot d_n + (1 - \alpha) \cdot (S_{n-1} + T_{n-1})$$

$$T_n = \beta \cdot (S_n - S_{n-1}) + (1 - \beta) \cdot T_{n-1}$$

"where d_n is the data for the transportation sector energy demand at time n. The two smoothing parameters can vary between 0 and 1"[15]. In fact, alpha and beta are set equal to 0,9 and 0,7. Both the initial trend and smoothed values were taken equal to the oldest data value and the difference between the two oldest data to initialize the method:

$S_1=d_1$

$T_1=d_2-d_1$

Historical series for each EU nation have been exported in MATLAB from which the forecasts and the RMSE are exported. In appendix, MATLAB script is reported.

Values highlighted are obtained by linear interpolation between known data.

Before adopting Holt Method, a corrective coefficient is used to define more precisely the amount of wood residues intended for energy purposes.

Here is presented MATLAB code used for the application of Holt method

```
% Holt method

alpha=0.9;
beta=0.7;

demand= % biomass production historical series (taking even more…
historical series together if they are at the same length).

for jj=1:length(demand(:,1))

        level(jj,1)=demand(jj,1);
        trend(jj,1)=demand(jj,2)-demand(jj,1);
        forecast(jj,1)=0;
        RMSE(jj)=0;

        for ii=2:length(demand(1,:))
            level(jj,ii)=alpha*demand(jj,ii)+(1-alpha)*(level(jj,ii-
1)+trend(jj,ii-1));
            trend(jj,ii)=beta*(level(jj,ii)-level(jj,ii-1))+(1-
beta)*trend(jj,ii-1);
            forecast(jj,ii)=level(jj,ii-1)+trend(jj,ii-1);
            error(jj,ii)=demand(jj,ii)-forecast(jj,ii);
            sq_err(jj,ii)=error(jj,ii)^2;
        end

        MSE(jj)=sum(sq_err(jj,:))/length(sq_err(jj,:));
        RMSE(jj)=sqrt(MSE(jj));

        k=1;
        while (k< % n_years of prevision)
            forecast(jj,ii+k)=level(jj,ii)+k*trend(jj,ii);
            k=k+1;
        end

end
```

Appendix III

Table A. 26: Available bovine heads for energy less than 1 years old

GEO/TIME	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Belgium	84711,58	83973,26	83234,95	82496,63	81758,31	81020	80281,68	79543,36	78805,05	78066,73
Bulgaria	13749,75	14324,79	14899,84	15474,88	16049,92	16624,96	17200	17775,04	18350,08	18925,12
Czechia	48455,54	48224,68	47993,82	47762,97	47532,11	47301,25	47070,39	46839,53	46608,67	46377,81
Denmark	62410,67	62069,35	61728,03	61386,72	61045,4	60704,09	60362,77	60021,46	59680,14	59338,83
Germany	397524	386793,5	376063,1	365332,7	354602,2	343871,8	333141,4	322410,9	311680,5	300950,1
Estonia	8736,284	8839,118	8941,951	9044,784	9147,618	9250,451	9353,284	9456,117	9558,951	9661,784
Ireland	250009,7	254941,5	259873,2	264804,9	269736,6	274668,4	279600,1	284531,8	289463,5	294395,3
Greece	18818,58	19086,53	19354,48	19622,44	19890,39	20158,34	20426,29	20694,24	20962,2	21230,15
Spain	307326,1	309488,9	311651,7	313814,5	315977,3	318140,1	320302,9	322465,7	324628,5	326791,3
France	563582	541710,8	519839,7	497968,5	476097,4	454226,2	432355,1	410483,9	388612,8	366741,6
Croatia	16966,99	16402,47	15837,95	15273,42	14708,9	14144,37	13579,85	13015,33	12450,8	11886,28
Italy	215595,5	218311,1	221026,8	223742,5	226458,2	229173,8	231889,5	234605,2	237320,9	240036,5
Cyprus	3138,742	3233,482	3328,222	3422,962	3517,702	3612,442	3707,182	3801,921	3896,661	3991,401
Latvia	13647,46	13954,37	14261,28	14568,18	14875,09	15182	15488,9	15795,81	16102,72	16409,62
Lithuania	20020,26	19890,41	19760,56	19630,72	19500,87	19371,03	19241,18	19111,34	18981,49	18851,64
Luxembourg	5957,523	5944,6	5931,676	5918,753	5905,83	5892,907	5879,984	5867,061	5854,138	5841,214
Hungary	32828,96	33746,96	34664,96	35582,96	36500,95	37418,95	38336,95	39254,95	40172,95	41090,95
Malta	509,8496	517,9654	526,0811	534,1969	542,3127	550,4284	558,5442	566,66	574,7757	582,8915
Netherlands	179539,1	178006,7	176474,2	174941,7	173409,2	171876,8	170344,3	168811,8	167279,4	165746,9
Austria	70774,41	69750,25	68726,09	67701,93	66677,77	65653,61	64629,45	63605,29	62581,12	61556,96
Poland	208761,1	208980,1	209199	209417,9	209636,8	209855,7	210074,6	210293,6	210512,5	210731,4
Portugal	63925,94	64557,94	65189,93	65821,92	66453,92	67085,91	67717,91	68349,9	68981,9	69613,89
Romania	45834,2	44565,07	43295,94	42026,81	40757,68	39488,56	38219,43	36950,3	35681,17	34412,04
Slovenia	18409,26	18485,48	18561,69	18637,9	18714,11	18790,32	18866,53	18942,74	19018,96	19095,17
Slovakia	15274,59	15498,67	15722,76	15946,84	16170,93	16395,01	16619,1	16843,18	17067,27	17291,35
Finland	34880,99	34884,02	34887,06	34890,09	34893,13	34896,16	34899,19	34902,23	34905,26	34908,3
Sweden	55778,22	56069,95	56361,68	56653,41	56945,14	57236,87	57528,6	57820,33	58112,06	58403,79

