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Report on the mapping of biomass value chains for improved sustainable energy use in the Baltic Sea Region countries

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Preface

This report is an output of the implementation of Work Package 2, Group of Activities 2.2 “Mapping of biomass value chains for improved sustainable energy use in the BSR countries” as specified in the latest approved version of the Application Form of the BalticBiomass4Value project.

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The general objective of this study was to map biomass resources and most commonly used bioenergy technologies in Baltic Sea Region countries and to exchange information on best practices and technologies between countries not only on bioenergy uses but also on additional value chains based on biological resources. More specific aims were:

- to asses biomass potential and biomass logistics from different sources (agriculture, food and feed industry, forestry, wood industry, municipal waste and sewage sludge, fishery),
- to asses biomass conversion technologies, including thermo-chemical, physico-chemical and biological conversion used in BSR countries,
- to provide information about technological solutions (including pilot plants under implementation experience) from different BSR countries and comparable/neighbouring regions,
- to identify different technological solutions, technology readiness level and the best bioenergy practices in bioenergy in BSR countries.

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1 List of partners involved in a task implementation

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Project partners:

- Ministry of Energy of the Republic of Lithuania (Lithuania)
- Forest and Land Owners Association of Lithuania (Lithuania)
- Lithuanian Biotechnology Association (Lithuania)
- Vidzeme Planning Region (Latvia)
- Latvia University of Life Sciences and Technologies (Latvia)
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- Estonian University of Life Sciences (Estonia)
- Agency for Renewable Resources (FNR) (Germany)
- 3N Lower Saxony Network for Renewable Resources and Bioeconomy (Germany)
- State Agency for Agriculture, Environment and Rural Areas of Schleswig-Holstein (Germany)
- University of Warmia and Mazury in Olsztyn (Poland)
- Halmstad University (Sweden)
- Norwegian Institute of Bioeconomy Research (Norway)
- Norwegian University of Life Sciences (Norway)
- Municipal enterprise of the city of Pskov “Gorvodokanal” (Russian Federation)

For more information, please visit the project’s website: www.balticbiomass4value.eu

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The detailed data presented on figures are shown in Appendix 1.

3 Assessment of biomass potential and logistics in selected sectors

3.1. General data on the use of areas in individual BSR countries

Analyses were made for 9 Baltic Sea Region (BSR) countries, including 8 which belong to the EU-28: Denmark (DK), Germany (DE), Estonia (EE), Finland (FI), Latvia (LV), Lithuania (LT), Poland (PL), Sweden (SE), and additionally Norway (NO), which does not belong to the EU-28. Based on Eurostat data, it was concluded that these states are considerably varied in terms of the size, structure of land use or population (Fig. 1). The largest of these states, covering nearly 45 million ha, is Sweden, while Denmark is the smallest, having around 4.3 million ha. Generally, five BSR countries (Germany, Finland, Poland, Sweden, Norway) are several-fold larger in size (over 30 million ha) than the other four states (Denmark, Estonia, Latvia, Lithuania). The largest population (nearly 83 million people) lives in Germany. The second most populous country is Poland, with ca 38 million inhabitants, and Sweden comes in the third place, having a population of ca 10 million. The population in the remaining six countries each does not exceed 6 million, and Estonia has the smallest population, of just 1.3 million. The structure of land use in Estonia, Finland, Latvia and Sweden shows the biggest share (over 50%) of woodlands. In Denmark, Germany, Lithuania and Poland, the total area of cropland and grassland make up over 50%. In Norway, this corresponded to 41% while in Sweden and Finland cropland and grassland corresponded to ca 10% of the total area.

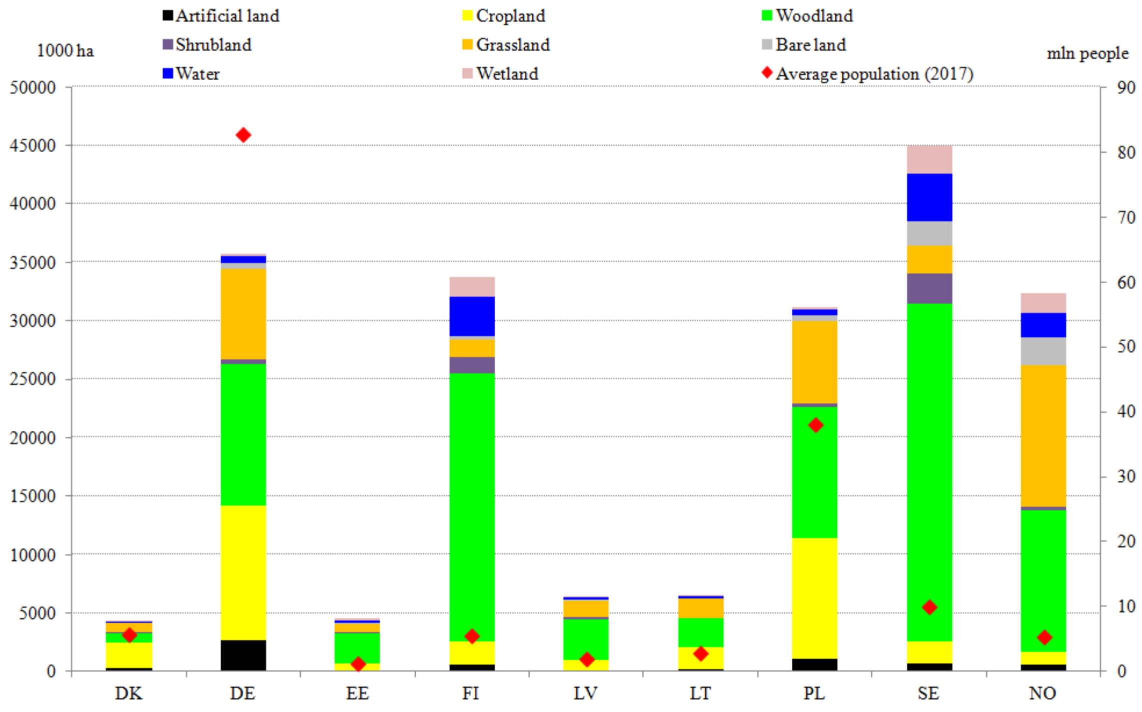

Fig. 1. Characterisation of land use and populations in the Baltic Sea Region countries in 2017
Source: Eurostat, 2019.

3.2. Characteristics of forest biomass area and potential

Description of the forest biomass production area and potential production was based on Eurostat data, including such information as: area of forests, timber supply as well as timber export and import [Eurostat, 2019]. Among the BSR countries, Sweden has the largest area covered with forests, namely 28 million hectares (Fig. 2). In turn, the area of forests available for wood supply in Sweden and Finland was over 19 million ha. The total area of forests in the BSR countries and forests available for wood supply corresponded to 56.9% and 55.5% of respective values for the entire EU-28. It needs to be emphasized that privately owned forests in Denmark, Sweden and Finland represent at least 70% of the total woodland area. In Poland, just 18% are private forests, while the remaining afforested area belongs to the state.

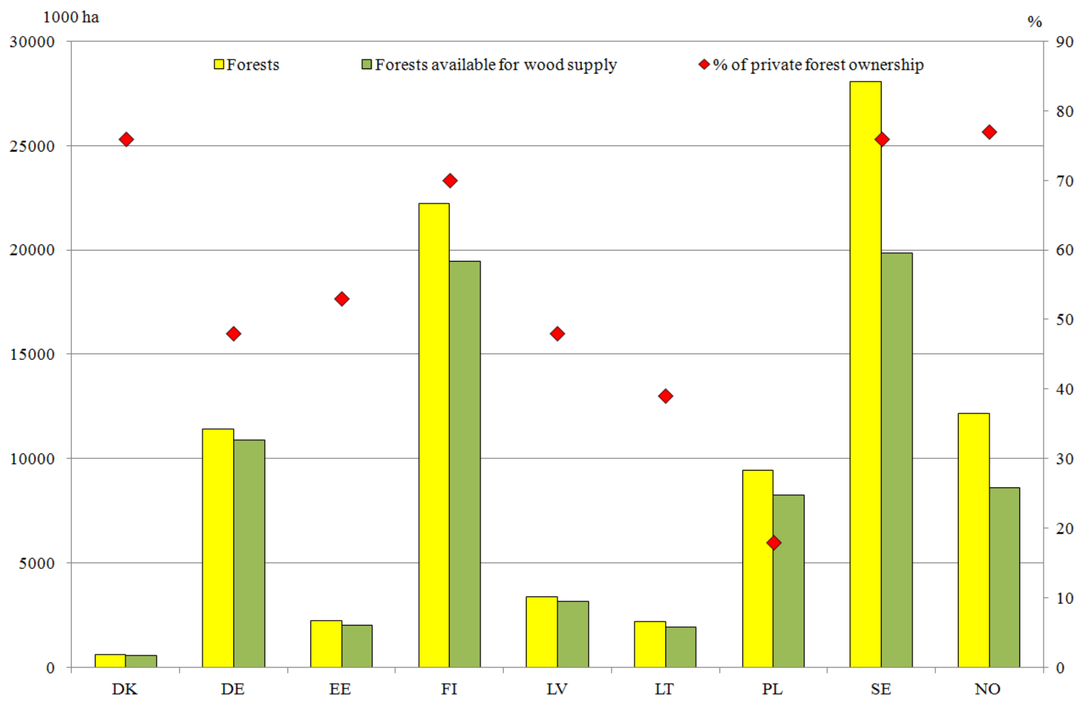

Fig. 2. Forest area, forests available for wood supply and % of private forest ownership in 2017
Source: Eurostat, 2019.

Among the BSR states, most roundwood (72.9 million m^3/year) was harvested in Sweden, followed by Finland, Germany and Poland: 63.3, 53.5 and 45.3 million m^3, respectively (Fig. 3). The amounts of harvested fuel wood were within 2 to nearly 10 million m^3/year, in Lithuania and Denmark, respectively. In total, the roundwood, fuel and industrial wood produced in the BSR states corresponded to 59.6%, 38.4% and 66.0% of such types of wood produced in the EU-28, respectively. It is justifiable to claim that the BSR states are the major source of wood in the EU-28. The highest wood import, i.e. 394,000 m^3 $year^{-1}$, was noted in Germany (Fig. 3). The highest export was found in Latvia, followed by Estonia.

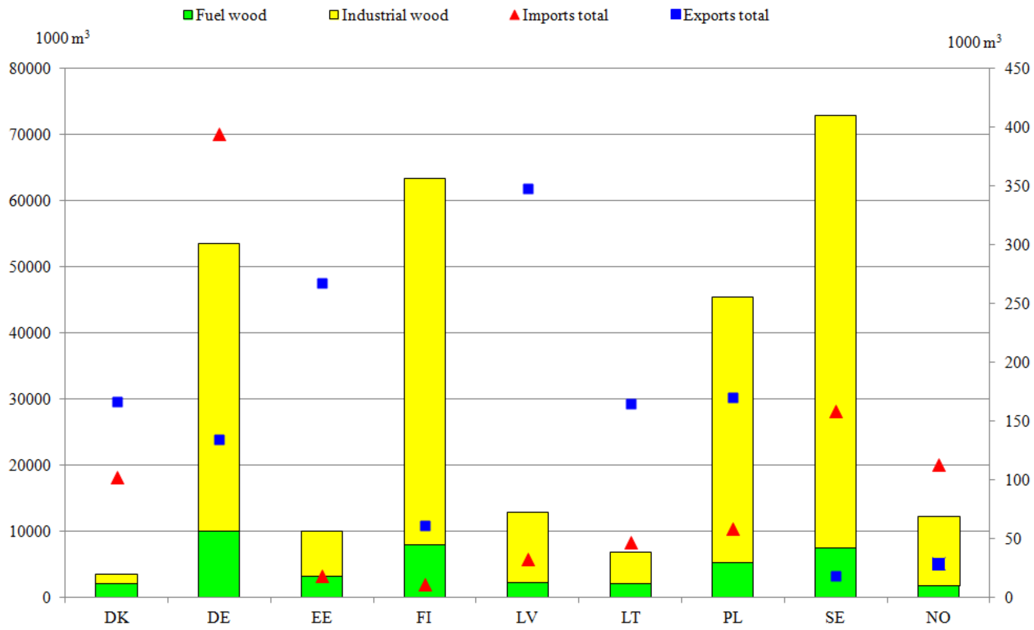

Fig. 3. Fuel and industrial wood removals from forests and fuel wood import and export (including wood for charcoal) in BSR countries in 2017
Source: Eurostat, 2019.

3.3. Characteristics of agricultural areas

The evaluation of the agricultural biomass production area and potential production was based on statistical data by Eurostat [Eurostat, 2019]. In Germany and in Poland, the total area of farmland cropped with the major agricultural plants was over 11 million ha. In the BSR states, cereals covered distinctly the largest area, such as ca 19.6 million ha, which corresponded to 35.3% of croplands in the EU-28. Among the BSR states, the largest area of farmland cropped with cereal was in Poland, 7.6 million ha, followed by Germany, with 6.3 million ha of cereal fields (Fig. 4). The second most widespread group of agricultural plants were plants harvested green from arable land, which were grown on 2.7 million ha in Germany and on around 1.0 million ha in Poland. The third most popular group was composed of industrial crops.

3.4. Yields of the main groups of crops

The structure of yields of the major crops produced in the BSR countries in 2017 was dominated by plants harvested green and cereals (Fig. 5). In Germany, over 115 million Mg plants harvested green were produced, while in Denmark and Poland the corresponding amounts were nearly 33 and 23 million Mg. In Sweden, the quantity of plants harvested green in that year reached over 15 million Mg. However, it should be added that in both Germany and Poland, the structure of plants harvested green from arable land was strongly dominated by green maize, while temporary grasses and grazings were prevalent in Denmark and Sweden (Fig. 6).

The overall yield of cereals in Germany and in Poland was, respectively, over 45 and over 31 million Mg (fig. 5). The total yield of cereals and of oil seed plants was, respectively, nearly 50 and nearly 34 million Mg (Fig. 7). Among cereals, the largest shares were made up by wheat and spelt, over 24 and over 11 million Mg ,respectively. These two species dominated in the other BSR states. Finland was an exception, with the prevalence of barley and oats.

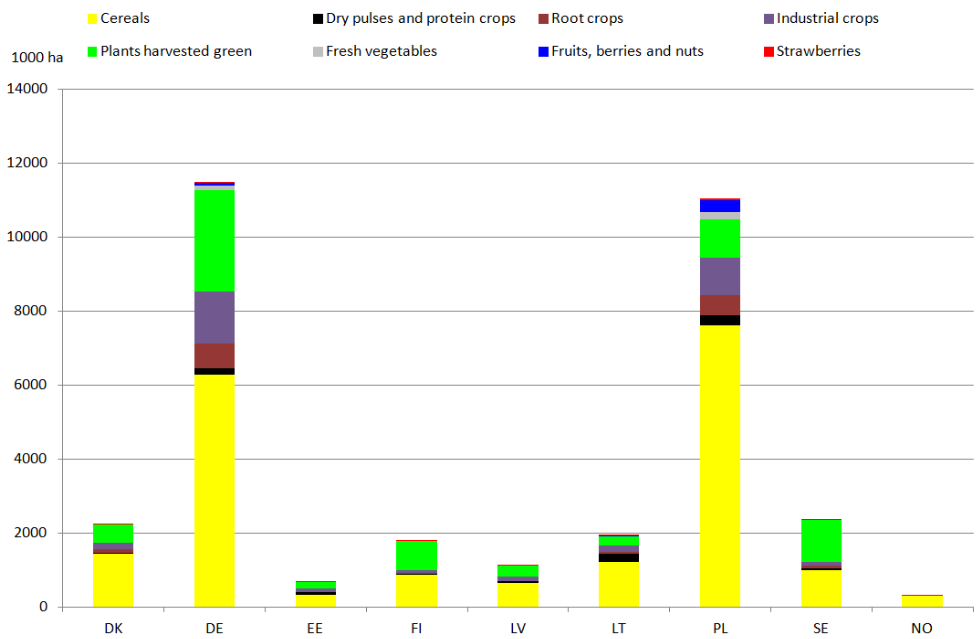

Fig. 4. Area cultivation of major agricultural crops in the BSR countries in 2017 (1000 ha)
Source: Eurostat, 2019.

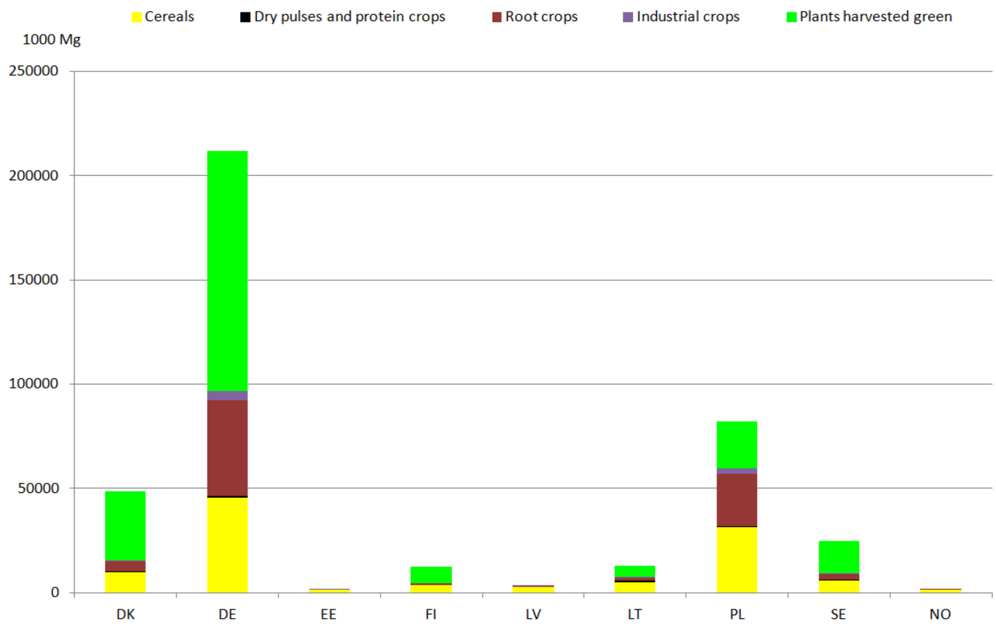

Fig. 5. Major crop production in the BSR countries in 2017 (1000 Mg)
Source: Eurostat, 2019.