Table A. 27: Available bovine heads for energy 1 to less than 2 years old

GEO/TIME	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Belgium	54760,731	54317,4	53874,07	53430,746	52987,418	52544,09	52100,762	51657,434	51214,106	50770,778
Bulgaria	9379,1557	10354,9	11330,64	12306,386	13282,129	14257,873	15233,616	16209,36	17185,103	18160,847
Czechia	35068,141	34667,97	34267,8	33867,632	33467,463	33067,293	32667,124	32266,954	31866,784	31466,615
Denmark	33112,042	32805,05	32498,05	32191,06	31884,066	31577,071	31270,077	30963,083	30656,089	30349,095
Germany	305182,34	293225,6	281268,8	269312	257355,23	245398,45	233441,67	221484,89	209528,11	197571,34
Estonia	5943,2051	5941,313	5939,422	5937,5299	5935,6381	5933,7464	5931,8547	5929,9629	5928,0712	5926,1795
Ireland	200772,01	196455,7	192139,4	187823,02	183506,69	179190,35	174874,02	170557,69	166241,36	161925,03
Greece	10501,105	10238,36	9975,619	9712,8763	9450,1333	9187,3904	8924,6475	8661,9046	8399,1617	8136,4188
Spain	102832,94	103095,3	103357,7	103620,09	103882,48	104144,86	104407,24	104669,62	104932,01	105194,39
France	295590,93	260933,4	226275,8	191618,29	156960,74	122303,2	87645,654	52988,109	18330,564	324294
Croatia	14082,339	14796,01	15509,68	16223,35	16937,02	17650,691	18364,361	19078,032	19791,702	20505,373
Italy	194611,74	197303,9	199996,1	202688,26	205380,44	208072,61	210764,78	213456,96	216149,13	218841,31
Cyprus	1437,6569	1453,623	1469,589	1485,5547	1501,5207	1517,4866	1533,4525	1549,4185	1565,3844	1581,3503
Latvia	7821,2452	7826,454	7831,663	7836,8717	7842,0805	7847,2894	7852,4982	7857,707	7862,9159	7868,1247
Lithuania	15101,91	14785,39	14468,88	14152,361	13835,844	13519,328	13202,811	12886,295	12569,778	12253,262
Luxembourg	4809,0277	4736,701	4664,374	4592,0472	4519,7204	4447,3935	4375,0667	4302,7399	4230,413	4158,0862
Hungary	24033,905	24606,51	25179,11	25751,719	26324,323	26896,928	27469,532	28042,137	28614,741	29187,346
Malta	331,69928	317,9358	304,1723	290,40884	276,64536	262,88188	249,1184	235,35492	221,59144	207,82796
Netherlands	54732,839	54682,4	54631,96	54581,528	54531,091	54480,654	54430,217	54379,781	54329,344	54278,907
Austria	48758,654	47693,15	46627,65	45562,145	44496,642	43431,139	42365,637	41300,134	40234,631	39169,128
Poland	220628,59	225300,4	229972,3	234644,1	239315,93	243987,76	248659,6	253331,43	258003,26	262675,1
Portugal	31781,632	32985,79	34189,94	35394,098	36598,253	37802,409	39006,564	40210,72	41414,875	42619,031
Romania	25415,379	24495,78	23576,17	22656,567	21736,964	20817,36	19897,756	18978,152	18058,548	17138,944
Slovenia	18400,621	18463,4	18526,17	18588,944	18651,718	18714,492	18777,266	18840,04	18902,815	18965,589
Slovakia	10627,239	10888,71	11150,17	11411,643	11673,111	11934,58	12196,048	12457,516	12718,984	12980,452
Finland	23324,951	22715,63	22106,3	21496,974	20887,648	20278,322	19668,997	19059,671	18450,345	17841,019
Sweden	37659,111	36350,92	35042,74	33734,548	32426,361	31118,173	29809,985	28501,798	27193,61	25885,422

Table A. 28: Available bovine heads for energy 2 or more than years old

GEO/TIME	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Belgium	137009,33	134371,3	131733,3	129095,25	126457,23	123819,2	121181,18	118543,15	115905,13	113267,1
Bulgaria	50602,629	53049,28	55495,94	57942,588	60389,241	62835,894	65282,548	67729,201	70175,854	72622,507
Czechia	75685,736	74361,55	73037,36	71713,172	70388,984	69064,796	67740,608	66416,42	65092,232	63768,043
Denmark	82862,509	82199,16	81535,82	80872,472	80209,126	79545,78	78882,435	78219,089	77555,743	76892,398
Germany	614347,83	597456,8	580565,8	563674,83	546783,83	529892,84	513001,84	496110,84	479219,84	462328,84
Estonia	15786,229	15729,02	15671,8	15614,59	15557,377	15500,163	15442,95	15385,737	15328,524	15271,311
Ireland	328339,31	323387,3	318435,4	313483,43	308531,47	303579,51	298627,55	293675,59	288723,63	283771,68
Greece	35311,193	35486,31	35661,43	35836,552	36011,672	36186,792	36361,912	36537,032	36712,152	36887,271
Spain	393037,16	396899,3	400761,5	404623,7	408485,88	412348,06	416210,24	420072,42	423934,6	427796,78
France	1193469	1189431	1185393	1181355,5	1177317,6	1173279,8	1169241,9	1165204,1	1161166,2	1157128,4
Croatia	19612,871	19540,64	19468,42	19396,19	19323,963	19251,736	19179,509	19107,282	19035,055	18962,828
Italy	361518,62	359766,8	358015	356263,2	354511,4	352759,59	351007,78	349255,97	347504,17	345752,36
Cyprus	5137,0462	5440,232	5743,418	6046,6045	6349,7906	6652,9767	6956,1628	7259,3489	7562,535	7865,7211
Latvia	26490,43	26357,31	26224,18	26091,062	25957,94	25824,817	25691,694	25558,572	25425,449	25292,326
Lithuania	38965,057	38145,38	37325,7	36506,027	35686,35	34866,673	34046,996	33227,32	32407,643	31587,966
Luxembourg	11870,995	11729,76	11588,53	11447,305	11306,075	11164,845	11023,615	10882,384	10741,154	10599,924
Hungary	57871,053	59197,28	60523,51	61849,744	63175,974	64502,204	65828,434	67154,665	68480,895	69807,125
Malta	832,73716	834,2232	835,7092	837,19528	838,68132	840,16736	841,6534	843,13944	844,62548	846,11152
Netherlands	202927,73	200040,3	197152,8	194265,34	191377,88	188490,41	185602,95	182715,48	179828,02	176940,56
Austria	99764,03	98564,42	97364,82	96165,212	94965,606	93766,001	92566,395	91366,789	90167,183	88967,577
Poland	330434,33	330868,1	331301,9	331735,67	332169,45	332603,23	333037,01	333470,79	333904,57	334338,35
Portugal	109602,54	110153,2	110703,9	111254,55	111805,23	112355,9	112906,57	113457,25	114007,92	114558,59
Romania	151403,53	149158,3	146913,1	144667,95	142422,76	140177,57	137932,38	135687,19	133442	131196,81
Slovenia	24068,228	24272,42	24476,61	24680,802	24884,993	25089,185	25293,376	25497,567	25701,758	25905,95
Slovakia	27418,613	27412,7	27406,79	27400,884	27394,974	27389,064	27383,154	27377,244	27371,334	27365,424
Finland	40696,179	40097,03	39497,87	38898,721	38299,568	37700,415	37101,262	36502,109	35902,956	35303,804
Sweden	71168,466	69943,16	68717,86	67492,55	66267,244	65041,939	63816,633	62591,328	61366,022	60140,717

Table A. 29: Liquid dejections bovine animals less than 1 year old [tonnes]

GEO/TIME	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Belgium	337582	334639,3	331697	328755	325812,6	322870	319928	316986	314044	311101
Bulgaria	54793,7	57085,31	59376,9	61668,5	63960,05	66251,6	68543,2	70834,8	73126,4	75417,9
Czechia	193099	192178,7	191259	190339	189418,8	188499	187579	186659	185739	184819
Denmark	248711	247350,7	245991	244630	243270,2	241910	240550	239190	237830	236469
Germany	1584161	1541399	1498638	1455876	1413115	1370353	1327592	1284830	1242069	1199307
Estonia	34814,7	35224,5	35634,3	36044,1	36453,9	36863,7	37273,5	37683,3	38093,1	38502,9
Ireland	996306	1015960	1035613	1055266	1074919	1094573	1114226	1133879	1153532	1173186
Greece	74993,4	76061,17	77129	78196,8	79264,59	80332,4	81400,2	82468	83535,8	84603,6
Spain	1224716	1233335	1241954	1250573	1259192	1267811	1276429	1285048	1293667	1302286
France	2245914	2158756	2071598	1984439	1897281	1810123	1722965	1635807	1548649	1461491
Croatia	67614,7	65364,99	63115,3	60865,7	58615,99	56366,3	54116,7	51867	49617,3	47367,7
Italy	859163	869985,2	880807	891629	902451,6	913274	924096	934918	945740	956562
Cyprus	12508,1	12885,65	13263,2	13640,7	14018,29	14395,8	14773,4	15150,9	15528,5	15906
Latvia	54386,1	55609,14	56832,2	58055,2	59278,28	60501,3	61724,4	62947,4	64170,5	65393,5
Lithuania	79782,1	79264,67	78747,2	78229,8	77712,34	77194,9	76677,5	76160	75642,6	75125,1
Luxembourg	23741,1	23689,65	23638,1	23586,6	23535,15	23483,6	23432,1	23380,6	23329,1	23277,6
Hungary	130826	134484	138142	141801	145458,9	149117	152775	156434	160092	163750
Malta	2031,79	2064,128	2096,47	2128,81	2161,154	2193,5	2225,84	2258,18	2290,52	2322,86
Netherlands	715476	709369	703262	697155	691048	684941	678834	672727	666620	660513
Austria	282041	277959,6	273878	269797	265715,6	261634	257553	253472	249390	245309
Poland	831928	832800,2	833673	834545	835417,4	836290	837162	838035	838907	839779
Portugal	254749	257267,9	259786	262305	264823,5	267342	269861	272379	274898	277416
Romania	182652	177594,9	172537	167480	162422,2	157365	152307	147250	142192	137134
Slovenia	73362,2	73665,91	73969,6	74273,3	74577,04	74880,7	75184,5	75488,2	75791,9	76095,6
Slovakia	60870,3	61763,3	62656,3	63549,3	64442,28	65335,3	66228,3	67121,3	68014,3	68907,3
Finland	139003	139015,3	139027	139039	139051,5	139064	139076	139088	139100	139112
Sweden	222280	223442,7	224605	225768	226930,4	228093	229255	230418	231581	232743

Table A. 30: Liquid dejections of bovine animals 1 to less than 2 years old [tonnes]

GEO/TIME	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Belgium	559974	555441,1	550908	546374	541840,9	537307	532774	528241	523707	519174
Bulgaria	95909,7	105887,5	115865	125843	135820,9	145799	155777	165754	175732	185710
Czechia	358601	354509,1	350417	346325	342232,9	338141	334049	329957	325865	321773
Danmark	338598	335459,2	332320	329181	326041,4	322902	319763	316624	313484	310345
Germany	3120746	2998478	2876210	2753941	2631673	2509405	2387137	2264869	2142601	2020333
Estonia	60774,3	60754,92	60735,6	60716,2	60696,89	60677,5	60658,2	60638,9	60619,5	60600,2
Ireland	2053062	2008924	1964786	1920648	1876510	1832372	1788234	1744096	1699958	1655819
Greece	107383	104695,9	102009	99322,3	96635,55	93948,8	91262	88575,3	85888,5	83201,7
Spain	1051553	1054236	1056919	1059602	1062286	1064969	1067652	1070335	1073018	1075701
France	3022666	2668263	2313860	1959458	1605055	1250653	896250	541848	187445	3316179
Croatia	144004	151301,6	158600	165897	173195,3	180493	187791	195089	202387	209685
Italy	1990069	2017598	2045128	2072658	2100187	2127717	2155247	2182777	2210306	2237836
Cyprus	14701,2	14864,51	15027,8	15191	15354,31	15517,6	15680,8	15844,1	16007,4	16170,6
Latvia	79978,8	80032,07	80085,3	80138,6	80191,86	80245,1	80298,4	80351,7	80404,9	80458,2
Lithuania	154430	151193,1	147956	144720	141483,1	138246	135010	131773	128537	125300
Luxembourg	49176,3	48436,75	47697,1	46957,5	46217,94	45478,3	44738,7	43999,1	43259,5	42519,9
Hungary	245767	251622,2	257478	263333	269188,3	275044	280899	286754	292610	298465
Malta	3391,9	3251,161	3110,42	2969,67	2828,931	2688,19	2547,44	2406,7	2265,96	2125,22
Netherlands	559689	559173,5	558658	558142	557626,2	557110	556595	556079	555563	555047
Austria	498598	487702,5	476807	465911	455015,5	444120	433224	422329	411433	400537
Poland	2256113	2303886	2351660	2399433	2447206	2494980	2542753	2590527	2638300	2686074
Portugal	324994	337307,4	349621	361934	374247,9	386561	398875	411188	423502	435815
Romania	259894	250489,9	241086	231682	222278,7	212875	203471	194068	184664	175260
Slovenia	73327,8	73577,92	73828,1	74078,2	74328,4	74578,6	74828,7	75078,9	75329	75579,2
Slovakia	108672	111346,2	114020	116694	119367,4	122041	124715	127389	130062	132736
Finland	238517	232286,4	226055	219825	213593,7	207363	201132	194901	188670	182439
Sweden	385096	371718,7	358341	344964	331586,8	318209	304832	291455	278078	264700

Table A. 31: Liquid dejections of bovine animals 2 or more years old [tonnes]