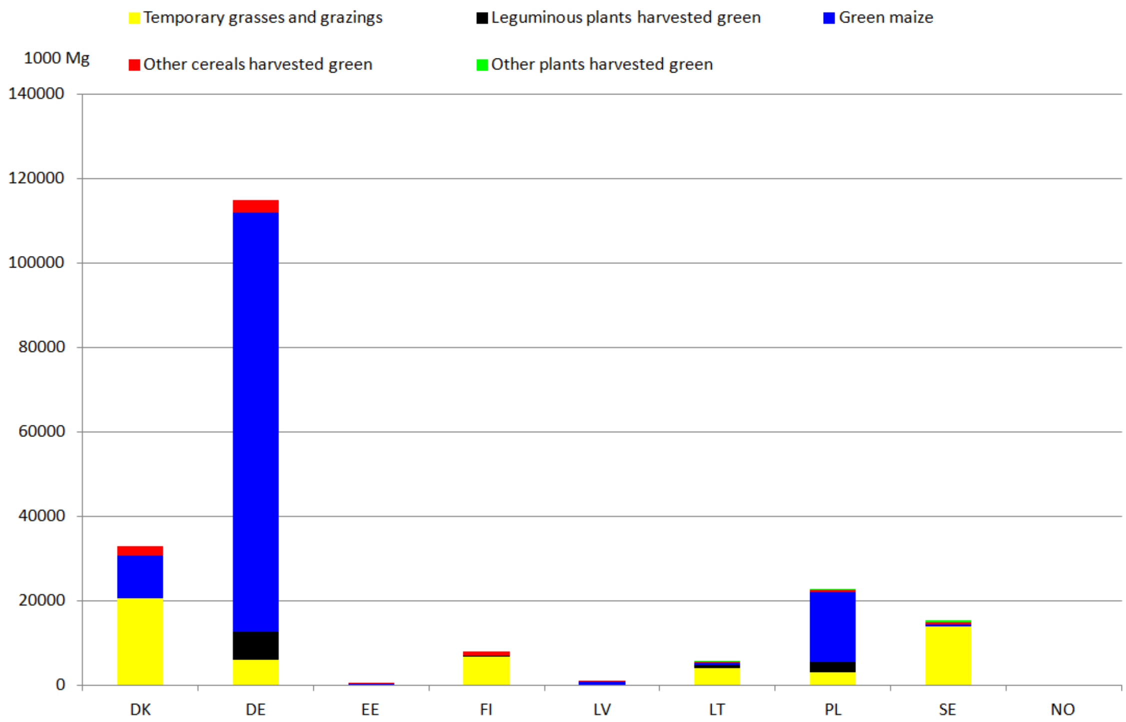

Fig. 6. Plants harvested green from arable land in the BSR countries in 2017 (1000 Mg) Source: Eurostat, 2019.

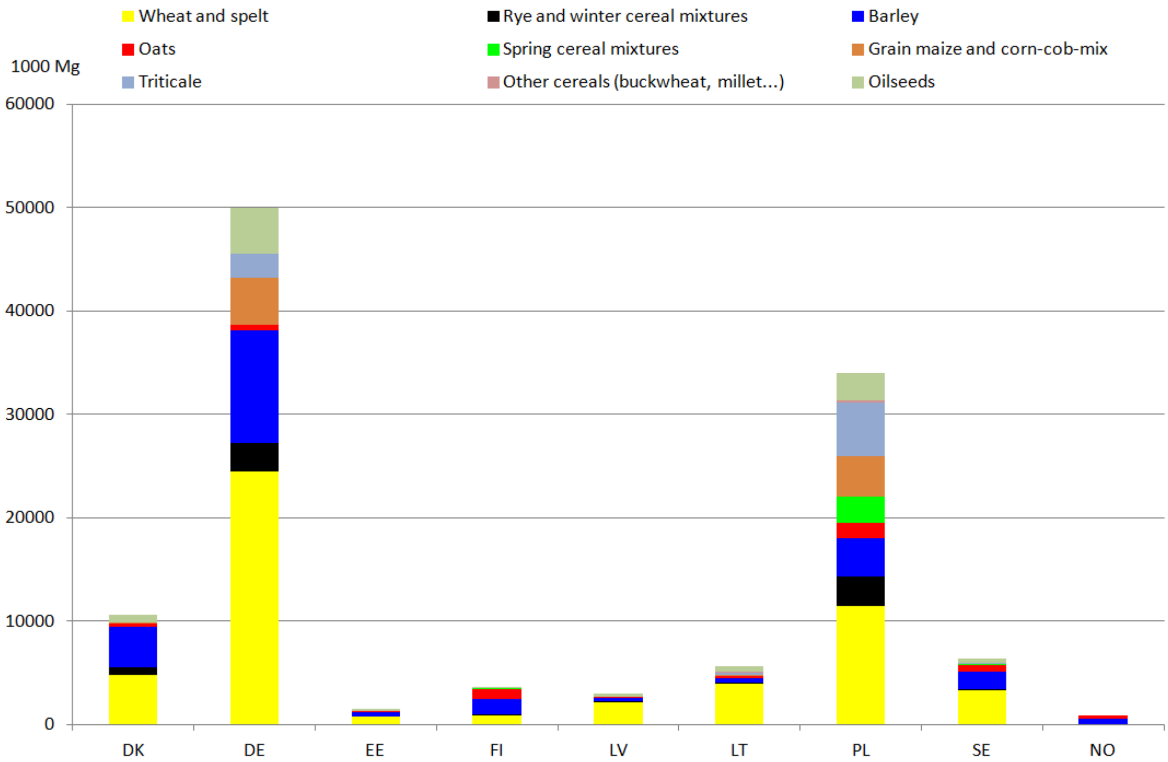

Fig. 7. Cereals and oil seeds for the production of seed in the BSR countries in 2017 (1000 Mg) Source: Eurostat, 2019.

As for root crops, sugar beet cultivation was prevalent in Denmark, Germany, Latvia, Poland and Sweden, whereas potato cultivation was more popular in the other countries (Fig. 8). Obviously, with its cropped area, Germany had the largest total yield of these crops, followed by Poland, Denmark and Sweden, nearly 46, 25, 5 and 3 million Mg, respectively.

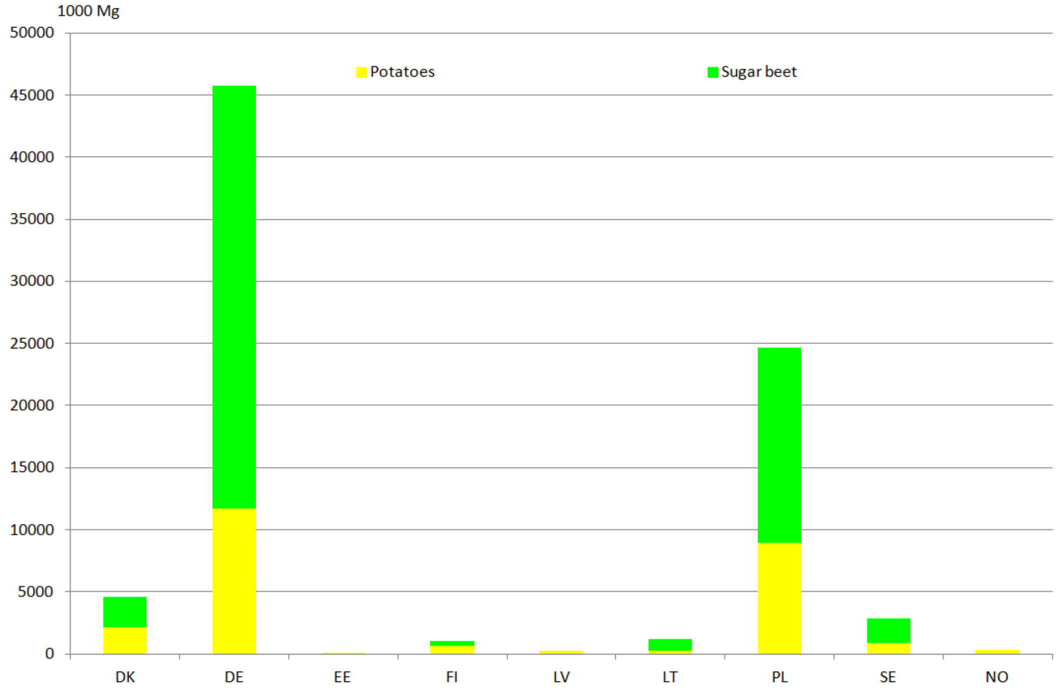

Fig. 8. Root crops production in BSR countries in 2017 (1000 Mg)
Source: Eurostat, 2019.

The largest production of vegetables and fruit was in Poland, with over 5.5 million Mg of vegetables and 3.5 million Mg of fruit produced (Fig. 9, 10). In Germany, the production of vegetables and fruit reached almost 4 and 0.8 million Mg, respectively. The other countries produced from 0.03 to 0.3 million Mg of vegetables, and from 0.02 to 0.08 million Mg of fruit. The structure of fruit production was distinctly dominated by apples, while the production of vegetables had a more complex structure.

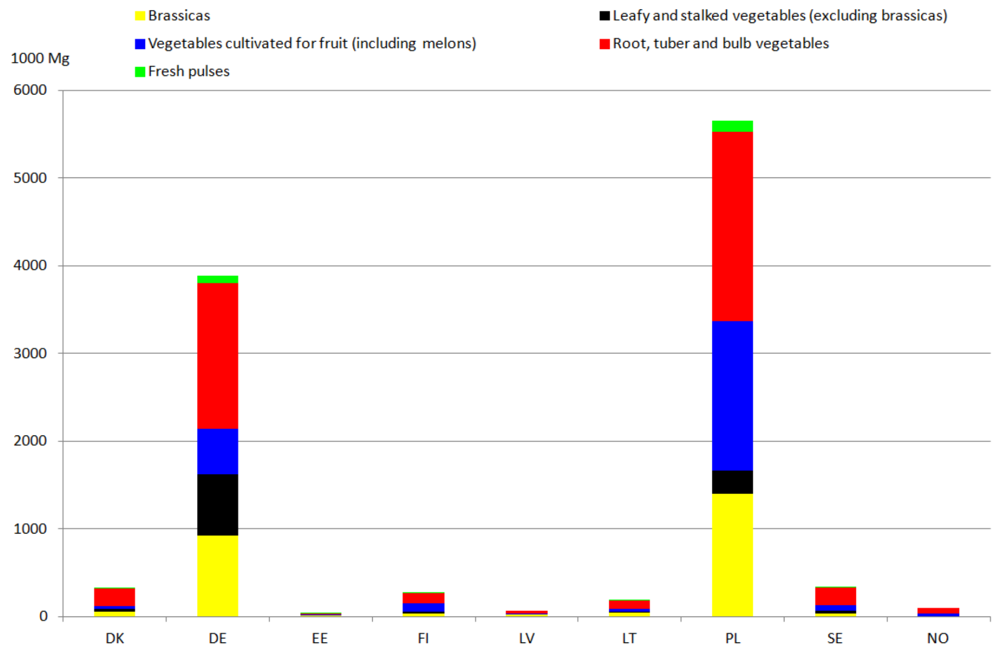

Fig. 9. Vegetable production in the BSR countries in 2017 (1000 Mg)
Source: Eurostat, 2019.

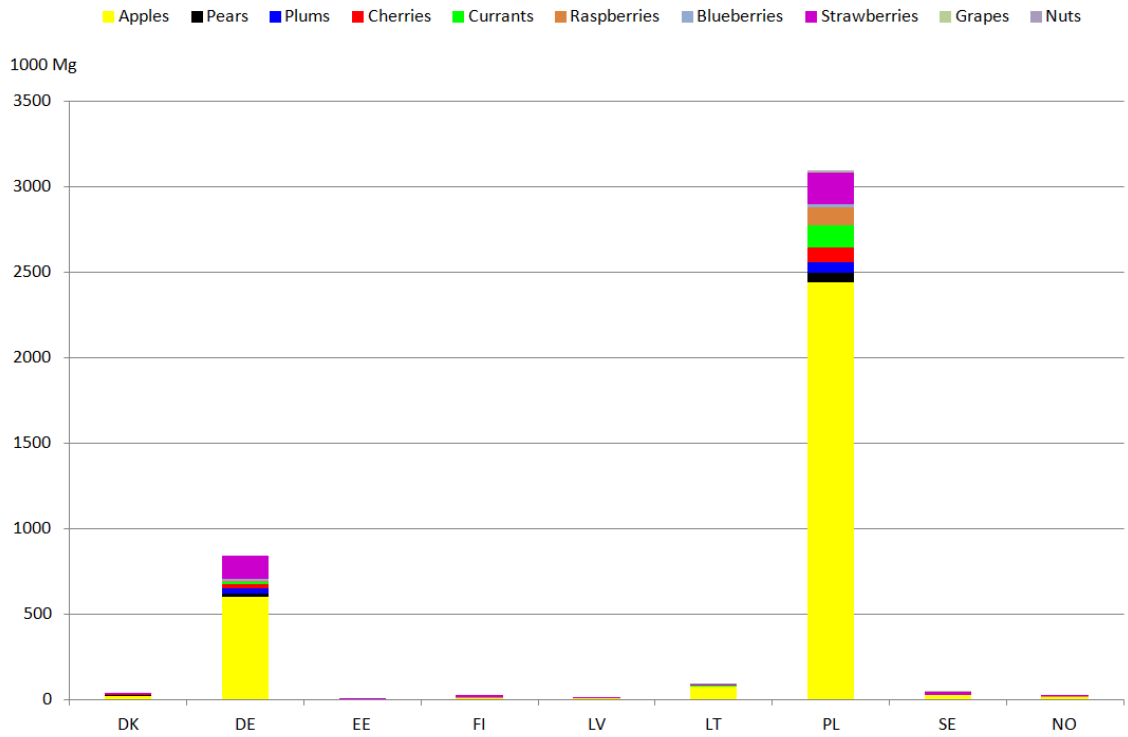

Fig. 10. Fruit production in the BSR countries in 2017 (1000 Mg)
Source: Eurostat, 2019.

3.4.1. Theoretical and technical potential of cereal and rapeseed straw

The analyses included the area cropped with the following plant species as well as yields of grain and seeds: wheat and spelt, rye and winter cereal mixtures, barley, oats, spring cereal mixtures, grain maize and corn-cob-mix, triticale, other cereals and oilseeds - mainly rape seed. The literature data demonstrate that the straw to grain ratio may vary highly, depending on the species, cultivar, cultivation technology, climate and soil conditions, applied agronomic practice, harvest technology, etc., and is comprised within the range of 0.5 to 1.5 [Pudełko et al., 2013; Scarlet et al., 2010]. Thus, in order to determine the theoretical yield of straw in the BSR countries, we assumed one averaged value of the straw to grain ratio, at 0.9. Next, the theoretical straw potential was calculated from the product of cropped area, yield of grain of particular species and the straw to grain ratio (0.9)

As a result of the above, the theoretical potential of cereal and oil plant straw was highly varied in the BSR states. Theoretically, most straw from cultivation of cereals and oilseed plants was in Germany and in Poland, approximately 45 and 30 million Mg/year, respectively (Fig. 11). In the remaining BSR countries, this amount was dozen-fold or even several dozen-fold lower, which was a direct consequence of the factors mentioned above. Considering the share of straw from particular plant species, it was found that wheat straw dominated in seven of the BSR countries, contributing from 34% to 71% of total straw yield, respectively in Poland and Latvia. In the other BSR states the potential share of wheat straw was also quite large. However, in Germany and Poland straw from triticale, maize and oil seeds made up a considerable share.

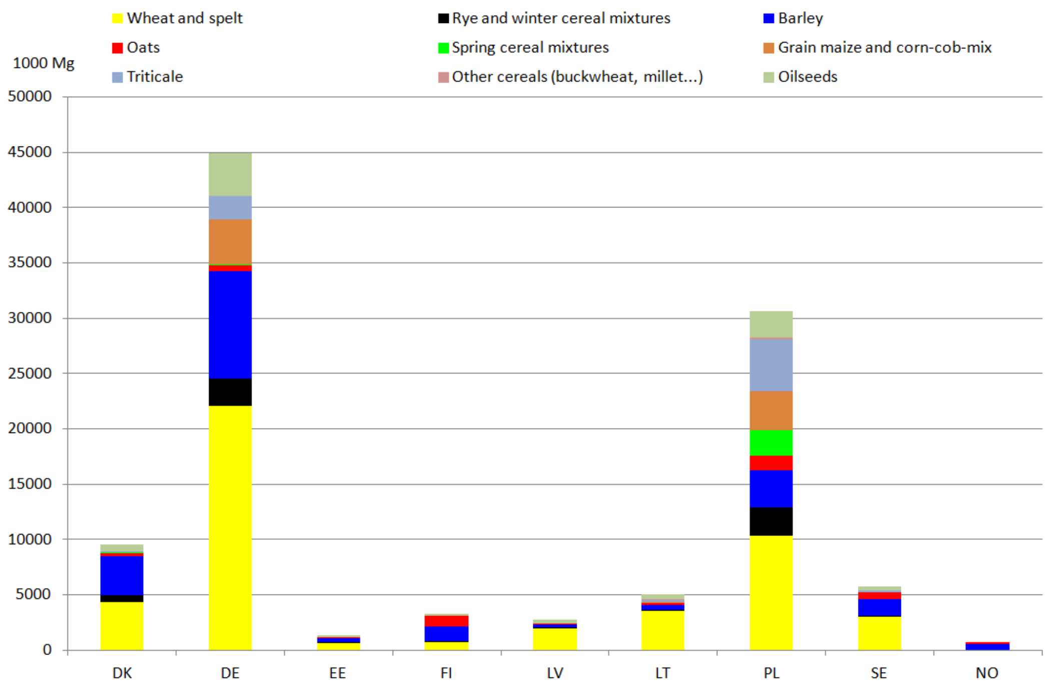

Fig. 11. Theoretical straw potential from cereals and oil seeds production in the BSR countries in 2017 (1000 Mg/year)
Source: own calculations.

When harvesting cereal or oil seed plants, it is impossible to collect all straw, for example because of land relief or the set cutting height of a combine. There are also straw losses during harvest and transport. Moreover, studies run in facilities equipped with straw-fired boilers have shown that when straw potential is calculated on the basis of the straw to grain ratio the resulting potentially available quantities of straw are overrated. Therefore, in our analysis we took into consideration technical, practical possibilities of obtaining straw from production of cereals and oil seed plants, which were assessed to be at a level of 60% (the 0.6 coefficient), to determine the technical potential amount of straw that could be used for energy purposes. This meant that the average technical yield of straw collected in the form of bales from a field corresponded to 60% of the mass of collected grain [Gradziuk and Stolarski, 2009]. Moreover, straw is used as raw material in animal production (both as feed and litter), and in mushroom production (as litter). It should also be ploughed in and be returned to the soil in order to maintain its balance of organic matter, which explains why not all straw is available for energy production. Hence, in our analysis it was assumed that 25% of annual yield of straw can be dedicated to energy purposes so as avoid detrimental effects on animal production, to maintain the soil organic matter balance and to supply straw for other alternative uses.

In view of the above, the technical potential of straw available for energy purposes was calculated from the product of the area cropped with the analysed plants, grain yields from individual plant species, the straw to grain ratio (0.6) and the quantity of straw dedicated to energy purposes.

Thus, having considered the above factors, the technical potential of straw was six-fold lower than the theoretical potential. It was comprised within a very broad range, from around 0.125 to nearly 7.5 million Mg/year, respectively in Norway and in Germany (Fig. 12). In Germany, nearly half of straw was wheat straw. The technical potential of straw in Poland was high and equalled ca 5.1 million Mg/year, and in Denmark it reached about 1.6 million Mg/year, and the share of wheat straw was 34 and 45%, respectively. In the other BSR states, the technical potential of all types of straw was less than 1 million Mg/year. It needs to be added that the technical potential of straw in all BSR countries analysed composed ca 34% of the potential in the whole EU-28.