GEO/TIME	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Belgium	2879334	2823894,2	2768454,5	2713014,8	2657575,12	2602135	2546695,7	2491256	2435816,3	2380377
Bulgaria	1063445	1114862,8	1166280,7	1217698,5	1269116,44	1320534	1371952,2	1423370,1	1474788	1526206
Czechia	1590582	1562752,9	1534924,3	1507095,7	1479267,08	1451438	1423609,9	1395781,2	1367952,6	1340124
Danmark	1741406	1727465,1	1713524,5	1699583,9	1685643,31	1671703	1657762,1	1643821,5	1629880,9	1615940
Germany	12910891	12555917	12200942	11845968	11490993,1	11136019	10781044	10426069	10071095	9716120
Estonia	331757,1	330554,78	329352,42	328150,05	326947,681	325745,3	324542,95	323340,58	322138,21	320935,8
Ireland	6900249	6796180,8	6692112,4	6588043,9	6483975,53	6379907	6275838,7	6171770,3	6067701,9	5963633
Greece	742086,1	745766,33	749446,58	753126,83	756807,078	760487,3	764167,58	767847,83	771528,08	775208,3
Spain	8259914	8341079,7	8422245,8	8503411,8	8584577,88	8665744	8746910	8828076	8909242	8990408
France	25081473	24996615	24911757	24826900	24742042	24657184	24572327	24487469	24402611	24317753
Croatia	412176,3	410658,45	409140,56	407622,66	406104,77	404586,9	403068,98	401551,09	400033,2	398515,3
Italy	7597533	7560717,3	7523902	7487086,7	7450271,45	7413456	7376640,9	7339825,6	7303010,3	7266195
Cyprus	107958,1	114329,77	120701,41	127073,05	133444,691	139816,3	146187,97	152559,61	158931,25	165302,9
Latvia	556712,4	553914,77	551117,11	548319,46	545521,807	542724,2	539926,5	537128,85	534331,2	531533,5
Lithuania	818874,3	801648,25	784422,25	767196,24	749970,237	732744,2	715518,23	698292,22	681066,22	663840,2
Luxembourg	249476,1	246508,11	243540,07	240572,03	237603,999	234636	231667,93	228699,89	225731,86	222763,8
Hungary	1216195	1244066,7	1271938,2	1299809,8	1327681,31	1355553	1383424,4	1411295,9	1439167,4	1467039
Malta	17500,48	17531,705	17562,935	17594,165	17625,3953	17656,63	17687,855	17719,085	17750,315	17781,55
Netherlands	4264649	4203967,2	4143285,4	4082603,6	4021921,84	3961240	3900558,2	3839876,4	3779194,6	3718513
Austria	2096601	2071391	2046180,6	2020970,1	1995759,67	1970549	1945338,8	1920128,3	1894917,9	1869707
Poland	6944277	6953393,5	6962509,6	6971625,8	6980741,94	6989858	6998974,3	7008090,4	7017206,6	7026323
Portugal	2303364	2314936,3	2326509,1	2338081,8	2349654,49	2361227	2372799,9	2384372,6	2395945,4	2407518
Romania	3181837	3134652,6	3087468,6	3040284,5	2993100,5	2945916	2898732,4	2851548,4	2804364,3	2757180
Slovenia	505808,4	510099,57	514390,78	518681,98	522973,187	527264,4	531555,6	535846,8	540138	544429,2
Slovakia	576218,7	576094,55	575970,35	575846,15	575721,949	575597,7	575473,55	575349,35	575225,15	575100,9
Finland	855254,8	842663,27	830071,71	817480,15	804888,59	792297	779705,47	767113,91	754522,35	741930,8
Sweden	1495648	1469897,8	1444147,3	1418396,8	1392646,23	1366896	1341145,2	1315394,6	1289644,1	1263894

Table A. 32: Solid dejections of bovine animals less than 1 year old [tonnes]

GEO/TIME	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Belgium	40814	40458,3	40102,6	39746,9	39391,2	39035,4	38679,7	38324	37968,3	37612,5
Bulgaria	6624,63	6901,69	7178,74	7455,8	7732,85	8009,91	8286,96	8564,02	8841,07	9118,13
Czechia	23345,9	23234,7	23123,4	23012,2	22901	22789,7	22678,5	22567,3	22456,1	22344,8
Denmark	30069,5	29905	29740,6	29576,1	29411,7	29247,2	29082,8	28918,3	28753,9	28589,4
Germany	191527	186357	181187	176017	170847	165677	160508	155338	150168	144998
Estonia	4209,14	4258,69	4308,23	4357,78	4407,32	4456,87	4506,41	4555,96	4605,5	4655,05
Ireland	120455	122831	125207	127583	129959	132335	134711	137087	139464	141840
Greece	9066,79	9195,89	9324,99	9454,09	9583,19	9712,29	9841,39	9970,49	10099,6	10228,7
Spain	148070	149112	150154	151196	152238	153280	154322	155364	156406	157448
France	271534	260996	250459	239921	229384	218846	208309	197771	187234	176696
Croatia	8174,7	7902,71	7630,72	7358,73	7086,75	6814,76	6542,77	6270,78	5998,8	5726,81
Italy	103874	105182	106491	107799	109108	110416	111724	113033	114341	115650
Cyprus	1512,25	1557,89	1603,54	1649,18	1694,83	1740,47	1786,12	1831,77	1877,41	1923,06
Latvia	6575,35	6723,22	6871,08	7018,95	7166,82	7314,69	7462,55	7610,42	7758,29	7906,16
Lithuania	9645,76	9583,2	9520,64	9458,08	9395,52	9332,96	9270,4	9207,84	9145,28	9082,72
Luxembourg	2870,33	2864,11	2857,88	2851,66	2845,43	2839,2	2832,98	2826,75	2820,52	2814,3
Hungary	15817	16259,3	16701,6	17143,9	17586,2	18028,5	18470,7	18913	19355,3	19797,6
Malta	245,646	249,556	253,466	257,376	261,286	265,196	269,107	273,017	276,927	280,837
Netherlands	86501,9	85763,6	85025,3	84286,9	83548,6	82810,2	82071,9	81333,5	80595,2	79856,8
Austria	34099,1	33605,7	33112,2	32618,8	32125,3	31631,9	31138,5	30645	30151,6	29658,1
Poland	100581	100687	100792	100898	101003	101108	101214	101319	101425	101530
Portugal	30799,5	31104	31408,5	31713	32017,5	32322	32626,5	32931	33235,5	33540
Romania	22082,9	21471,5	20860	20248,5	19637,1	19025,6	18414,1	17802,7	17191,2	16579,7
Slovenia	8869,58	8906,3	8943,02	8979,74	9016,46	9053,18	9089,9	9126,61	9163,33	9200,05
Slovakia	7359,3	7467,26	7575,23	7683,19	7791,15	7899,12	8007,08	8115,05	8223,01	8330,97
Finland	16805,7	16807,1	16808,6	16810	16811,5	16813	16814,4	16815,9	16817,4	16818,8
Sweden	26873,9	27014,5	27155,1	27295,6	27436,2	27576,7	27717,3	27857,8	27998,4	28138,9

Table A. 33: Solid dejections of bovine animals 1 to less than 2 years old [tonnes]