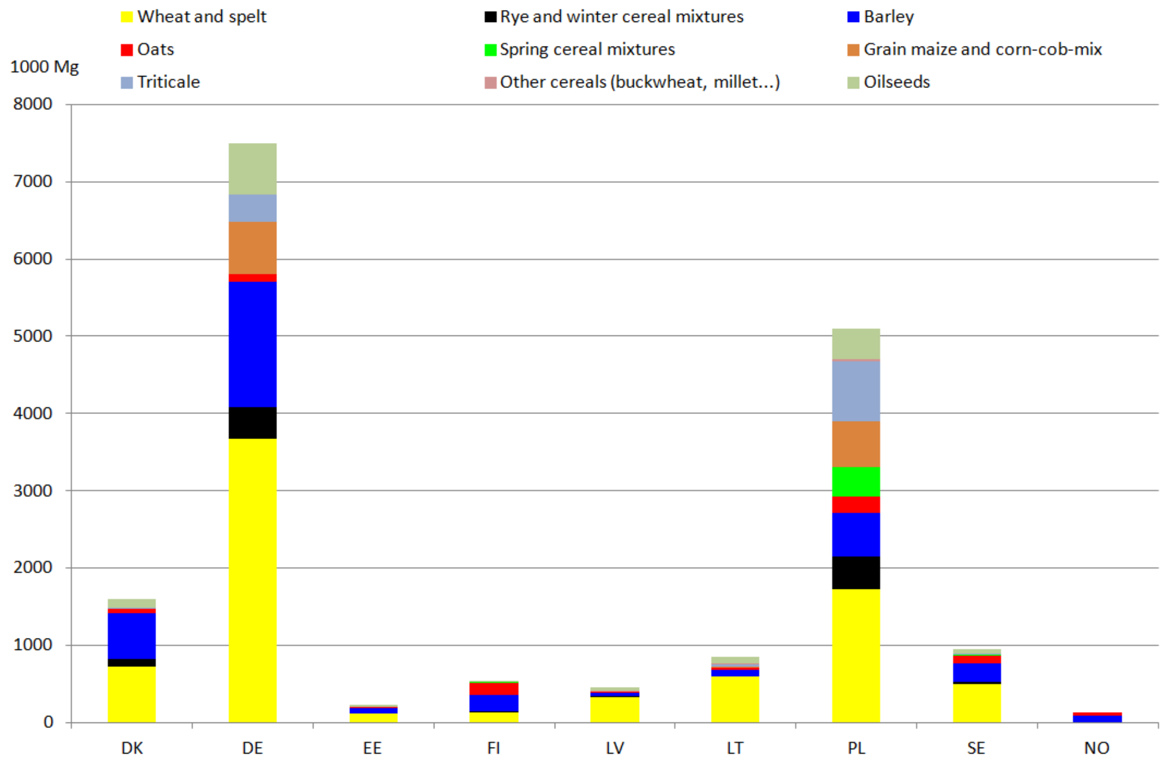

Fig. 12. Technical straw potential for energy purposes from cereals and oil seeds in the BSR countries in 2017 (1000 Mg/year)
Source: own calculations.

3.4.2. Biomass potential from dedicated perennial crops plantations

Dedicated perennial energy crops is another source of agricultural biomass. This group comprises Short Rotation Coppice (SRC), grasses and herbaceous crops [Stolarski et. al., 2018]. The biomass yield of dedicated perennial energy crops depends on several factors, such as: selection of an appropriate species and variety, soil conditions, type and level of plant fertilising rates, climate conditions, agritechnical treatments, planting density, frequency of plant harvest, and harvest technology [Stolarski et al., 2019b, 2019c; Vanbeveren et al., 2017; Stolarski et al., 2015; Aronsson et al., 2014; Larsen et al., 2014; Sevel et al., 2014; Serapiglia et al., 2013]. The above literature references suggest that the potential of SRC yields can vary widely, and is in a range from a few to a few dozens of Mg/ha/year DM (dry matter). However, technical yields obtained from commercial plantations are always lower, and therefore in our analyses we assumed that an average SCR yield was 7 Mg/ha/year DM [Stolarski et al., 2019a; Mola-Yudego et al., 2015]. Yields of grasses can be highly varied as well, depending on the aforementioned factors [Stolarski et al., 2018; Rancane et al., 2017; Iqbal et al., 2015; Monti et al., 2015; Pocienė et al., 2013, 2016]. Because of the geographical and climate conditions typical of the BSR countries (mostly in northern Europe), average yields of grasses were assumed to be on the same level as those of SRC, i.e. 7 Mg/ha/year DM. Thus, the technical potential of lignocellulose biomass from dedicated perennial energy crops was calculated from the product of the area cropped with dedicated perennial energy crops [Bioenergy Europe, 2018] and the average biomass yield of SRC and grasses.

Dedicated perennial crops (SRC, grasses and herbaceous crops) are a promising form of bioenergy owing to their low demand for inputs and low emission of greenhouse gases caused by their production [Krzyżaniak et al., 2018, 2019]. In 2017, plantations of dedicated perennial energy crops appeared in seven BSR countries (Denmark, Germany, Finland, Latvia, Lithuania, Poland, Sweden) while two countries (Estonia, Norway) did not have such plantations (Fig. 13) [Bioenergy Europe, 2019e]. The total area of these plantations in the BSR states was nearly 65 thousand ha, which was on average 55.1% of the total area of such plantations in the EU-28 states. However, this percentage rose to 75.1% in the case of SRC and equalled 31.1% for grasses. Having considered the average yields of biomass, it was concluded that the highest potential in this regard was in Poland, where it totalled about 125,000 Mg/year DM (Fig. 14). Of this amount, 94% of lignocellulose biomass would originate from SRC plantations, and the remaining 6% would come from plantations of grasses. The same percent breakdown was determined in Sweden, although the total potential was lower than in Poland. In turn, the total potential of biomass from dedicated energy crops in Germany was 111,000 Mg/year DM, and around 58% of this amount originated from grasses. In the remaining BSR countries, the potential quantities of biomass from dedicated perennial energy crops were lower, and SRC biomass was prevalent in Denmark, Latvia and Lithuania, while in Finland the biomass from grasses dominated.

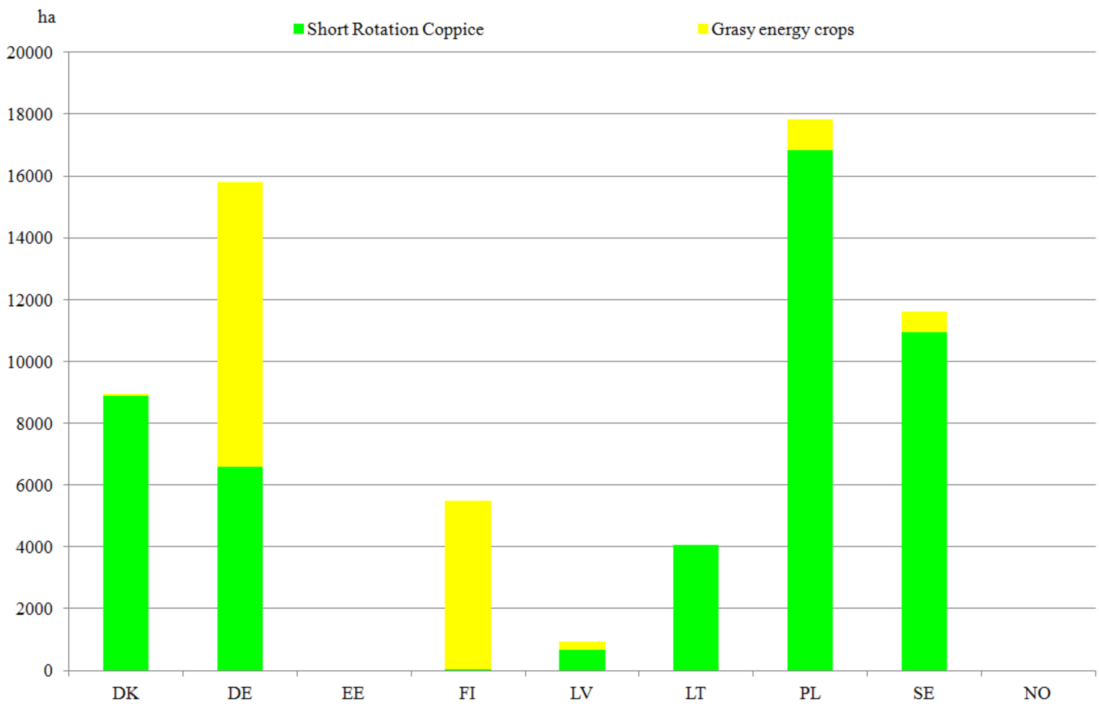

Fig. 13. Area cropped with perennial energy crops in the BSR countries in 2017 (ha)
Source: Bioenergy Europe, 2019e.

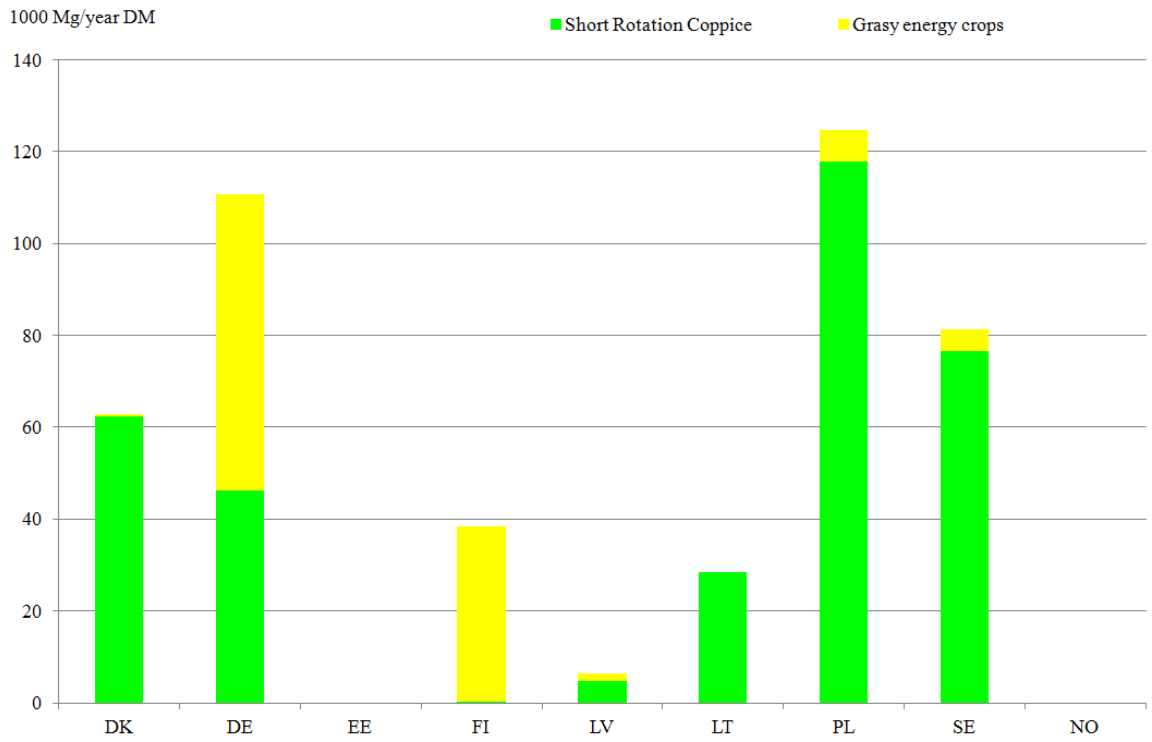

Fig. 14. Theoretical potential of biomass from perennial energy crops in the BSR countries in 2017 (1000 Mg/year)
Source: own calculations.

3.5. Population of main livestock and production potential of manure and slurry

The highest number of livestock was evidently present in Germany and in Poland, over 215 million heads (Fig. 15). The animal rearing structure shows that chickens were most numerous farm animals in all BSR countries. Moreover, considerable numbers of pigs and cattle are reared in Germany, Denmark and Poland, while sheep are common in Norway.

The potential of manure and slurry production was calculated as the product of the number of livestock in the BSR countries and the manure and slurry production rates for particular livestock types. For our analysis, it was assumed that the average manure production rates were: 14.80, 1.50, 1.20, 5.00, 1.00, 0.035, 0.060, 0.060, 0.040 Mg per animal per year, for the respective animals: cattle, pigs, sheep, horses, goats, chickens, turkeys, ducks, and geese including guinea fowls [NRIAP, 2012]. The rates for slurry production were on average: 23.00 and 1.90 m^3 per animal per year for cattle and pigs, respectively. In Europe, pigs are mostly kept in a litterless system with slurry production, while cattle are maintained in a system with manure production. For the sake of our analysis, it was assumed that 84% of pigs are farmed in a system that generates slurry, while for cattle the respective percentage is 41% [AMEC, 2014]. The remaining percentage in both cases falls to manure production. The contribution of rearing systems for other farm animals with production of slurry in Europe is very small, which is why it was assumed that 100% of poultry, horses, sheep and goats generate manure.

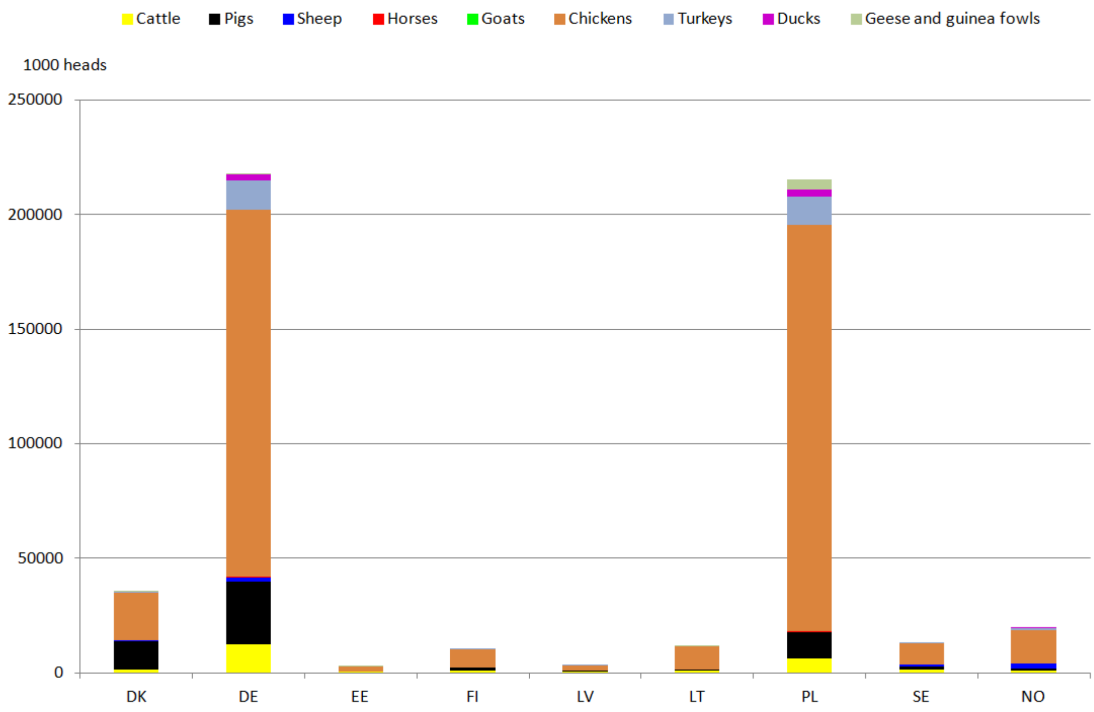

Fig. 15. Animals in the BSR countries in 2017 (1000 heads)
Source: FAO, 2019.

The potential of manure production depended and resulted directly from the number of livestock in particular BSR countries. Consequently, the said potential was highly varied. Theoretically, the highest amounts of manure from animal rearing were evidently in Germany and in Poland: ca 124.7 and 65.0 million Mg/year, respectively (Fig. 16). In the other BSR countries, this potential was a few or even a few dozen-fold lower, which was a direct consequence of the number of livestock, and was within the range of 2.4 to 17.6 million Mg/year in Estonia and Denmark, respectively. Considering the contribution of particular animal species to the production of manure, it was determined that cattle manure prevailed in all BSR states, from 66% in Norway to 91% in Latvia. In the total volume of manure generated in all BSR states, cattle manure corresponded to 84%. Chicken manure (6%) and swine manure (5%) contributed much less to the total amount. The potential of manure production in the BSR states made up about 25% of the potential manure production by all EU-28 states.

Likewise, the potential of slurry production depended on and resulted directly from the number of livestock. Consequently, it was also highly varied, although only cattle and swine slurry were included in the analysis. Again, most slurry was generated in Germany and in Poland, about 159.8 and 76.0 million m^3/year, respectively (Fig. 17). In the other BSR states, this potential was by a few to a few dozen-fold lower, and ranged within ca 2.8 to 34.2 million m^3/year in Estonia and in Denmark, respectively. Considering the contribution of particular animal species to the production of slurry, it was found that in eight BSR countries most slurry originated from cattle, between 72% and 88% of the total volume in Germany and Latvia, respectively. Swine slurry dominated in Denmark (57%), while in the other BSR countries this type of slurry was within 12-28% of the total slurry produced. In the whole volume of slurry generated in the BSR states, cattle slurry made up 72%, while pig slurry composed the remaining 28%. The potential of slurry production in the BSR countries corresponded to 30% of the said potential in the whole EU-28 region.