GEO/TIME	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Belgium	65559,5	65028,8	64498	63967,3	63436,5	62905,8	62375	61844,3	61313,5	60782,8
Bulgaria	11228,7	12396,9	13565	14733,2	15901,4	17069,5	18237,7	19405,8	20574	21742,2
Czechia	41983,6	41504,5	41025,4	40546,3	40067,2	39588,2	39109,1	38630	38150,9	37671,8
Denmark	39641,7	39274,2	38906,7	38539,1	38171,6	37804,1	37436,5	37069	36701,5	36333,9
Germany	365364	351050	336735	322420	308106	293791	279476	265162	250847	236532
Estonia	7115,21	7112,94	7110,68	7108,41	7106,15	7103,88	7101,62	7099,35	7097,09	7094,82
Ireland	240364	235197	230029	224862	219694	214527	209359	204192	199024	193857
Greece	12571,9	12257,4	11942,8	11628,3	11313,7	10999,1	10684,6	10370	10055,5	9740,92
Spain	123112	123426	123740	124054	124368	124682	124996	125310	125625	125939
France	353881	312389	270897	229405	187913	146421	104929	63437,4	21945,4	388245
Croatia	16859,4	17713,8	18568,2	19422,6	20277	21131,4	21985,8	22840,2	23694,6	24549
Italy	232989	236212	239435	242658	245881	249105	252328	255551	258774	261997
Cyprus	1721,16	1740,28	1759,39	1778,51	1797,62	1816,73	1835,85	1854,96	1874,08	1893,19
Latvia	9363,59	9369,83	9376,07	9382,3	9388,54	9394,77	9401,01	9407,25	9413,48	9419,72
Lithuania	18080	17701,1	17322,1	16943,2	16564,3	16185,3	15806,4	15427,5	15048,5	14669,6
Luxembourg	5757,37	5670,78	5584,19	5497,6	5411,01	5324,42	5237,83	5151,24	5064,65	4978,06
Hungary	28773,4	29458,9	30144,4	30830	31515,5	32201	32886,5	33572	34257,6	34943,1
Malta	397,11	380,633	364,155	347,677	331,2	314,722	298,245	281,767	265,289	248,812
Netherlands	65526,2	65465,8	65405,4	65345	65284,6	65224,2	65163,9	65103,5	65043,1	64982,7
Austria	58373,9	57098,2	55822,6	54547	53271,4	51995,8	50720,1	49444,5	48168,9	46893,3
Poland	264137	269730	275323	280916	286509	292102	297695	303288	308882	314475
Portugal	38049	39490,6	40932,2	42373,8	43815,4	45257	46698,7	48140,3	49581,9	51023,5
Romania	30427,3	29326,3	28225,4	27124,4	26023,5	24922,5	23821,6	22720,6	21619,7	20518,7
Slovenia	22029,2	22104,4	22179,5	22254,7	22329,8	22405	22480,1	22555,3	22630,4	22705,6
Slovakia	12722,9	13036	13349	13662	13975	14288,1	14601,1	14914,1	15227,2	15540,2
Finland	27924,6	27195,1	26465,7	25736,2	25006,7	24277,2	23547,7	22818,2	22088,8	21359,3
Sweden	45085,5	43519,3	41953,2	40387	38820,8	37254,7	35688,5	34122,4	32556,2	30990

Table A. 34: Solid dejections of bovine animals more than 2 years old [tonnes]

GEO/TIME	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Belgium	341307	334736	328164	321592	315021	308449	301877	295306	288734	282163
Bulgaria	126057	132152	138247	144342	150437	156532	162627	168722	174817	180912
Czechia	188543	185244	181945	178646	175348	172049	168750	165452	162153	158854
Denmark	206421	204768	203116	201463	199811	198158	196506	194854	193201	191549
Germany	1530417	1488340	1446262	1404184	1362107	1320029	1277952	1235874	1193797	1151719
Estonia	39325,5	39182,9	39040,4	38897,9	38755,4	38612,8	38470,3	38327,8	38185,3	38042,7
Ireland	817934	805598	793262	780926	768590	756255	743919	731583	719247	706911
Greece	87964,6	88400,8	88837,1	89273,3	89709,6	90145,8	90582,1	91018,3	91454,6	91890,8
Spain	979105	988726	998347	1007968	1017589	1027211	1036832	1046453	1056074	1065695
France	2973080	2963022	2952963	2942904	2932845	2922787	2912728	2902669	2892610	2882551
Croatia	48858,1	48678,2	48498,3	48318,3	48138,4	47958,5	47778,6	47598,6	47418,7	47238,8
Italy	900588	896224	891860	887496	883132	878768	874404	870040	865676	861312
Cyprus	12797	13552,3	14307,6	15062,8	15818,1	16573,4	17328,7	18083,9	18839,2	19594,5
Latvia	65991	65659,3	65327,7	64996,1	64664,5	64332,8	64001,2	63669,6	63338	63006,3
Lithuania	97066,8	95024,9	92983	90941,1	88899,2	86857,2	84815,3	82773,4	80731,5	78689,6
Luxembourg	29572,1	29220,3	28868,5	28516,7	28164,8	27813	27461,2	27109,4	26757,6	26405,7
Hungary	144164	147468	150772	154075	157379	160683	163987	167291	170594	173898
Malta	2074,45	2078,15	2081,86	2085,56	2089,26	2092,96	2096,66	2100,37	2104,07	2107,77
Netherlands	505518	498325	491132	483939	476746	469553	462360	455167	447974	440781
Austria	248525	245536	242548	239560	236571	233583	230594	227606	224618	221629
Poland	823153	824234	825314	826395	827476	828556	829637	830717	831798	832879
Portugal	273034	274405	275777	277149	278521	279893	281264	282636	284008	285380
Romania	377165	371572	365979	360386	354793	349200	343607	338014	332421	326828
Slovenia	59957	60465,6	60974,3	61483	61991,6	62500,3	63009	63517,6	64026,3	64535
Slovakia	68303,2	68288,5	68273,7	68259	68244,3	68229,6	68214,9	68200,1	68185,4	68170,7
Finland	101379	99886,7	98394,1	96901,6	95409	93916,4	92423,9	90931,3	89438,8	87946,2
Sweden	177290	174237	171185	168132	165080	162028	158975	155923	152870	149818

Table A. 35: Liquid dejections of piglets of weight less than 20 kg [tonnes]

GEO/TIME	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Belgium	39182,7	40124,1	41065,5	42006,9	42948,3	43889,7	44831,1	45772,5	46713,9	47655,3
Bulgaria	3092,96	3285,94	3478,93	3671,91	3864,9	4057,88	4250,86	4443,85	4636,83	4829,82
Czechia	11333,9	11425	11516,1	11607,2	11698,3	11789,4	11880,5	11971,6	12062,7	12153,8
Denmark	110223	111943	113663	115383	117103	118823	120544	122264	123984	125704
Germany	178845	178736	178628	178519	178411	178302	178193	178085	177976	177867
Estonia	2384,85	2329,28	2273,71	2218,14	2162,57	2107	2051,42	1995,85	1940,28	1884,71
Ireland	9722,95	9442,69	9162,43	8882,17	8601,91	8321,65	8041,38	7761,12	7480,86	7200,6
Greece	4751,81	4804,62	4857,43	4910,24	4963,05	5015,86	5068,67	5121,48	5174,29	5227,1
Spain	194168	193584	193000	192416	191832	191248	190664	190080	189496	188912
France	145811	174086	202361	230637	258912	287187	315463	343738	372013	400289
Croatia	6400,52	6478,4	6556,27	6634,14	6712,02	6789,89	6867,77	6945,64	7023,52	7101,39
Italy	33390	33651,7	33913,5	34175,3	34437	34698,8	34960,6	35222,3	35484,1	35745,9
Cyprus	3042,35	3091,97	3141,6	3191,22	3240,84	3290,47	3340,09	3389,71	3439,34	3488,96
Latvia	1246,72	1199,06	1151,41	1103,76	1056,11	1008,45	960,801	913,149	865,496	817,844
Lithuania	2410,72	2374,21	2337,71	23012	22646,9	22281,8	21916,7	21551,7	21186,6	20821,5
Luxembour	386,448	382,166	377,885	373,604	369,322	365,041	360,76	356,478	352,197	347,916
Hungary	17246,3	17974	18701,6	19429,3	20157	20884,6	21612,3	22340	23067,6	2379,53
Malta	307,594	359,568	411,541	463,515	515,488	567,461	619,435	671,408	723,382	775,355
Netherlands	109418	105395	101373	97350	93327,3	89304,7	85282	81259,3	77236,7	73214
Austria	15562,4	15720,4	15878,4	16036,4	16194,4	16352,4	16510,4	16668,4	16826,4	16984,4
Poland	55287,1	55846,6	56406,2	56965,7	57525,3	58084,9	58644,4	59204	59763,5	60323,1
Portugal	19684,1	20231,1	20778	21325	21871,9	22418,9	22965,9	2351,28	2405,98	2460,67
Romania	16632,1	16467,1	16302	16136,9	15971,9	15806,8	15641,8	15476,7	15311,6	15146,6
Slovenia	1107,76	1048,4	989,038	929,678	870,317	810,957	751,597	692,236	632,876	573,516
Slovakia	4955,84	5159,68	5363,51	5567,34	5771,18	5975,01	6178,84	6382,68	6586,51	6790,34
Finland	7186,71	7506,15	7825,6	8145,04	8464,49	8783,93	9103,38	9422,82	9742,27	10061,7
Sweden	8496,21	8390,22	8284,22	8178,23	8072,23	7966,23	7860,24	7754,24	7648,25	7542,25

Table A. 36: Liquid dejections of pigs of weight 20 kg to 50 kg [tonnes]

GEO/TIME	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Belgium	275580	277168	278755	280343	281931	283519	285107	286695	288282	289870
Bulgaria	26088,7	24286	22483,2	206805	188777	170750	152722	134695	116667	98639,9
Czechia	82170,7	86588,8	91007	95425,1	99843,2	104261	108679	113098	117516	121934
Denmark	905106	927169	949233	971297	993361	1015425	1037488	1059552	1081616	1103680
Germany	981590	943714	905839	867963	830087	792212	754336	716460	678585	640709
Estonia	12701,1	13157,3	13613,6	14069,8	14526,1	14982,3	15438,5	15894,8	16351	16807,3
Ireland	96919,4	99480,6	102042	104603	107164	109726	112287	114848	117409	119971
Greece	38828,7	39472,1	40115,4	40758,7	41402	42045,3	42688,6	43331,9	43975,3	44618,6
Spain	1711252	1791096	1870940	1950784	2030628	2110472	219032	227016	235000	2429848
France	289341	73658,6	-142024	-357706	-573389	-789072	-1E+06	-1E+06	-1E+06	469611
Croatia	37676,8	35416,5	33156,3	30896	28635,8	26375,6	24115,3	21855,1	195948	173346
Italy	352058	352334	352610	352885	353161	353437	353713	353989	354265	354541
Cyprus	15198,6	15073,1	14947,6	14822,1	14696,5	14571	14445,5	14319,9	14194,4	14068,9
Latvia	19862,8	19896,6	19930,3	19964	19997,8	20031,5	20065,2	20099	20132,7	20166,4
Lithuania	32281,2	31853,5	31425,8	30998,1	30570,4	30142,7	29714,9	29287,2	28859,5	28431,8
Luxembour	4693,17	4346,94	4000,71	3654,48	3308,25	2962,02	2615,78	2269,55	19233,2	15770,9
Hungary	118124	114291	110458	106625	102792	98958,7	95125,6	91292,6	87459,5	83626,5
Malta	2789,46	3036,68	3283,91	3531,13	3778,35	4025,58	4272,8	4520,03	4767,25	5014,48
Netherlands	369894	372041	374189	376336	378484	380631	382778	384926	387073	389221
Austria	162708	165247	167785	170324	172862	175401	177939	180478	183016	185555
Poland	762596	779755	796914	814073	831232	848392	865551	882710	899869	917029
Portugal	87848,7	82013,2	76177,6	70342,1	64506,6	58671,1	52835,6	47000,1	41164,6	35329
Romania	142989	133351	123713	114076	104438	94800,2	85162,5	75524,8	65887,1	56249,3
Slovenia	8784,23	7909,43	7034,63	6159,82	5285,02	4410,22	3535,42	2660,62	1785,82	911,016
Slovakia	14798,1	8090,58	1383,1	-5324,4	-12032	-18739	-25447	-32154	-38862	21140,1
Finland	58741,8	60270,8	61799,9	63328,9	64858	66387	67916	69445,1	70974,1	72503,1
Sweden	71746,2	69596,4	67446,5	65296,7	63146,8	60997	58847,1	56697,3	54547,4	52397,5

Table A. 37: Liquid dejections of fattening pigs of weight 50 or more kg [tonnes]

GEO/TIME	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Belgium	1984507	1991979	1999451	2006923	2014395	2021867	2029338	2036810,2	2044282,1	2051753,9
Bulgaria	186178,5	196446	206713,5	216981	227248,5	237516	247783,4	258050,92	268318,41	278585,89
Czechia	383874,2	381986,3	380098,5	378210,6	376322,8	374434,9	372547,1	370659,24	368771,39	366883,55
Denmark	2418633	2578910	2739187	2899464	3059742	3220019	3380296	3540573,1	3700850,3	3861127,5
Germany	8170657	8218795	8266933	8315071	8363209	8411347	8459486	8507623,7	8555761,8	8603899,9
Estonia	95345,94	103845,9	112345,9	120845,9	129345,9	137845,9	146345,9	154845,93	163345,93	171845,92
Ireland	484709	517932	551155	584378	617601	650824	68404,7	71727,005	75049,306	78371,607
Greece	185630,9	189064,6	192498,3	195931,9	199365,6	202799,3	206233	209666,65	213100,32	216534
Spain	10113974	10606753	11099532	11592310	12085089	12577868	13070646	13563425	14056204	14548983
France	3655162	3617427	3579692	3541957	3504222	3466487	3428752	3391017,5	3353282,5	3315547,5
Croatia	313731,9	317874,8	322017,6	326160,4	330303,3	334446,1	338588,9	342731,78	346874,61	351017,45
Italy	3348440	3350103	3351767	3353430	3355093	3356756	3358420	3360083	3361746,3	3363409,6
Cyprus	86776,03	87284,94	87793,86	88302,77	88811,69	89320,6	89829,52	90338,431	90847,346	91356,26
Latvia	84287,59	83110,23	81932,88	80755,53	79578,17	78400,82	77223,46	76046,108	74868,754	73691,399
Lithuania	170645,6	168963,3	167280,9	165598,5	163916,2	162233,8	160551,4	158869,05	157186,68	155504,31
Luxembourg	25815,04	26000,78	26186,52	26372,26	26558	26743,74	26929,48	27115,224	27300,964	27486,704
Hungary	922407,9	957899,6	993391,4	1028883	1064375	1099867	1135358	1170850,2	1206341,9	1241833,7
Malta	13066,48	14536,29	16006,11	17475,93	18945,74	20415,56	21885,38	23355,191	24825,008	26294,824
Netherlands	2737913	2710782	2683651	2656520	2629389	2602259	2575128	2547997	2520866,2	2493735,3
Austria	799950	800817,1	801684,1	802551,2	803418,2	804285,3	805152,3	806019,37	806886,42	807753,47
Poland	3577867	3703101	3828336	3953571	4078805	4204040	4329275	4454509,5	4579744,2	4704978,9
Portugal	545446,4	564116,9	582787,4	601457,8	620128,3	638798,8	657469,2	676139,69	69481,015	71348,062
Romania	1314225	1270133	1226040	1181947	1137854	1093761	1049669	1005575,8	961482,95	917390,13
Slovenia	78002,02	75094,34	72186,67	69279	66371,33	63463,66	60555,99	57648,315	54740,643	51832,971
Slovakia	114042,8	101348,7	88654,52	75960,36	63266,2	50572,05	37877,89	25183,735	12489,578	126296,02
Finland	312944,9	319599,7	326254,4	332909,2	339564	346218,7	352873,5	359528,25	366183,01	372837,77
Sweden	353311,2	338447,6	323583,9	308720,2	293856,5	278992,9	264129,2	249265,53	234401,86	219538,19