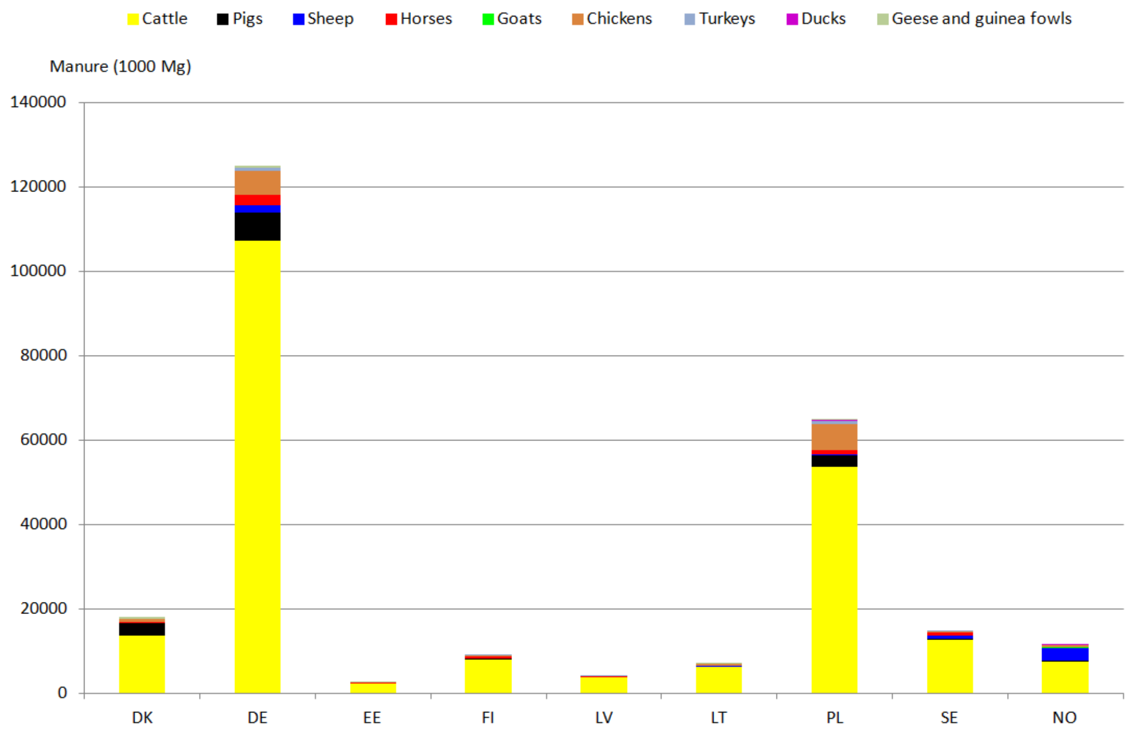

Fig. 16. Theoretical manure potential in the BSR countries in 2017 (1000 Mg/year)
Source: own calculations

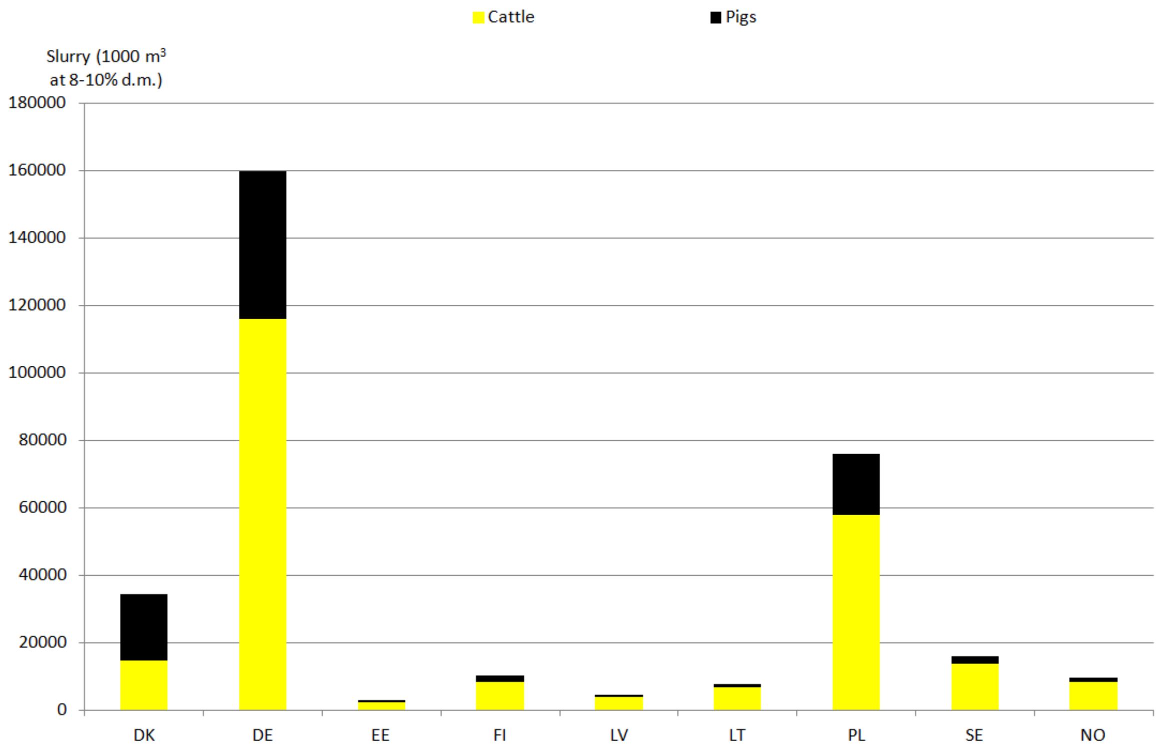

Fig. 17. Theoretical slurry potential in the BSR countries in 2017 (1000 m^3/year at 8-10% DM)
Source: own calculations

3.6. Potential characteristics of municipal waste and sewage sludge

The potential of municipal waste and sewage sludge was determined on the basis of Eurostat data [Eurostat, 2019].

Quantities of generated municipal waste were directly dependent on the population in each BSR state. Hence, most municipal waste was in Germany: 51.79 million Mg/year (Fig. 18). The second position was occupied by Poland, with nearly 12 million Mg/year of municipal waste. The least municipal waste was generated in Latvia and Estonia. The potential of municipal waste in the BSR states represented around 33% of the said potential of the entire EU-28. In the BSR states, most municipal waste was used as recycling material, 41% on 19% in Latvia to 49% in Germany. Municipal waste used for energy recovery composed a 34% share on average, from 3% in Latvia to 59% in Finland. The subsequently most common ways to utilise municipal waste were: recycling - composting and digestion (16%), disposal - landfill and other (8%) and disposal – incineration (1%).

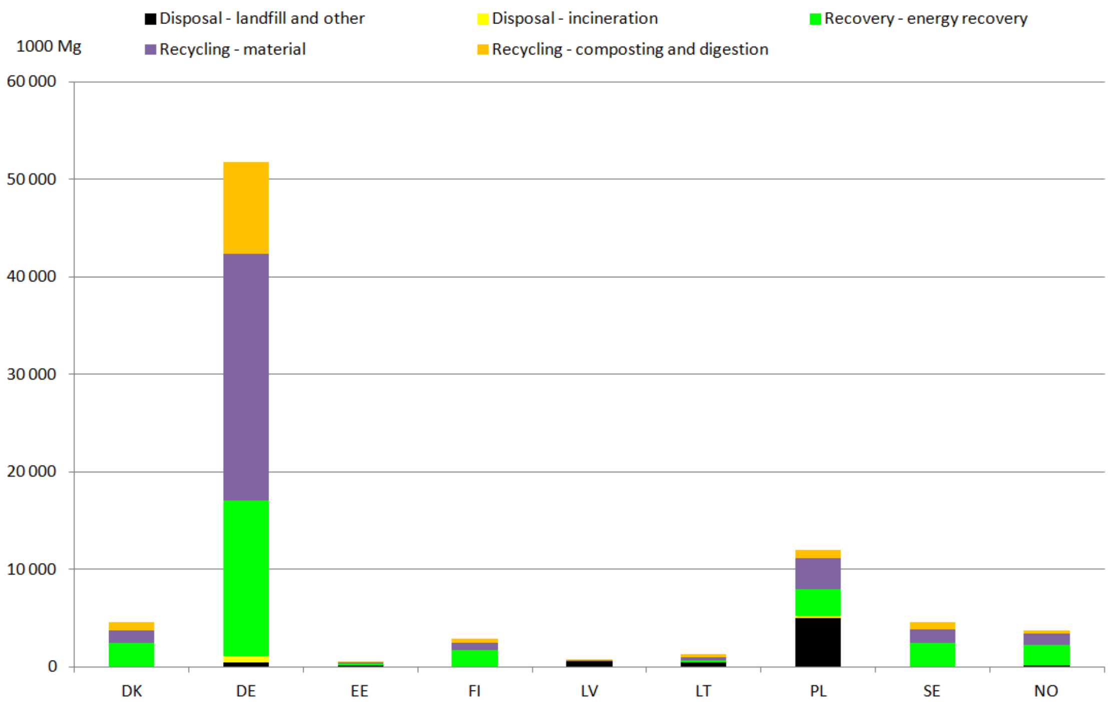

Fig. 18. Municipal waste by waste operation in the BSR countries in 2017 (1000 Mg/year) Source: Eurostat, 2019.

Likewise, the amounts of generated sewage sludge were strictly connected with the number of population in each BSR state. Hence, most sewage sludge was in Germany: 1.80 million Mg/year DM (Fig. 19), followed by Poland: 0.95 m Mg/year DM. Data regarding sewage sludge management are incomplete, but in Germany most of it was submitted to incineration (64%), in Latvia and Poland other sludge disposal was most common (ok. 50%), and in Norway agricultural use prevailed (62%).

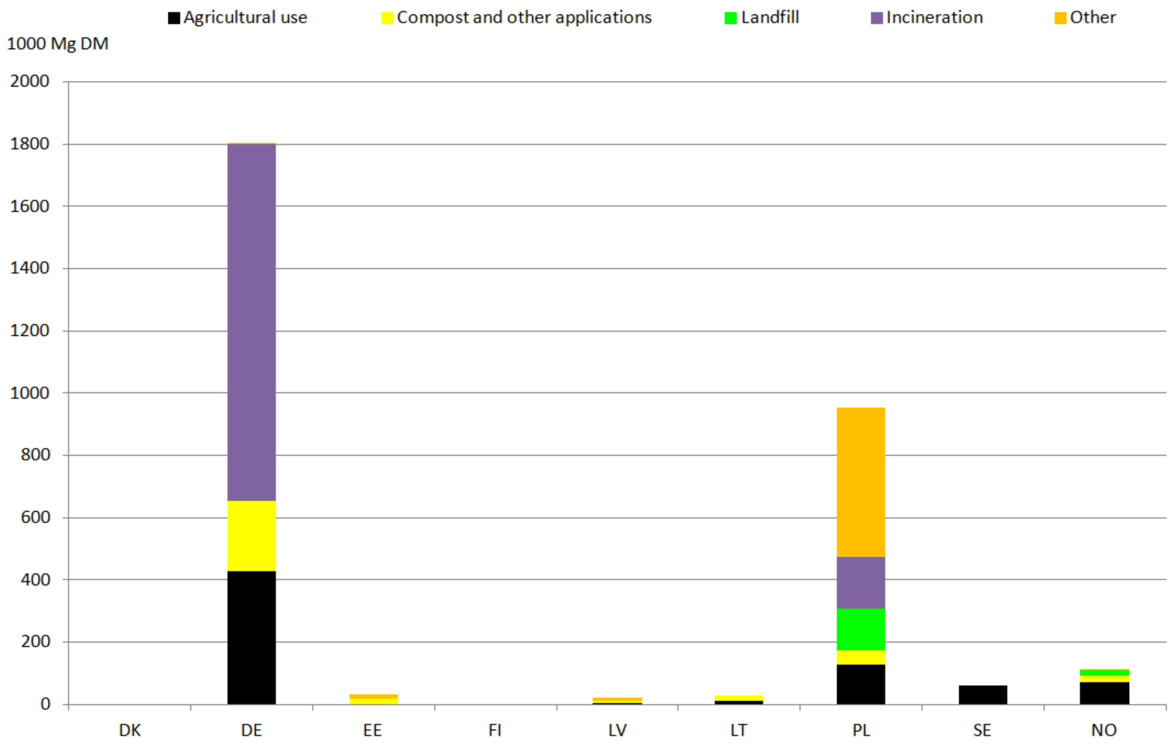

Fig. 19. Sludge disposal from wastewater treatment plants in the BSR countries in 2015 (1000 Mg/year DM)
Source: Eurostat, 2019.

3.7. Fishery characteristics

The evident leader among the BSR countries in fish catches and production from aquaculture excluding hatcheries and nurseries is Norway (Fig. 20). The total fish catch in this country was over 3.5 million Mg. The second place was occupied by Denmark, with the total fish catch of 0.94 million Mg. In the other countries this value ranged from 0.08 in Lithuania to 0.27 million Mg in Germany.

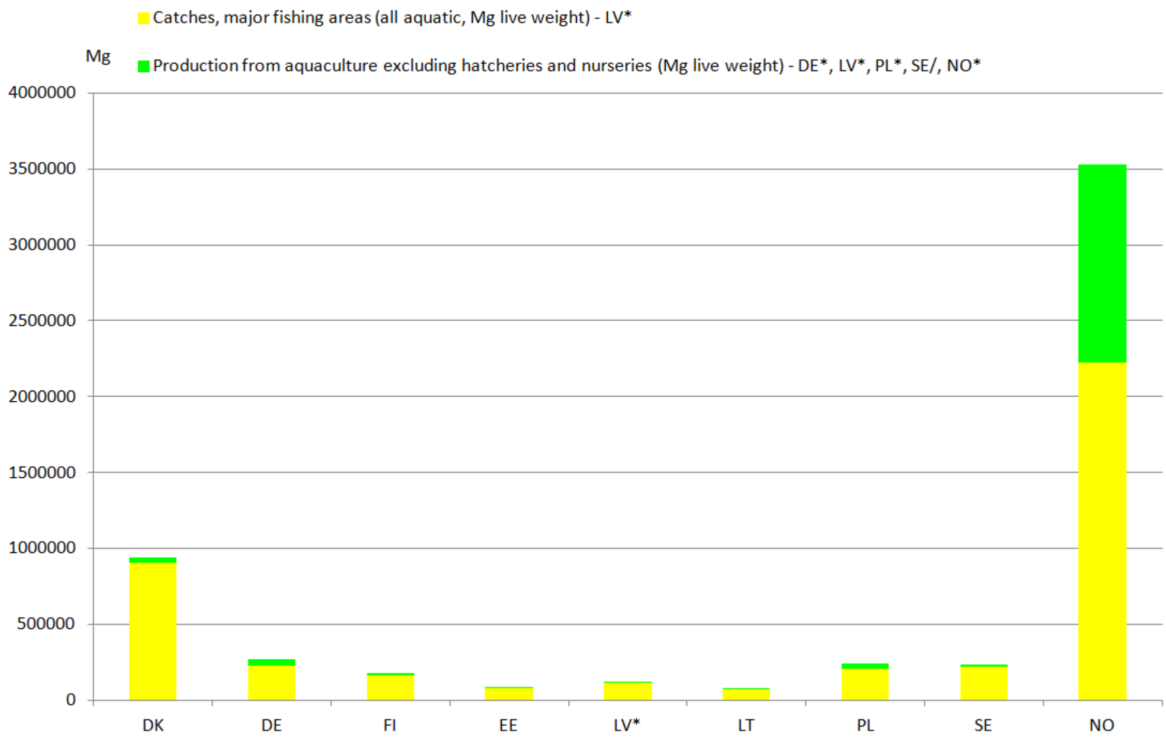

Fig. 20. Catches - major fishing areas and production from aquaculture excluding hatcheries and nurseries in 2017 (Mg live weight) *data for 2016 (Mg).
Source: Eurostat, 2019.

Fig. 21 presents estimated theoretical amount of processing waste and potential of biogas generation from aquatic biomass resources. Data collected on amount of processing waste (excluding Norway) show that Germany and Denmark produced the highest amount of waste from aquatic biomass resources, 59223 and 43707 tonnes, respectively. This resulted with a simultaneous high potential of biogas production, 3638 ktoe/year for Germany and 2685 ktoe/year for Denmark. Estonia had the least waste and the lowest biogas potential among all BSR countries.

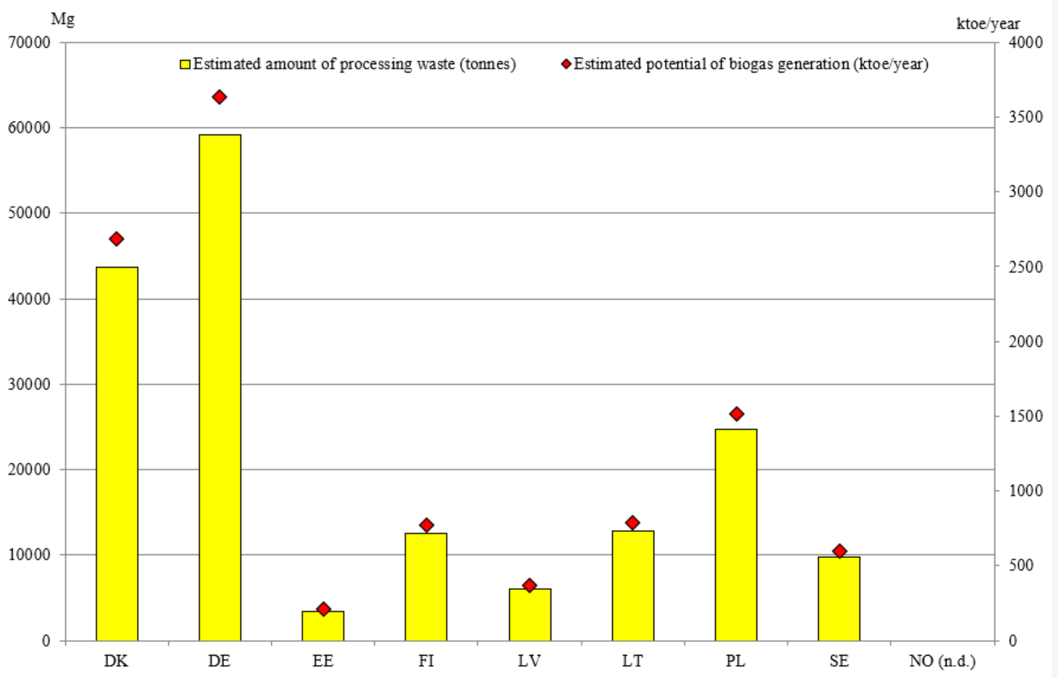

Fig. 21. Estimated amount of processing waste (tonnes) and estimated potential of biogas generation (ktoe/year) from aquatic biomass resources (imported fish & seafood, capture fisheries and aquaculture), Source: Calculations based on:
https://datam.jrc.ec.europa.eu/datam/public/pages/previousFilters.xhtml?dataset=34178536-7fd1-4d5e-b0d4-116be8e4b124
https://datam.jrc.ec.europa.eu/datam/mashup/BIOMASS_FLOWS/index.html

Information on algae situation in the BSR countries are presented in Appendix 2.

3.8. Biomass potential from different sources in the BSR countries based on results from BioBoost project

Figure 22 illustrates the technical potential of biomass from different sources in the BSR countries, based on results of the project BioBoost (http://bioboost.eu). These analyses included the technical potential for: straw, residuals of pruning, livestock residues, hay from permanent grassland, forestry residues, green urban areas, perennial crops, roadside vegetation, biodegradable municipal waste, bio-waste of food industry. The highest total biomass potential was in Germany, over 55 million Mg. In Poland, the total biomass potential was estimated to be at 32 million Mg, and in Sweden it was nearly 19 million Mg. In the other BSR countries, the biomass potential was assessed to range from 2 to nearly 7 million Mg, in Estonia and Denmark, respectively. The structure of biomass sources is distinctly dominated by straw and forestry residues, followed by perennial crops and biodegradable municipal waste.

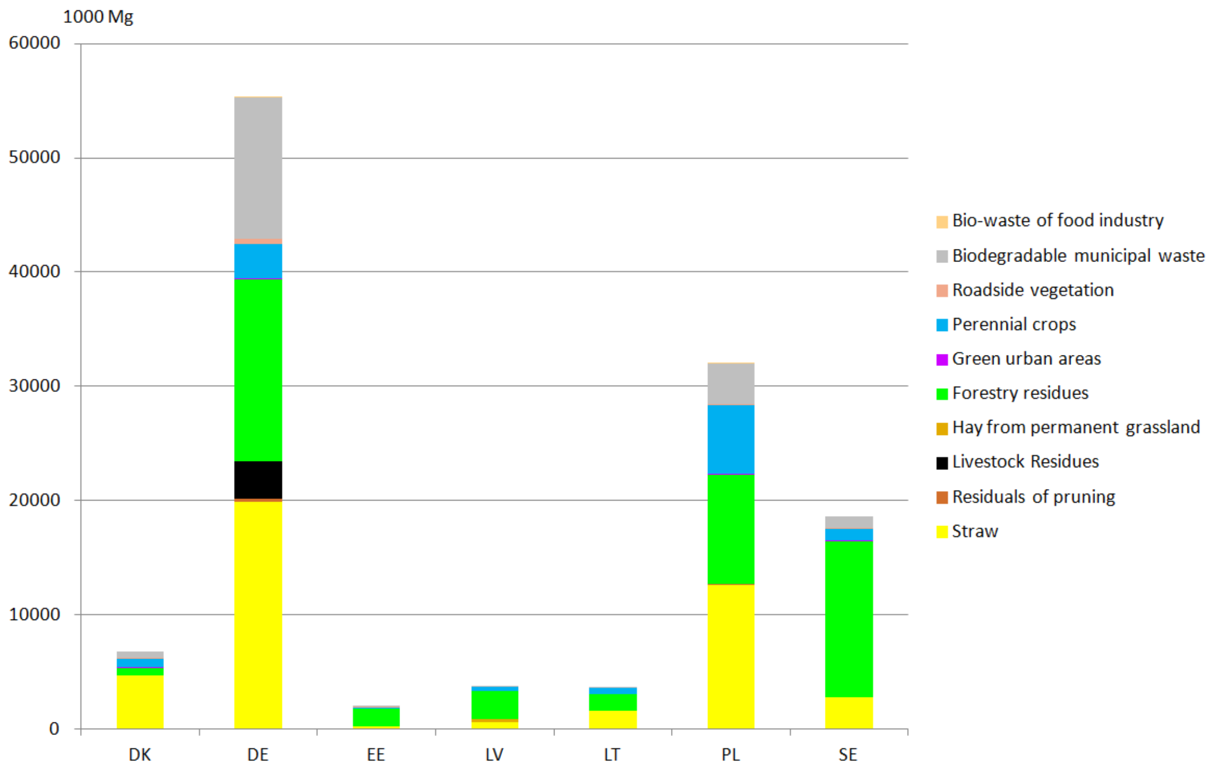

Fig. 22. Technical biomass potential from different sources in the BSR countries based on the results of project BioBoost (1000 Mg)
Source: http://bioboost.eu

4. Documented good practice solutions for improved biomass value chains in the BSR countries

4.1. General data on bioenergy

In 2017, renewable energy sources (RES) in the final energy consumption in the EU-28 countries represented 17.5%, and this share is expected to reach 20% on average by the end of the year 2020. The highest contribution of RES among the BSR countries was noted in Norway (71.2%). Moreover, in most BSR states, e.g. in Denmark, Estonia, Finland, Latvia, Lithuania and Sweden, this contribution of RES was distinctly higher, at 25.8-54.5%. However, it was much lower in Poland and Germany, at 10.9 and 15.8%, respectively (Fig. 23). It needs to be added that five of the BSR states (DK, EE, FI, LT, SE) reached the RES share targeted for the year 2020.

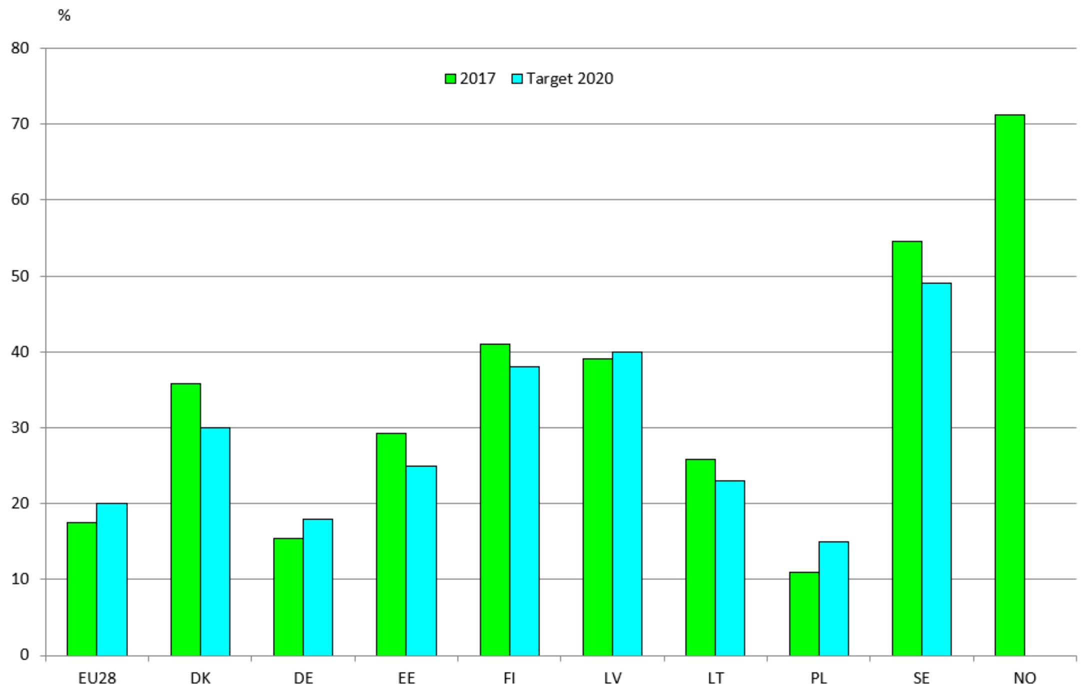

Fig. 23. Share of renewable energy in gross final energy consumption in BSR countries in 2017 and target for 2020 (%)
Source: Eurostat, 2019.

Bioenergy plays a very important role in supply of renewable energy in most of the BSR countries (Fig. 24). All bioenergy (all sectors: solid biomass, biogas, renewable municipal waste and liquid biofuels) constituted 70% on average of all RES, although there were differences between the countries, especially large with respect to Norway, which obtain most of energy from hydropower plants. The highest share of all bioenergy in the RES structure was in Estonia (93.9%), followed by Lithuania (88.8%), Poland (81.5%) and Finland (81.0%). In the other countries, this share was within the range of 58.4 to 79.8% in Sweden and Latvia, respectively, while being as low as 11.5% in Norway [Eurostat, 2019]. Among the different bioenergy sectors, the highest share was contributed by solid biofuels, equal as much as 58.5% on average for all BSR countries. In the particular countries, it ranged from 6.4 to 92.6% in Norway and Estonia, respectively (Fig. 24). The second most important product in the bioenergy sector was biogas, contributing 4.3% on average, with its smallest share in Norway (0.2% and the highest one in Germany (18.4%). In turn, the share of liquid biofuels for transport, equal 4.1% on average in the RES structure, varied from 0.1% in Estonia to 7.9% in Sweden. The smallest contribution (3.2%) to the whole RES structure in the BSR countries was achieved by renewable municipal waste. A relatively high share of the utilisation of this waste for energy was found in Denmark and in Germany, 8.7 and 7.5%, respectively.

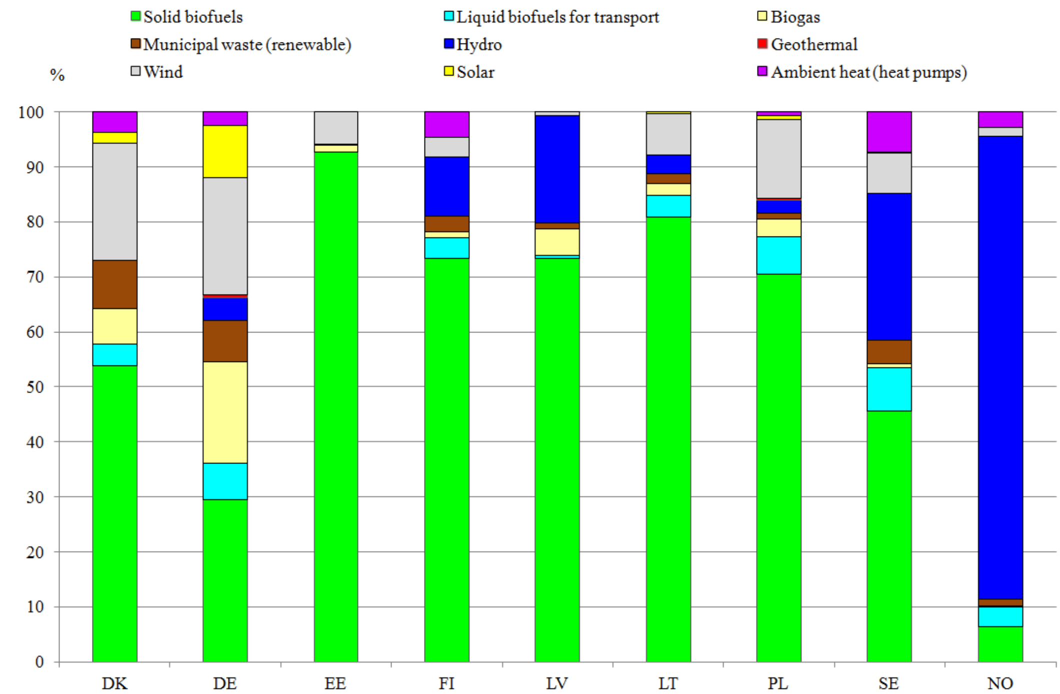

Fig. 24. Share of different types of renewable energy sources in gross inland consumption of total renewable energy sources in BSR countries in 2017 (%)
Source: Eurostat, 2019.

4.2. Pellets

Solid biofuels for energy purposes are most often used in the form of wood chips, briquettes and pellets. Pellets are gaining more importance on the EU-28 and world markets because they compose standardised solid biofuel, and this considerably facilitates their logistics and subsequently the operation of bioenergy plants. In 2017, in all BSR states there were 279 plants producing pellets, with 64 of this number situated in Sweden (Fig. 25) [Bioenergy Europe, 2018]. The second largest producers of pellets were Poland and Germany, while Norway had the fewest of such plants (4). The number of pellet manufacturing plants in particular BSR states was not directly mirrored in statistics of pellet production by volume, because it was the highest in Germany (2.25 million Mg/year), followed by Sweden (1.68 million Mg/year). The third largest volume of production was in Latvia (1.47 million Mg/year), which had 27 pellet production plants. Also, high pellet production (ca 1 million Mg/year) was noted in Estonia (in 23 plants) and in Poland (in 55 plants). In contrast, the smallest volume of pellet production was in Norway. On the other hand, the highest consumption of pellet, among all BSR countries, was in Denmark (3.26 million Mg/year) (Fig. 26). Thus, Denmark had to import large quantities of pellet, as its domestic production was more than 18-fold lower than consumption, and equalled just 180 thousand Mg/year (Fig. 27). The situation was reverse in Estonia, Latvia, Lithuania and in Poland, where pellet production exceeded domestic consumption by 26-, 11-, 6- and 3-fold, respectively. Sweden and Germany had the most balanced production and consumption of pellet. A reverse situation was noted in Finland and Norway, where production of pellet was lower than consumption. The total number of pellet production plants, volumes of produced and consumed pellet in the BSR countries was 42.5%, 54.6% and 32.7% of the respective values noted for the entire EU-28. Based on the above data, the situation in the BSR countries with regard to the pellet market was additionally illustrated in fig. 28. Figure 29, in turn, shows a more detailed map of the Polish pellet market as an example.

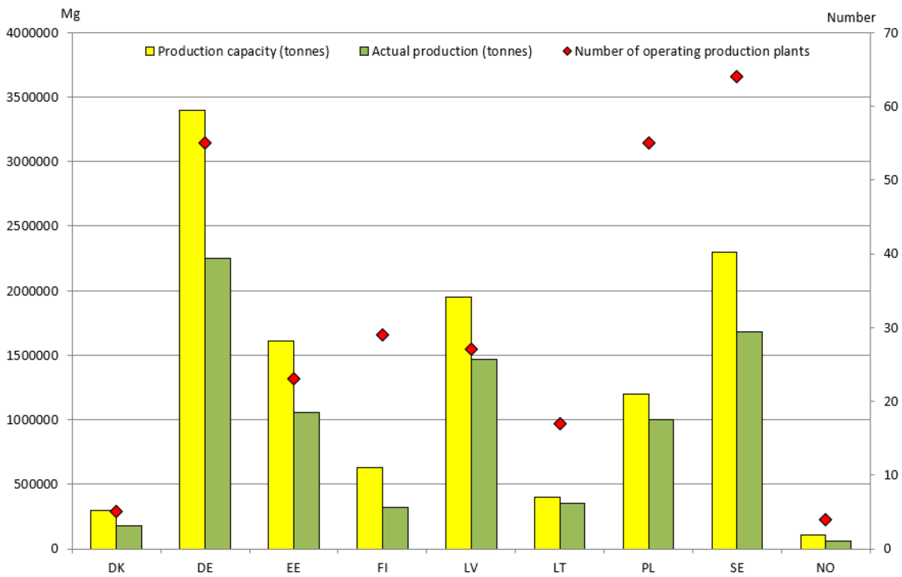

Fig. 25. Pellet capacity, production and number of pellet manufacturing plants in the BSR countries in 2017

Source: Bioenergy Europe, 2018.

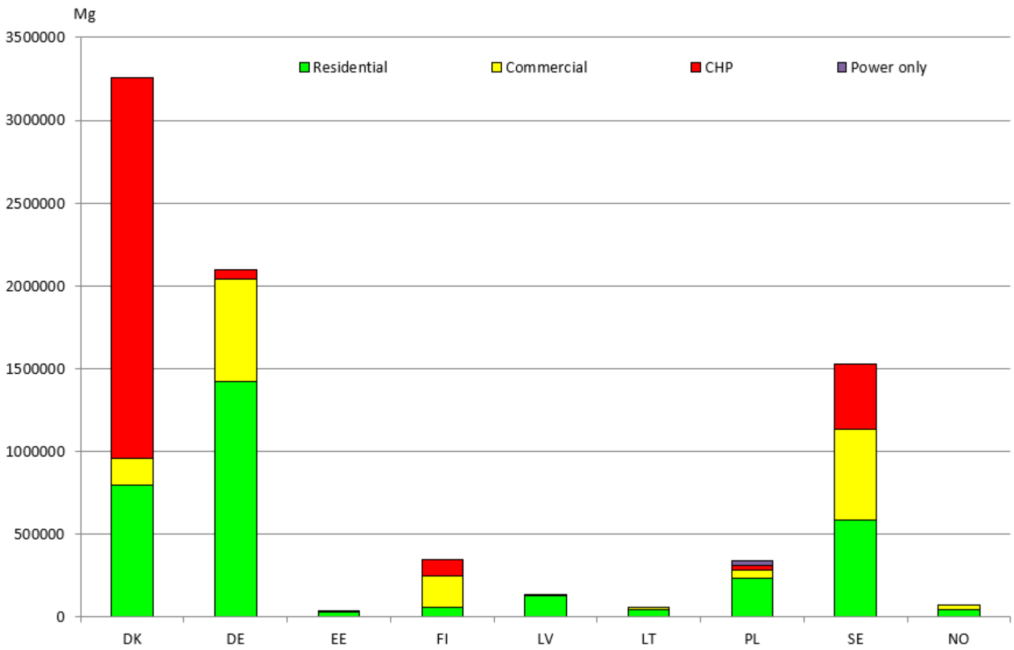

Fig. 26. Pellet consumption in the BSR countries in 2017
Source: Bioenergy Europe, 2018.

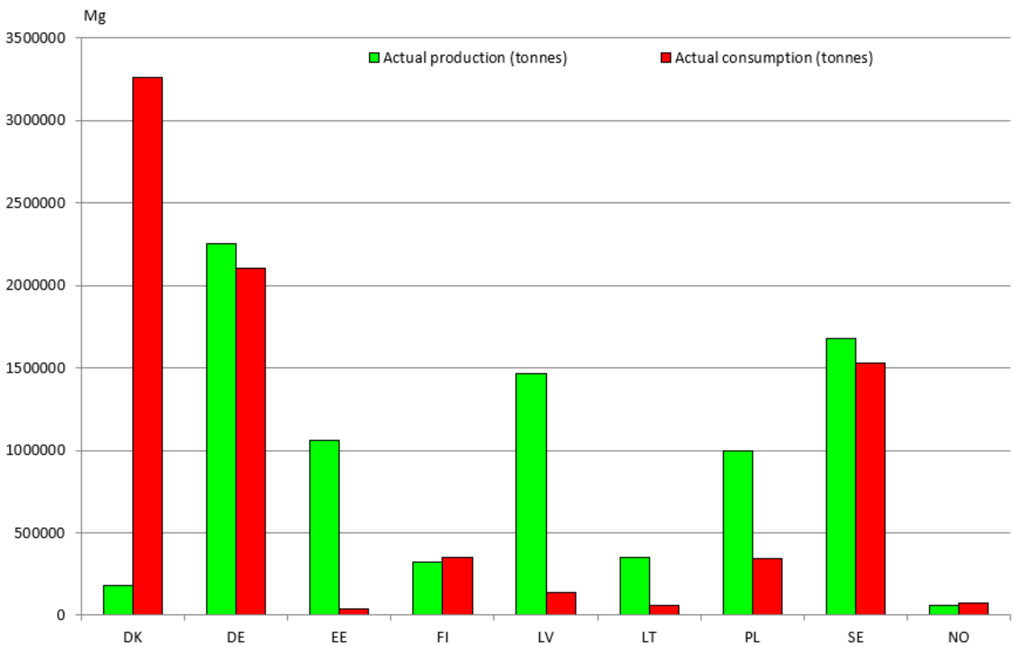

Fig. 27. Pellet production and consumption in the BSR countries in 2017
Source: Bioenergy Europe, 2018.

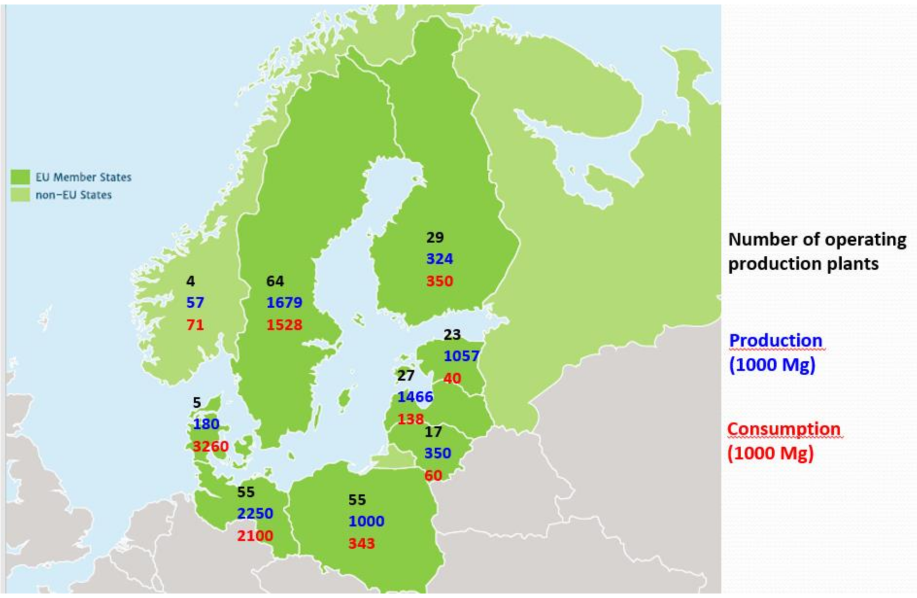

Fig. 28. Pellet market map of the BSR countries in 2017

Fig. 29. Pellet market map of Poland
Source: https://magazynbiomasa.pl/gdzie-kupic-dobry-pellet-mapa-producentow-pelletu/

4.3. Residential heat production

The distribution of populations by the degree of urbanisation in the BSR states is shown in Fig. 30. Most of the residents in the BSR countries live in towns and suburbs (2-40%) or in rural areas (20-55%) [Eurostat, 2019]. The percentage of population inhabiting cities ranges within 29-44%. The most uniform distribution appears in Denmark. As for the total of population in the BSR states, it was found that 55.5 million of people live in cities, 53.2 million in towns and suburbs, and 44.9 million in rural areas (Fig. 31). With respect to the total population distribution by dwelling type in BSR countries, it was determined that around 56.4 million people live in detached houses, 19.2 million in semi-detached houses, 76.6 million in flats and 1.2 million people dwell in other types of housing (Fig. 32). It is therefore right to conclude that half the population of the BSR states live in flats, while the other half live in houses.