Table A. 38: Solid dejections of piglets (< 20 kg weight) [tonnes]

GEO/TIME	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Belgium	11108,112	11374,9923	11641,873	11908,7535	12175,634	12442,515	12709,3953	12976,276	13243,156	13510,037
Bulgaria	876,83937	931,54938	986,25939	1040,9694	1095,6794	1150,3894	1205,09943	1259,8094	1314,5195	1369,22946
Czechia	3213,099	3238,9261	3264,7532	3290,58033	3316,4074	3342,2346	3368,06168	3393,8888	3419,7159	3445,54303
Denmark	31247,724	31735,3538	32222,983	32710,6132	33198,243	33685,872	34173,5021	34661,132	35148,761	35636,3911
Germany	50701,723	50670,9259	50640,129	50609,3315	50578,534	50547,737	50516,9401	50486,143	50455,346	50424,5486
Estonia	676,09446	660,34022	644,58598	628,831743	613,0775	597,32326	581,569026	565,81479	550,06055	534,30631
Ireland	2756,4104	2676,9575	2597,5046	2518,05175	2438,5989	2359,146	2279,69312	2200,2402	2120,7874	2041,33449
Greece	1347,1155	1362,0867	1377,0579	1392,02915	1407,0004	1421,9716	1436,94283	1451,9141	1466,8853	1481,8565
Spain	55045,569	54880,0061	54714,443	54548,8804	54383,318	54217,755	54052,1919	53886,629	53721,066	53555,5034
France	41336,651	49352,5672	57368,483	65384,3998	73400,316	81416,232	89432,1485	97448,065	105463,98	113479,897
Croatia	1814,5166	1836,59368	1858,6708	1880,7479	1902,825	1924,9021	1946,97923	1969,0563	1991,1334	2013,21056
Italy	9465,8944	9540,10344	9614,3125	9688,5216	9762,7307	9836,9398	9911,14883	9985,3579	10059,567	10133,7761
Cyprus	862,49093	876,559008	890,62708	904,695161	918,76324	932,83131	946,899391	960,96747	975,03554	989,103621
Latvia	353,43766	339,928454	326,41924	312,910036	299,40083	285,89162	272,382409	258,8732	245,36399	231,854782
Lithuania	683,42808	673,078207	662,72833	6523,7846	6420,2859	6316,7871	6213,28839	6109,7897	6006,2909	5902,79218
Luxembourg	109,55607	108,34233	107,12859	105,914855	104,70112	103,48738	102,273642	101,0599	99,846167	98,6324299
Hungary	4889,2408	5095,53106	5301,8214	5508,11167	5714,402	5920,6923	6126,98258	6333,2729	6539,5632	674,585349
Malta	87,201448	101,935673	116,6699	131,404122	146,13835	160,87257	175,606795	190,34102	205,07524	219,809468
Netherlands	31019,472	29879,0657	28738,659	27598,2524	26457,846	25317,439	24177,0324	23036,626	21896,219	20755,8124
Austria	4411,862	4456,65503	4501,448	4546,24104	4591,034	4635,827	4680,62005	4725,4131	4770,2061	4814,99907
Poland	15673,615	15832,2472	15990,88	16149,512	16308,144	16466,777	16625,4093	16784,042	16942,674	17101,3066
Portugal	5580,3586	5735,41685	5890,4751	6045,53327	6200,5915	6355,6497	6510,7079	666,57661	682,08243	697,588253
Romania	4715,1276	4668,33318	4621,5387	4574,74425	4527,9498	4481,1553	4434,36086	4387,5664	4340,7719	4293,97747
Slovenia	314,04416	297,215796	280,38743	263,559074	246,73071	229,90235	213,073991	196,24563	179,41727	162,588908
Slovakia	1404,9575	1462,74323	1520,529	1578,31473	1636,1005	1693,8862	1751,67199	1809,4577	1867,2435	1925,02924
Finland	2037,3964	2127,95752	2218,5187	2309,07984	2399,641	2490,2022	2580,76332	2671,3245	2761,8856	2852,44681
Sweden	2408,6354	2378,586	2348,5366	2318,48729	2288,4379	2258,3886	2228,33923	2198,2899	2168,2405	2138,19116

Table A. 39: Solid dejections (pigs from 20 to 50 kg weight) [tonnes]