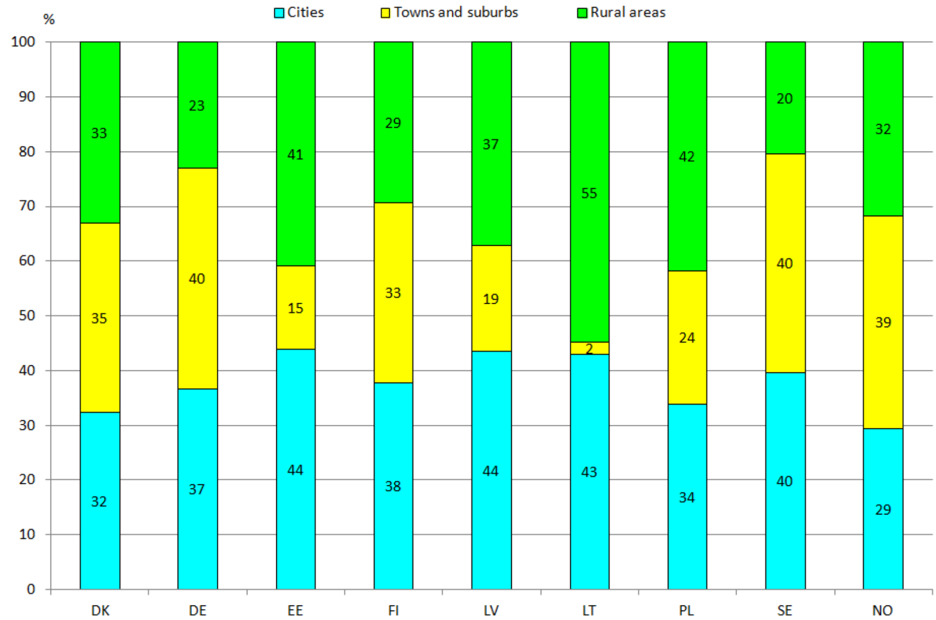

Fig. 30. Distribution of population by degree of urbanisation in the BSR countries in 2017
Source: Eurostat, 2019.

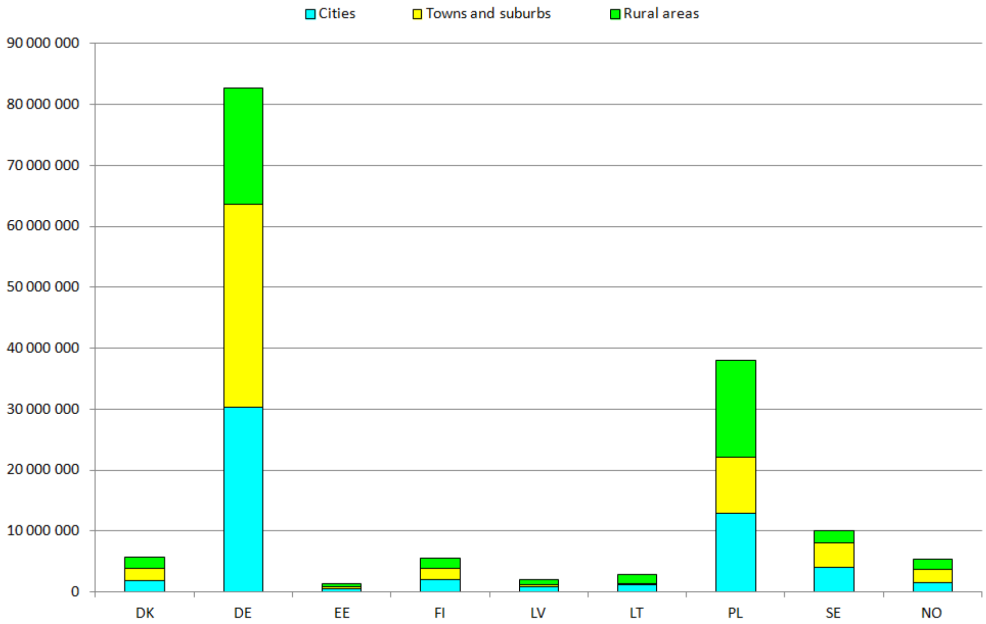

Fig. 31. Distribution of population by degree of urbanisation in the BSR countries in 2017
Source: own calculations based on Eurostat, 2019.

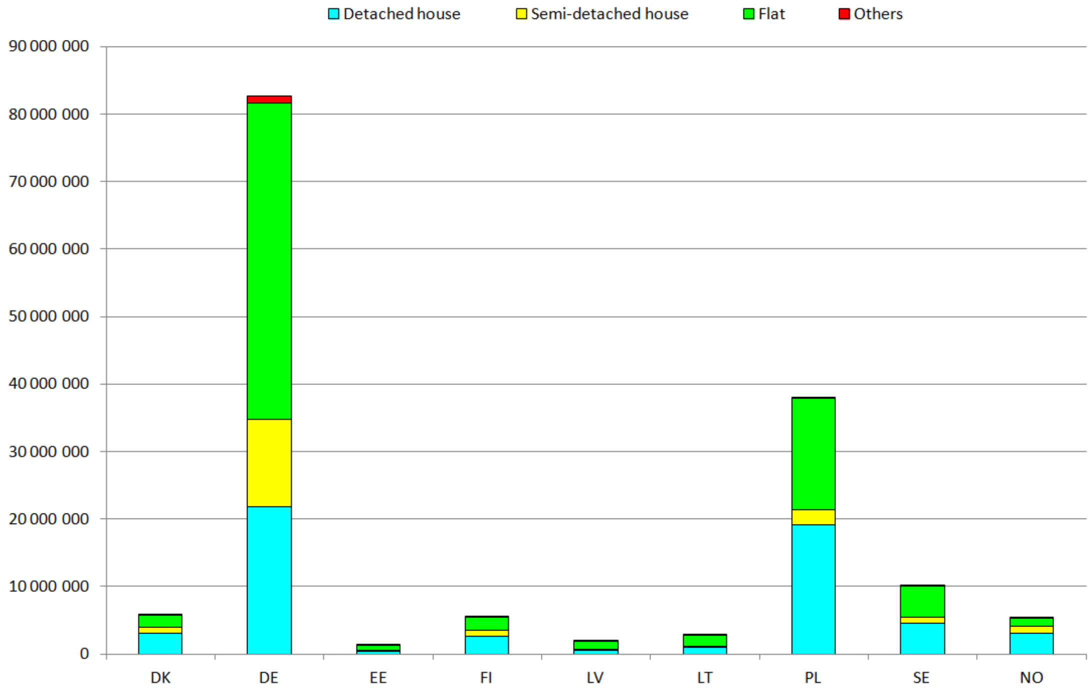

Fig. 32. Distribution of population by dwelling types in the BSR countries in 2017
Source: Eurostat, 2019.

The highest residential heat production (over 50,000 ktoe) was in Germany, and natural gas dominated among the fuels (Fig. 33). In Poland, however, there was a large share of coal. Thus, the BSR countries in total consumed around 76% solid fossil fuels in comparison to the whole EU-28. In turn, biomass in structure of residential heat production by fuel in the BSR states ranged from 12 to 50%, in Germany and in Estonia, respectively (Fig. 34) [Bioenergy Europe, 2019d].

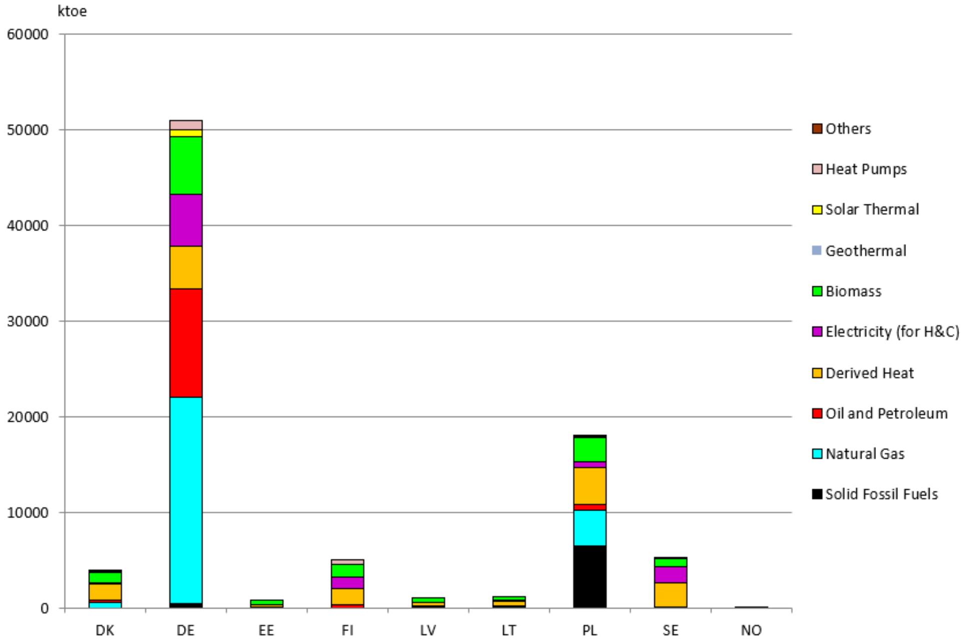

Fig. 33. Residential heat production by fuel in the BSR countries in 2017 (ktoe)
Source: Bioenergy Europe, 2019d

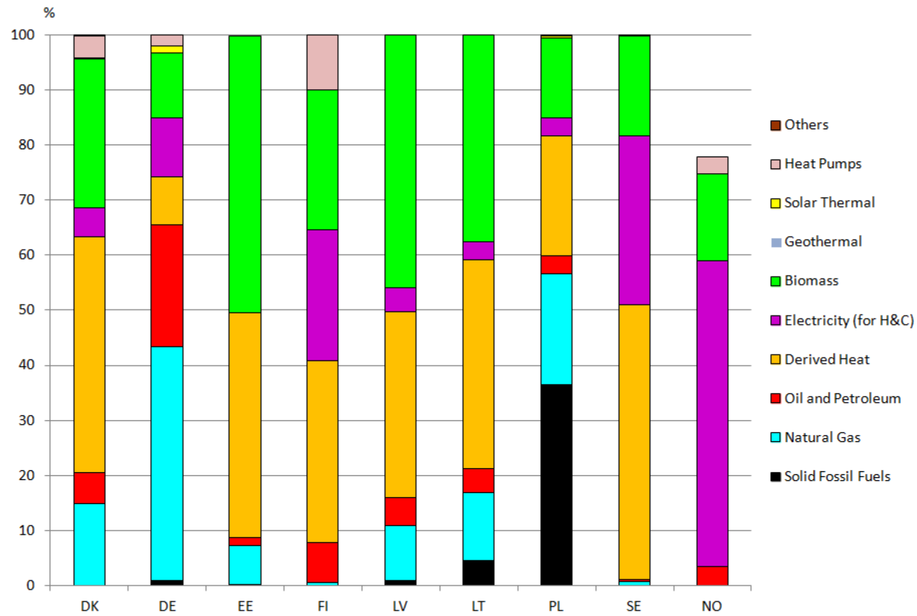

Fig. 34. Structure of residential heat production by fuel in the BSR countries in 2017 (%)
Source: Bioenergy Europe, 2019d.

4.4. Heat and cool

Heat energy plays a very important role in satisfying demand for energy by population in the BSR countries because the share of energy for heating and cooling (mostly heating) in most of these states exceeded 50% of final energy consumption, but in Latvia this indicator was even higher, at 60.8% (Fig. 35).

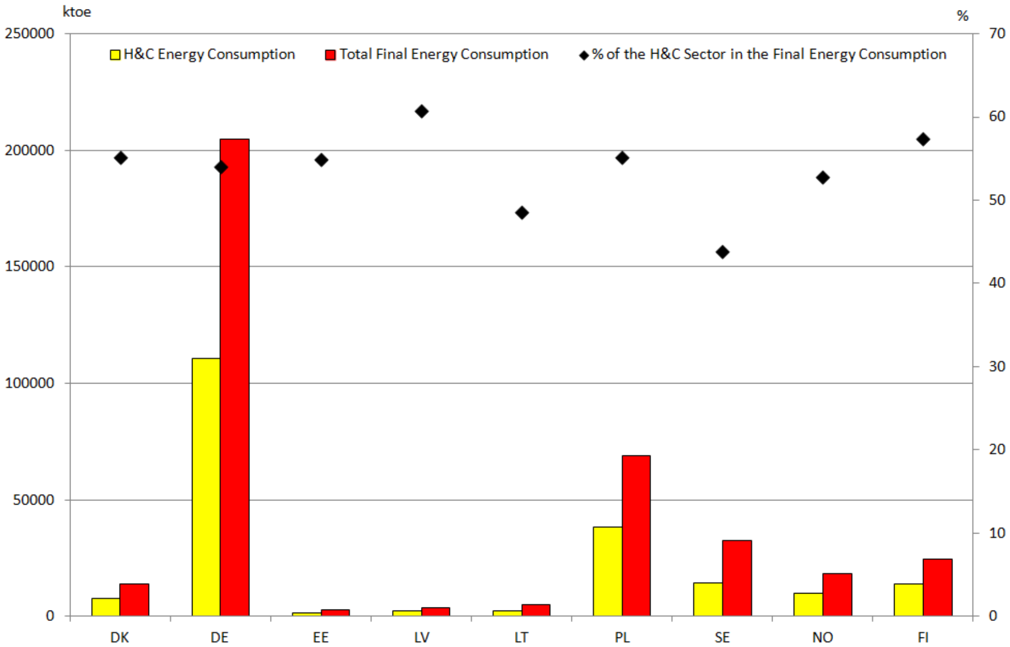

Fig. 35. Heating and cooling consumption compared with total final energy consumption in the BSR countries in 2017
Source: Bioenergy Europe, 2019d.

Gross production of derived heat from biomass in the BSR countries was the highest in Sweden: 3154 ktoe (Fig. 36, 38). In Finland, Denmark and Germany, the value of this indicator was in the range of 1600-1897 ktoe. In the other BSR countries, the gross production of derived heat from biomass was considerably lower. It also needs to be added that the total gross production of derived heat from biomass in the BSR countries corresponded to 68.9% of the total value of this indicator for the EU-28 [Bioenergy Europe, 2019d]. In most BSR states, solid biomass dominated strongly in the structure of the gross production of derived bioheat, within the range of 80 to 100%, in Sweden and in Estonia, respectively (Fig. 37). It was only in Germany that the structure of the gross production of derived bioheat was dominated by the use of renewable waste (48%), while solid biomass represented 38%. Moreover, the share of biogas was notable in Germany, Latvia and Poland (7-13%).

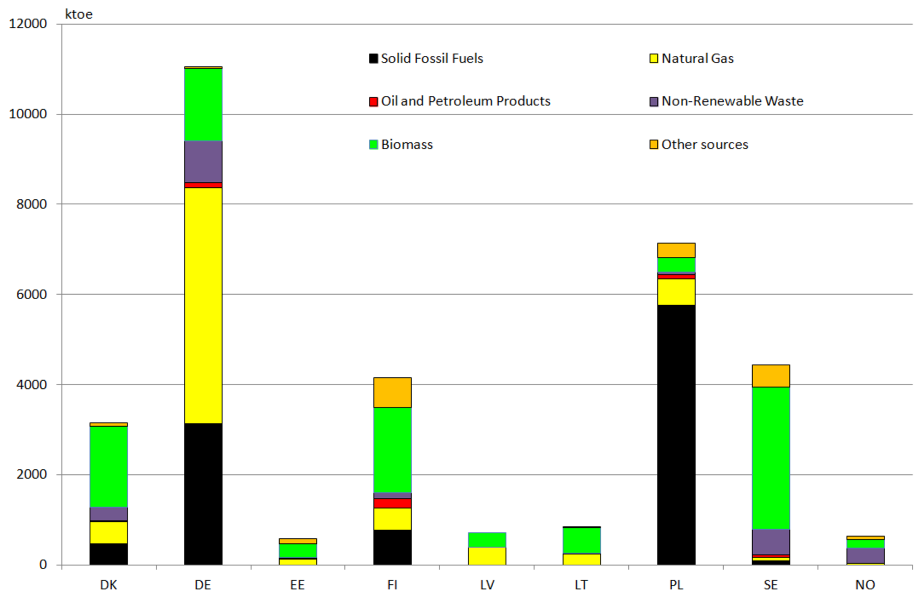

Fig. 36. Gross production of derived heat by type of fuels in the BSR countries in 2017
Source: Bioenergy Europe, 2019d.

The share of total biomass in the total derived heat production was the highest in Sweden, 71% (Fig. 38). The value of this indicator was also recorded in Lithuania and Denmark, 67 and 57%, respectively. In four other countries (Estonia, Finland, Latvia and Norway) the share of this indicator was also high, within the range of 51 and 29%. In Germany, it equalled 14%, while the lowest one was in Poland, just 4%. Considering the above information, it should be concluded that there are large deficits in Poland regarding this system of heat delivery, and hence there are big opportunities for the development in this sector.

Final energy consumption of bioheat in the BSR countries in 2017 in all sectors (household, industry, derived heat, commercial and public services and other sectors) was the highest in Germany, 13042 ktoe (Fig. 38). The subsequent places were occupied by Sweden, Finland, and Poland, with the consumption in the range of 8465-5397 ktoe. The smallest consumption of the final energy consumption of bioheat (725 ktoe) was in Estonia.

Fig. 37. Share of solid biomass, biogas, renewable waste and liquid biofuels in gross production of derived bioheat in the BSR countries in 2017 (%)
Source: Bioenergy Europe, 2019d.

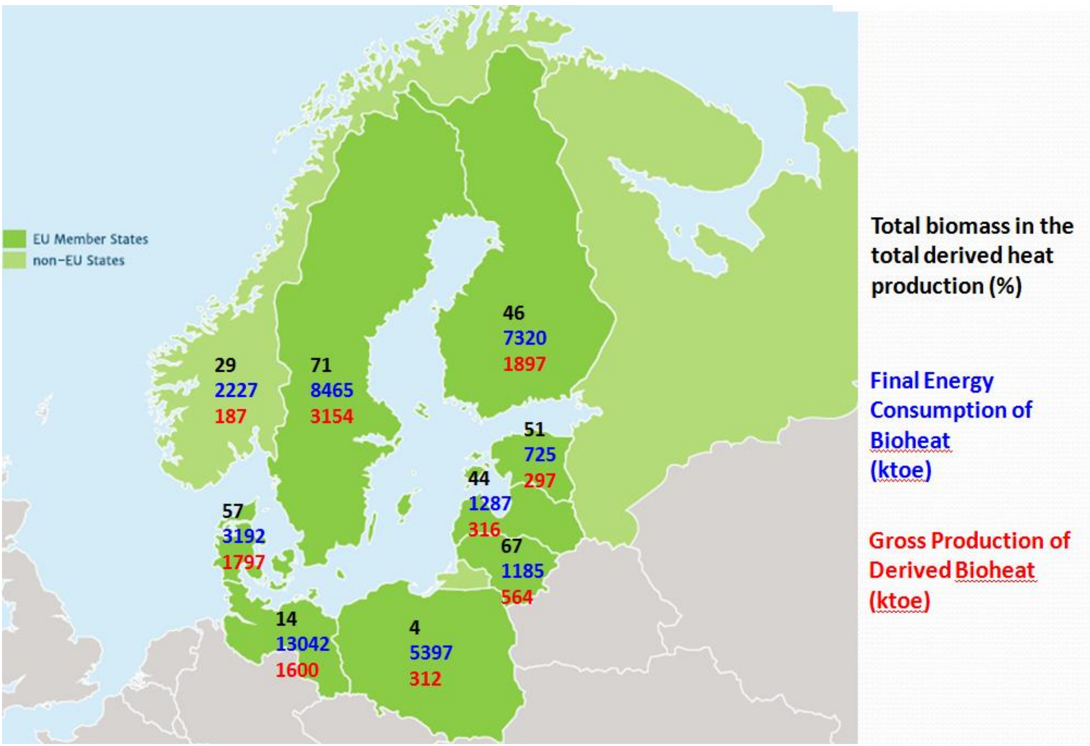

Fig. 38. Derived bioheat in the BSR countries in 2017
Source: Bioenergy Europe, 2019d.

4.5. Bioelectricity

Gross electricity production in the BSR countries in 2017 is shown in Fig. 39. The total electrical capacity from all biomass plants (solid biomass, biogas, renewable waste and liquid biofuels) in all the BSR countries was 21,123 MW, which corresponded to 52% of the value for the EU-28. Among the BSR states, evidently the highest total electrical capacity from all biomass was in Germany (10,007 MW), and in Sweden (5,389 MW), which corresponded to 47 and 26% among the BSR countries (Fig. 40). Denmark and Finland were in the third and fourth place in terms of this indicator, with its value of around 9% each of the total value for all BSR countries. In the other BSR states, the electrical biomass capacity was much lower, with the lowest one in Lithuania: 87 MW [Bioenergy Europe, 2019a].

Fuels inputs for bioelectricity generation and gross electricity generation from biomass were reflected in values of electrical capacity. Hence, the largest fuels inputs and gross electricity generation from biomass were in Germany, where they corresponded to 49 and 56%, respectively, of the total values for the BSR countries (Fig. 40). Sweden and Finland were in the second and third place in terms of the gross electricity generation from biomass, generating over 1000 ktoe each. In Poland and in Denmark, the statistics showed more than 500 ktoe, and in the other BSR countries the value of this indicator was much lower than 90 ktoe.

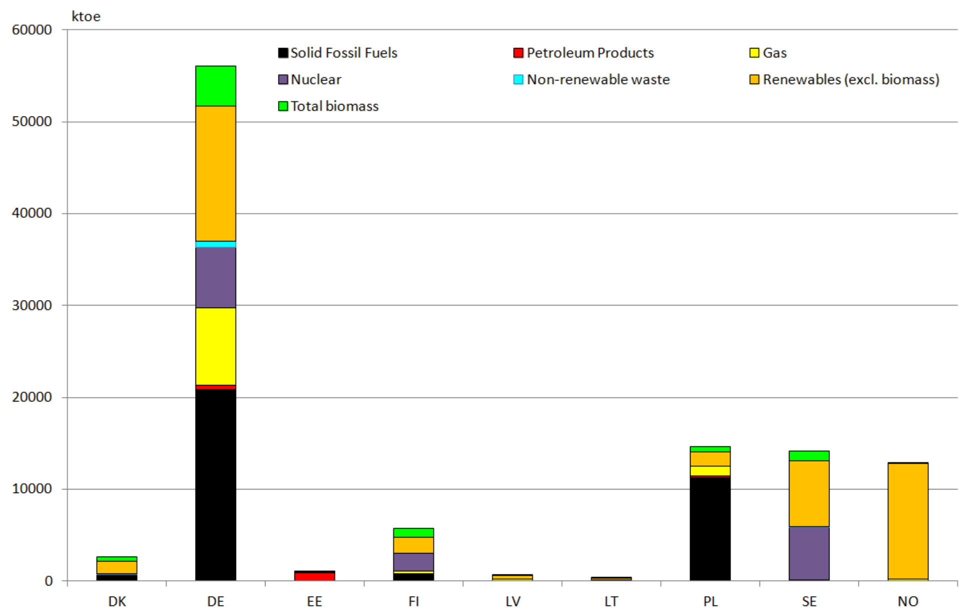

Fig. 39. Gross electricity production in the BSR countries in 2017
Source: Eurostat, 2019.

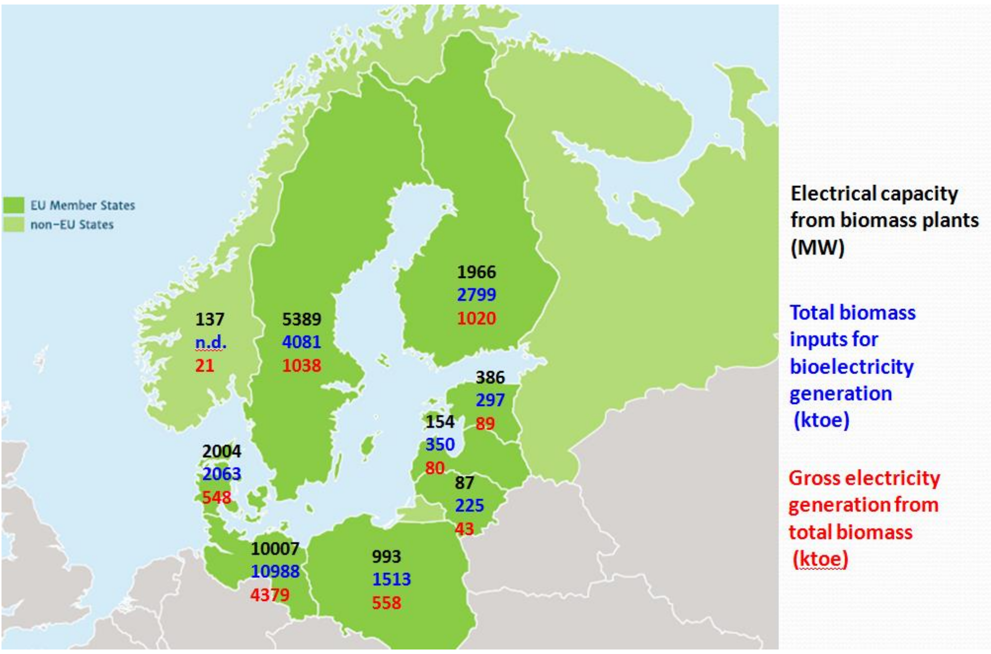

Fig. 40. Bioelectricity in the BSR countries in 2017
Source: Bioenergy Europe, 2019a.

The structure of gross electricity generation from biomass in seven among nine BSR countries was dominated by solid biomass (Fig. 41). It ranged from 56% in Latvia and 97% in Estonia, and the average percentage was 78%. In turn, in Norway the highest share in the gross electricity generation from biomass was composed of renewable waste, 86%. However, in Germany the highest share in this indicator was made by biogas (67%), followed by solid biomass (21%) and only then renewable waste (12%).

The share of bioelectricity in total gross electricity generation among the BSR states was the highest in Denmark, 21% (Fig. 41). A high value of this indicator was also in Finland (18%), and in Lithuania and Latvia (13 and 12%, respectively). In Estonia, Germany and Sweden, the share of bioelectricity was 7-8%, in Poland it was 4%, and in Norway it was just 0.2%.

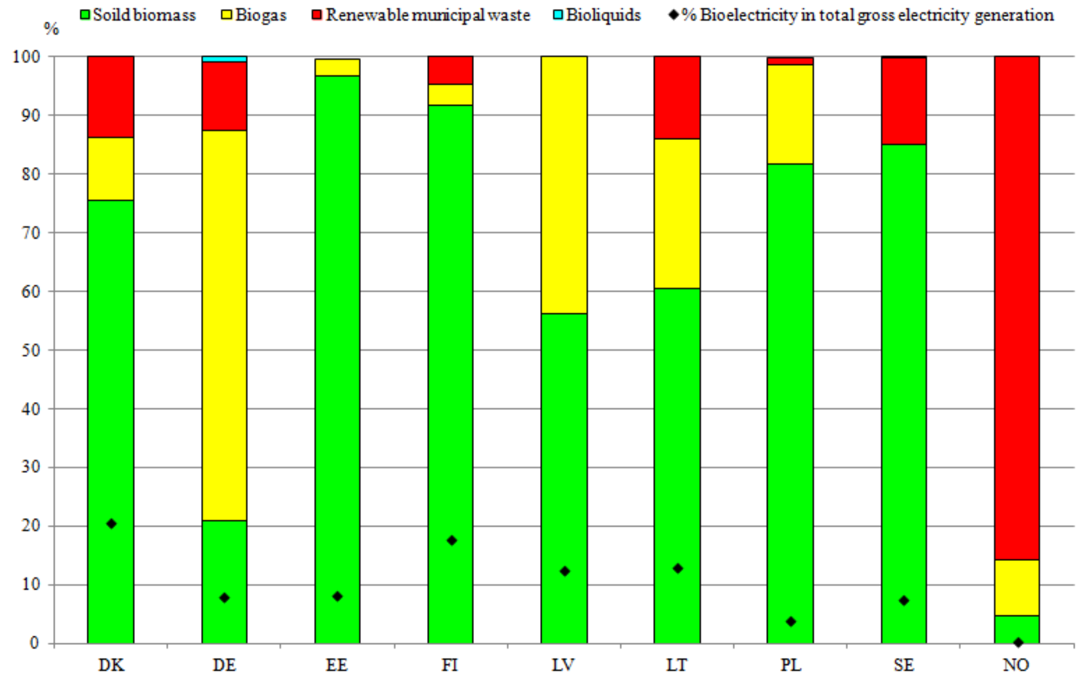

Fig. 41. Share of solid biomass, biogas, renewable municipal waste and liquid biofuels in gross electricity generation from biomass and share of bioelectricity in total gross electricity generation in the BSR countries in 2017
Source: Bioenergy Europe, 2019a.

4.6. Liquid biofuels

Total liquid biofuels capacity (biodiesel, bioethanol and others in total) in the BSR countries in 2017 was 12.41 million Mg. Of this, the distinctly highest potential was for biodiesel (51.6%), followed by other liquid biofuels (32.8%) and bioethanol (15.5%) (Fig. 42). In the BSR states, the distinctly highest total liquid biofuels capacity was in Germany, and next in Poland, 8.9 and 2.2 million Mg, respectively, which corresponded to 72 and 18% of the total for all BSR countries (Fig. 43). In the other BSR countries, the liquid biofuels capacity was much lower. In view of the above, the highest total primary production of liquid biofuels was also in Germany: 3337 ktoe/year, and then in Poland 918 ktoe/year, which corresponded to 66 and 18% of the total for all the BSR countries. In turn, the final energy consumption of liquid biofuels in the transport sector among the BSR countries in 2017 was also in Germany (2561 ktoe/year), followed by Sweden (1520 ktoe/year) and then in Poland (605 ktoe/year), with the respective shares of 45, 26 and 10% of the total for all BSR countries. Thus, Finland, Sweden, Norway and Denmark imported liquid biofuels, and the countries situated south of the Baltic Sea (mainly Germany and Poland, but also Lithuania and Latvia) could export their excess amounts of liquid biofuels (Fig. 44, 45) [Bioenergy Europe, 2019b; Eurostat, 2019].

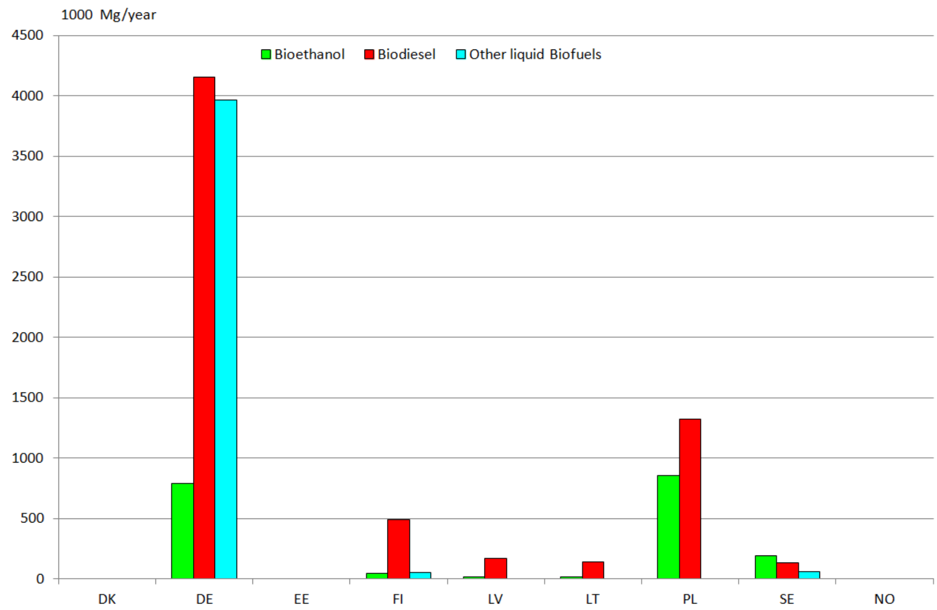

Fig. 42. Biofuels capacity in the BSR countries in 2017
Source: Bioenergy Europe, 2019b.

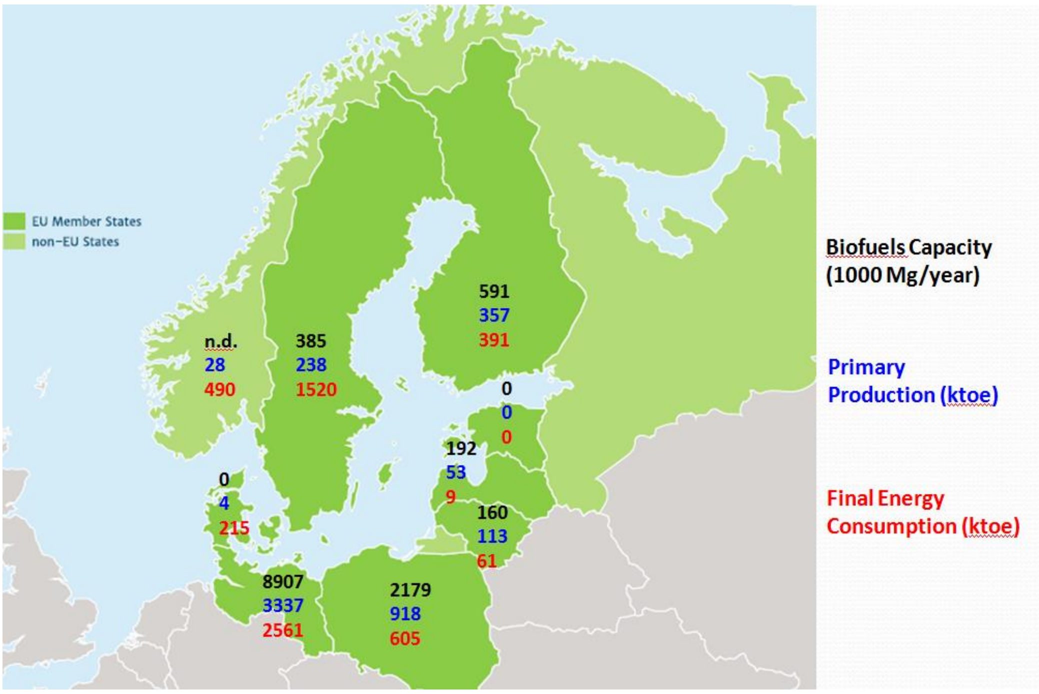

Fig. 43. Liquid biofuels map of the BSR countries in 2017
Source: Bioenergy Europe, 2019b.

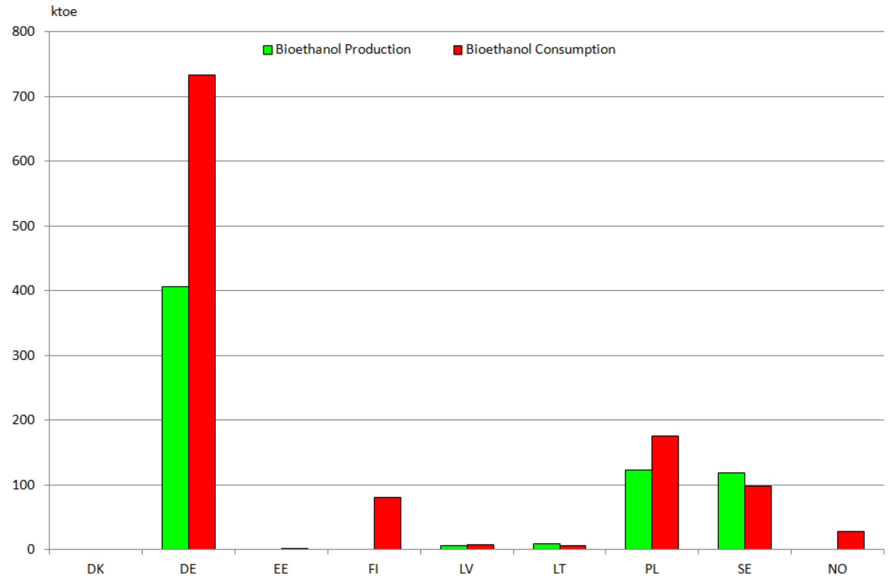

Fig. 44. Primary bioethanol production and final energy consumption in the transport sector in the BSR countries in 2017
Source: Bioenergy Europe, 2019b.