GEO/TIME	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Belgium	13377,658	13454,7381	13531,818	13608,8974	13685,977	13763,057	13840,1363	13917,216	13994,296	14071,3752
Bulgaria	1266,4423	1178,93032	1091,4184	10039,064	9163,9444	8288,8248	7413,70522	6538,5856	5663,466	4788,3464
Czechia	3988,8694	4203,34168	4417,8139	4632,28619	4846,7584	5061,2307	5275,70296	5490,1752	5704,6475	5919,11973
Denmark	43937,168	45008,2258	46079,283	47150,3407	48221,398	49292,455	50363,5129	51434,57	52505,628	53576,6851
Germany	47649,991	45811,3679	43972,745	42134,1223	40295,5	38456,877	36618,2541	34779,631	32941,009	31102,3858
Estonia	616,55606	638,704068	660,85207	683,000075	705,14808	727,29608	749,444085	771,59209	793,74009	815,888096
Ireland	4704,8231	4829,15532	4953,4875	5077,81974	5202,1519	5326,4842	5450,81636	5575,1486	5699,4808	5823,81299
Greece	1884,8906	1916,11945	1947,3483	1978,57711	2009,8059	2041,0348	2072,2636	2103,4924	2134,7213	2165,9501
Spain	83070,465	86946,3906	90822,316	94698,2422	98574,168	102450,09	10632,6019	11020,195	11407,787	117953,797
France	14045,688	3575,6621	-6894,3642	-17364,3905	-27834,417	-38304,44	-48774,469	-59244,496	-69714,522	22796,6681
Croatia	1828,9689	1719,24853	1609,5282	1499,80782	1390,0875	1280,3671	1170,64675	1060,9264	9512,0604	8414,8569
Italy	17090,182	17103,5748	17116,968	17130,3602	17143,753	17157,146	17170,5384	17183,931	17197,324	17210,7165
Cyprus	737,79824	731,704553	725,61086	719,517176	713,42349	707,3298	701,236112	695,14242	689,04874	682,955047
Latvia	964,21477	965,852314	967,48986	969,1274	970,76494	972,40249	974,040029	975,67757	977,31512	978,952658
Lithuania	1567,0479	1546,28546	1525,523	1504,76047	1483,998	1463,2355	1442,473	1421,7105	1400,948	1380,18553
Luxembourg	227,82393	211,016579	194,20923	177,40188	160,59453	143,78718	126,979831	110,17248	933,65132	765,577821
Hungary	5734,1682	5548,09826	5362,0283	5175,95833	4989,8884	4803,8184	4617,74844	4431,6785	4245,6085	4059,53855
Malta	135,41059	147,41176	159,41293	171,414107	183,41528	195,41645	207,417626	219,4188	231,41997	243,421146
Netherlands	17956,007	18060,2516	18164,496	18268,7411	18372,986	18477,231	18581,4752	18685,72	18789,965	18894,2094
Austria	7898,4536	8021,68335	8144,9131	8268,14289	8391,3727	8514,6024	8637,8322	8761,062	8884,2917	9007,5215
Poland	37019,204	37852,1751	38685,147	39518,1181	40351,09	41184,061	42017,0325	42850,004	43682,975	44515,9469
Portugal	4264,499	3981,22152	3697,9441	3414,66662	3131,3892	2848,1117	2564,83428	2281,5568	1998,2794	1715,00193
Romania	6941,206	6473,35544	6005,5048	5537,65422	5069,8036	4601,953	4134,1024	3666,2518	3198,4012	2730,55058
Slovenia	426,41886	383,952773	341,48668	299,020596	256,55451	214,08842	171,622331	129,15624	86,690154	44,2240655
Slovakia	718,35239	392,746511	67,140637	-258,465238	-584,07111	-909,677	-1235,2829	-1560,8887	-1886,4946	1026,21894
Finland	2851,544	2925,76916	2999,9943	3074,2194	3148,4445	3222,6696	3296,89476	3371,1199	3445,345	3519,57011
Sweden	3482,8271	3378,46524	3274,1034	3169,74146	3065,3796	2961,0177	2856,65577	2752,2939	2647,932	2543,57009

Table A. 40: Solid dejections (pigs more than 50 kg weight) [tonnes]

GEO/TIME	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Belgium	77.068,25	77.358,42	77.648,59	77.938,76	78.228,92	78.519,09	78.809,26	79.099,43	79.389,60	79.679,76
Bulgaria	7.230,23	7.628,97	8.027,71	8.426,45	8.825,18	9.223,92	9.622,66	10.021,40	10.420,13	10.818,87
Czechia	14.907,73	14.834,42	14.761,11	14.687,79	14.614,48	14.541,16	14.467,85	14.394,53	14.321,22	14.247,90
Denmark	93.927,48	100.151,84	106.376,20	112.600,56	118.824,91	125.049,27	131.273,63	137.497,98	143.722,34	149.946,70
Germany	317.307,06	319.176,50	321.045,95	322.915,39	324.784,83	326.654,27	328.523,71	330.393,15	332.262,59	334.132,04
Estonia	3.702,76	4.032,85	4.362,95	4.693,05	5.023,14	5.353,24	5.683,34	6.013,43	6.343,53	6.673,63
Ireland	18.823,65	20.113,86	21.404,08	22.694,29	23.984,51	25.274,72	2.656,49	2.785,51	2.914,54	3.043,56
Greece	7.208,97	7.342,31	7.475,66	7.609,01	7.742,35	7.875,70	8.009,05	8.142,39	8.275,74	8.409,09
Spain	392.775,69	411.912,73	431.049,77	450.186,81	469.323,85	488.460,88	507.597,92	526.734,96	545.872,00	565.009,04
France	141.948,06	140.482,62	139.017,18	137.551,74	136.086,31	134.620,87	133.155,43	131.690,00	130.224,56	128.759,12
Croatia	12.183,76	12.344,65	12.505,54	12.666,42	12.827,31	12.988,20	13.149,09	13.309,97	13.470,86	13.631,75
Italy	130.036,51	130.101,10	130.165,70	130.230,29	130.294,88	130.359,48	130.424,07	130.488,66	130.553,26	130.617,85
Cyprus	3.369,94	3.389,71	3.409,47	3.429,23	3.449,00	3.468,76	3.488,52	3.508,29	3.528,05	3.547,82
Latvia	3.273,30	3.227,58	3.181,86	3.136,14	3.090,41	3.044,69	2.998,97	2.953,25	2.907,52	2.861,80
Lithuania	6.627,01	6.561,68	6.496,35	6.431,01	6.365,68	6.300,34	6.235,01	6.169,67	6.104,34	6.039,00
Luxembourg	1.002,53	1.009,74	1.016,95	1.024,17	1.031,38	1.038,59	1.045,81	1.053,02	1.060,23	1.067,44
Hungary	35.821,67	37.199,99	38.578,31	39.956,63	41.334,95	42.713,27	44.091,59	45.469,91	46.848,23	48.226,55
Malta	507,44	564,52	621,60	678,68	735,76	792,84	849,92	907,00	964,08	1.021,16
Netherlands	106.326,71	105.273,08	104.219,46	103.165,84	102.112,21	101.058,59	100.004,96	98.951,34	97.897,72	96.844,09
Austria	31.066,02	31.099,69	31.133,36	31.167,04	31.200,71	31.234,38	31.268,05	31.301,72	31.335,39	31.369,07
Poland	138.946,28	143.809,76	148.673,25	153.536,73	158.400,21	163.263,69	168.127,18	172.990,66	177.854,14	182.717,63
Portugal	21.182,39	21.907,45	22.632,52	23.357,59	24.082,65	24.807,72	25.532,79	26.257,85	2.698,29	2.770,80
Romania	51.037,88	49.325,54	47.613,20	45.900,85	44.188,51	42.476,17	40.763,83	39.051,49	37.339,14	35.626,80
Slovenia	3.029,20	2.916,29	2.803,37	2.690,45	2.577,53	2.464,61	2.351,69	2.238,77	2.125,85	2.012,93
Slovakia	4.428,85	3.935,87	3.442,89	2.949,92	2.456,94	1.963,96	1.470,99	978,01	485,03	4.904,70
Finland	12.153,20	12.411,64	12.670,08	12.928,51	13.186,95	13.445,39	13.703,82	13.962,26	14.220,70	14.479,14
Sweden	13.720,82	13.143,59	12.566,36	11.989,13	11.411,90	10.834,67	10.257,44	9.680,21	9.102,98	8.525,76