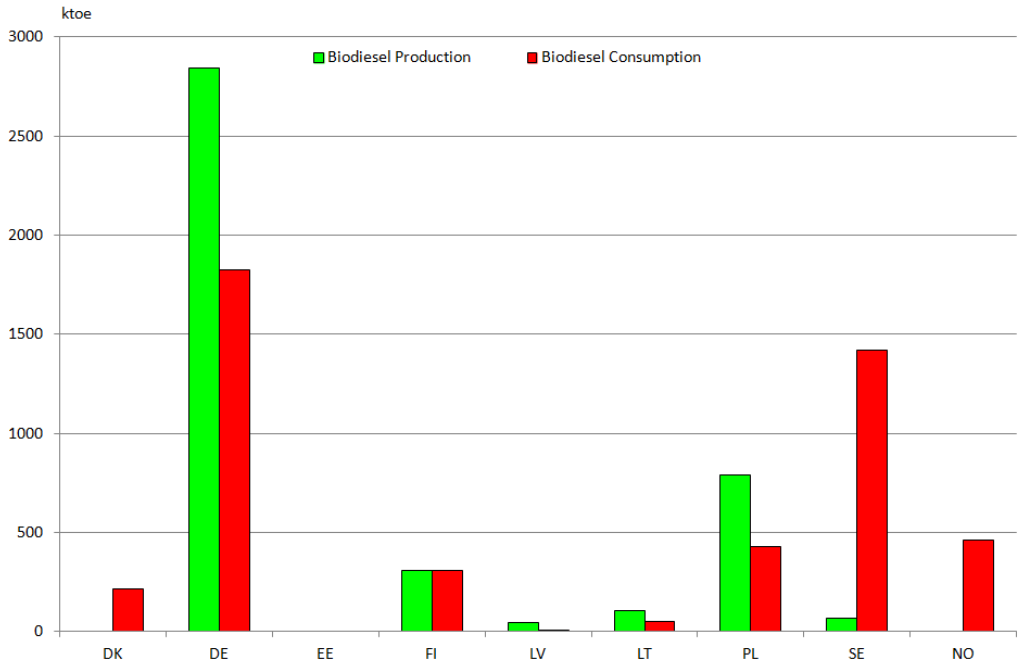

Fig. 45. Primary biodiesel production and final energy consumption in the transport sector in the BSR countries in 2017
Source: Bioenergy Europe, 2019b.

4.7. Biogas

In 2017, the number of biogas plants in the BSR countries was 11,964 in total, of which as many as 92% (10,971) were in Germany (Fig. 46). In the other BSR countries, the number of biogas plants was much lower, within the range of 17 to 308 in Estonia and Poland, respectively. However, it needs to emphasised that there were big differences between the BSR countries in the number of biogas plants, and the total number of these facilities in the BSR states made up 70% of the total number of biogas plants in the EU-28. Furthermore, the number of biogas plants in Germany alone corresponded to as much as 65% of these plants in the whole EU-28. Consequently, Germany was the leader in terms of the gross inland consumption of biogas (7845 ktoe/year), which corresponded to 87.3% of such consumption in all BSR states in total. This indicator in the other BSR countries varied from 13 to 389 ktoe/year in Estonia and in Denmark, respectively.

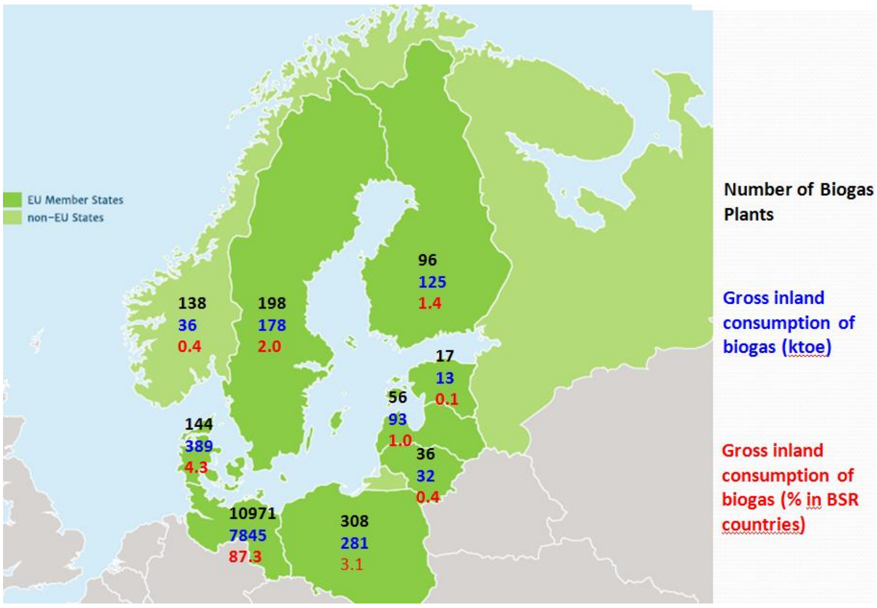

Fig. 46. Biogas map of the BSR countries in 2017
Source: Bioenergy Europe, 2019c; Eurostat, 2019.

It is worth drawing attention to the structure of the utilised substrates (Fig. 47) and the primary energy production by biogas plant type. In the BSR countries, as much as 87% of the total production was generated by agricultural biogas plants. Next, there were 8% from sewage sludge, 3% from landfill gas and 2% from biogas from thermal processes. However, the structure of primary energy production by different biogas plants in individual BSR countries was varied (Fig. 48). For example, the dominant type of primary energy production in Finland was by thermal processes biogas plant (45%). In Estonia, landfill biogas prevailed (69%). In the other countries, agricultural biogas was dominant, from 42% in Poland to 92% in Germany. It should be added that sewage sludge gas had a considerable share in Poland (41%) and in Sweden (44%). Germany was a strong leader in the gross electricity production (63%) from biogas (Fig. 49). This ratio in the other BSR countries was from 0.4% in Sweden to 52% in Lithuania. It is worth emphasising that in Sweden much more energy was dedicated to direct use (industry, household, commercial etc.) and transport rather than to electricity production.

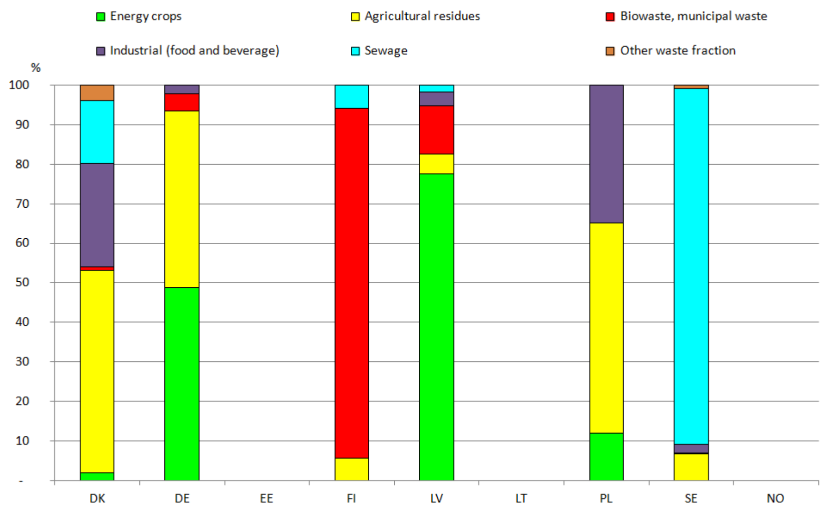

Fig. 47. Feedstock use for biogas production (excluding landfill - expressed as a mass percentage) in the BSR countries in 2017
Source: Bioenergy Europe, 2019c.

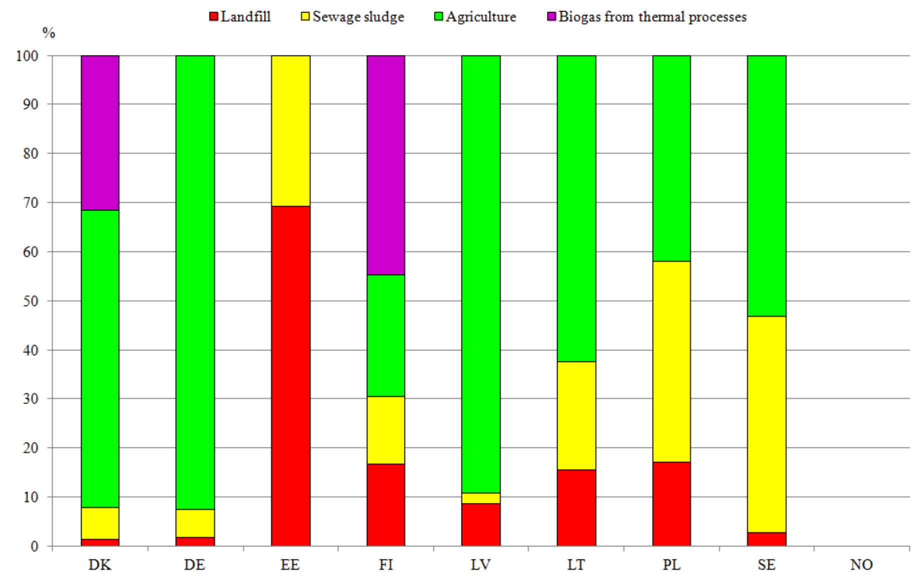

Fig. 48. Primary energy production of biogas by biogas plant type in the BSR countries in 2017
Source: Bioenergy Europe, 2019c.

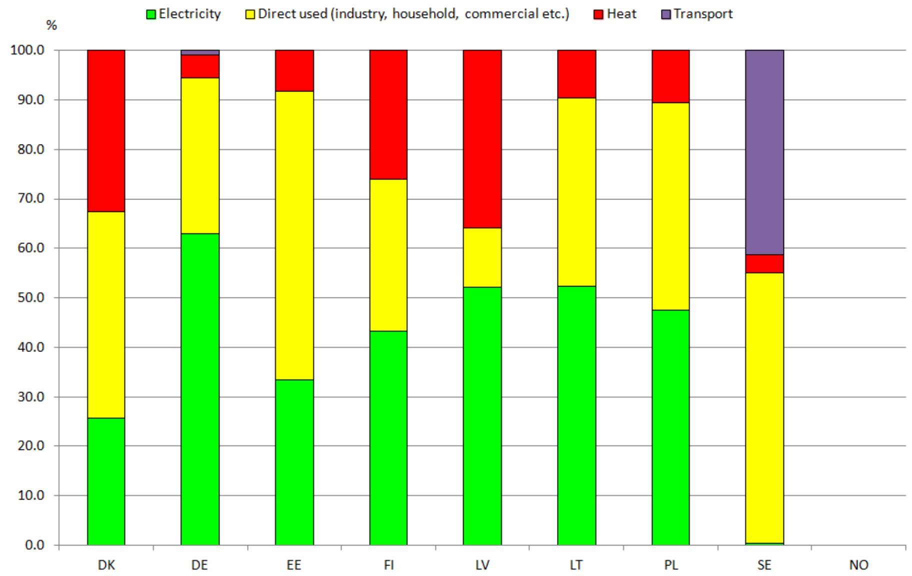

Fig. 49. Gross final energy consumption from biogas by end-use in the BSR countries in 2017
Source: Bioenergy Europe, 2019c.

4.8. Incineration plants

In 2017, there were 191 incineration plants in total in all the BSR states, with Germany having the highest number of these facilities (96) (Fig. 50). There were also many incineration plants in Sweden, Denmark and Norway: 34, 26 and 18, respectively. The other BSR countries had much fewer such facilities, and there were none in Latvia. The Figure 49 shows also an amount of the incinerated municipal waste (total) with the simultaneous use of thermal energy, but gross consumption of renewable municipal (ktoe) applies only to fractions that are of biological origin. The non-renewable fraction was not included in gross consumption. In 2017, the amount of municipal waste used for energy recovery in all BSR states was 15.95 million Mg, 58% of which was the waste incinerated in Germany. The next biggest share of municipal waste transformed to energy, 10%, was in Poland (2.72 m Mg), while Sweden and Denmark each had 9% of such waste recycled in incineration plants (2.4 m Mg). In Norway and Finland, the respective quantities were 2.1 and 1.6 million Mg. Therefore, the gross consumption of renewable municipal was the highest in Germany: 3217 ktoe/year, which corresponded to 61% of the total for all BSR countries. Sweden came the second (874 ktoe/year), and Denmark was the third (521 ktoe/year) [Eurostat, 2019].

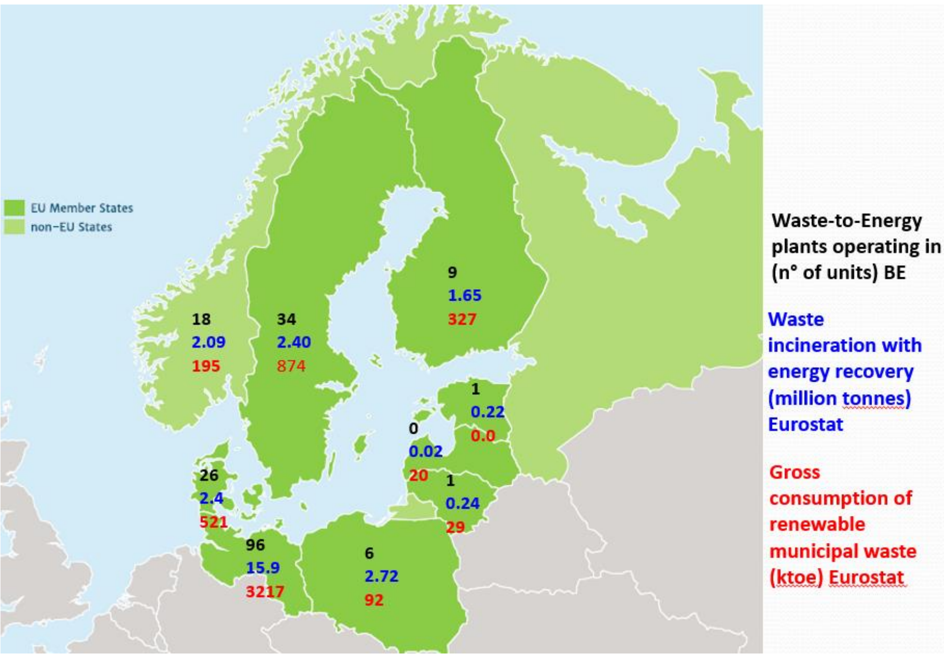

Fig. 50. Incineration plants and renewable municipal waste for energy recovery and gross energy consumption of renewable municipal waste in the BSR countries in 2017
Source: BE - Bioenergy Europe, 2019e; Eurostat, 2019.

5. Catalogue of selected enabling technologies, covering energy and directly connected other uses of biomass

5.1. Pros and cons of the biomass potential and technology of its use for energy in BSR countries

Denmark: The country with the smallest surface area and second most densely populated one. It possesses the fifth largest total biomass energy potential. It consumes the distinctly biggest amount of pellet to generate energy among all BSR states, although most of this fuel (over 90%) is imported. It has a well-developed biogas sector, as it is in the second place in terms of the gross inland consumption of biogas. It is also the third country among the BSR states in terms of the number of incineration plants and gross consumption of renewable municipal waste. It does not employ a liquid biofuel generation technology and the consumption of this fuel relies on import. The share of total bioenergy in the total energy consumption is on a high level (24%), which gave Denmark the fourth position among the nine BSR states.

Germany: The country with the highest population density rate and the biggest population, as well as the second one in surface area. It has the biggest biomass energy potential. It is the leading country among the BSR states in terms of the volume of generated bioenergy in every sector, i.e. solid biomass, biogas, renewable municipal waste and liquid biofuels, in addition to which it has the distinctly highest number of biogas plants and experience in this sector. However, the percentage of total bioenergy as shares of gross total energy consumption was not too high (8.2%), which put Germany on the seventh place among the nine BSR countries.

Estonia: This country is the eighth and sixth in terms of the area and population density rate, respectively, and it has the smallest population among the BSR states. It has the smallest (ninth) potential of energy from biomass. However, this country has a large potential of pellet production and occupies the fourth place in this regard. Moreover, this country's share in the total EU-28 pellet exports was high, at 16%. Estonia had the biggest (50%) share of biomass in the total of residential heat production. It does not possess implemented technology for generating liquid biofuels and it has the fewest biogas plants among the BSR states. It is distinguished by a high percentage of the whole population employed in bioenergy markets (0.68%). The share of total bioenergy as shares of gross total energy is moderate (17.3%), which gives Estonia the sixth position among the nine BSR countries. In terms of the GHG emissions, it comes the fifth.

Finland: This country is on the third and eighth place in terms of the surface area and population density rate, respectively. It has the fourth largest total biomass energy potential. The country is on the third position among the BSR states with regard to residential bioheat production, final energy consumption of bioheat, gross electricity generation from biomass and biofuel installed capacity, and on the fourth one in terms of the gross consumption of renewable municipal waste. The percentage of total bioenergy as shares of gross total energy consumption is high (28.1%), securing this country the second place among the nine BSR states. As for the GHG emission rate, it comes the fourth.

Latvia: This country is on the seventh and fifth place in terms of the area and population density rate, respectively. It has the sixth total biomass energy potential with respect to its size. The country also has a large potential in pellet production, which gives it the third place. Moreover, the contribution of Latvia to the total EU-28 pellet exports was high, at 20%. This is the country with the highest share of heating and cooling (61%) in final energy consumption. It occupies the second place in terms of the share of biomass in the total of residential heat production (46%). It lacks incineration plants and has the smallest volume of renewable municipal waste used for energy recovery. It shows the highest percentage of the whole population employed in bioenergy markets (1.32%) and the share of total bioenergy as shares of gross total energy consumption is on an average level (33.9%) among the nine BSR states. The low total GHG emission secured this country the eighth position among the BSR countries.

Lithuania: This country comes the sixth and fourth in terms of the surface area and population density rate. It has the seventh biggest total biomass energy potential. The country is on the second place with respect to total biomass in the total of derived heat production (67%) and on the third place regarding the share of biomass in the total of residential heat production (38%). It has a small number of incineration plants and biogas plants. The contribution of total bioenergy as shares of gross total energy consumption is moderate (18.8%), which gave this country the fifth place among the nine BSR states. Concerning the GHG emission index, Lithuania was on the sixth place.

Poland: This country is on the fifth, second and third place in terms of the area, population and population density rate, respectively. It has the second largest biomass energy potential. The country is on the second place with respect to the number of biogas plants, biofuel installed capacity and primary production as well as the number pellet plants, but it is only the fifth largest pellet producer. Poland has the lowest percentage of the total biomass in the total derived heat production (just 4%) and is on the penultimate place in terms of the total of residential heat production (15%) among the BSR countries. It has a low share of total bioenergy as shares of gross total energy consumption (6.9%), which gives it the penultimate, eighth place among the nine BSR states. With respect to the GHG emission rate, it came the second.

Sweden: This is the country with the largest area and on the seventh place in terms of the population and population density rate. It has the third largest biomass energy potential in size. Sweden has the biggest number of pellet plants and is the second biggest pellet producer. It is also the second country in terms of the number of incineration plants and gross consumption of renewable municipal waste. It is on the third place in terms of the number of biogas plants and has the highest share of biogas used for transport. Sweden has the highest percentage of total biomass in the total derived heat production (71%). This country is the third in turnover in the bioenergy sector. The percentage of the total bioenergy as shares of gross total energy consumption is 24.2%, which gives Sweden the third place among the nine BSR states. Moreover, Sweden has the lowest GHG emission rate.

Norway: This is the fourth country in terms of the surface, with the lowest population density rate. It has the eighth largest total biomass energy potential. It is on the fourth place with respect to the number of incineration plants, and on the fifth place regarding the number of biogas plants. Norway has the largest percentage of renewable waste in the structure of gross electricity generation from biomass (86%). The smallest number of pellet plants is accompanied by the lowest pellet production. The percentage of total bioenergy as shares of gross total energy consumption was the lowest (5.4%), which gave the country the last place among the nine BSR states. However, it was the fifth with respect to the GHG emission rate.

5.2. Integrated biorefineries as modern installations for cascade use of biomass

Development factors

Biorefinery processing offers an opportunity to increase the value and improve the effective use of biomass and to produce new, high quality bioproducts (food, fodder, materials, chemicals) and bioenergy (fuels, electric and/or heating power). It also enables manufacture of raw materials and biopolymers for production of plastics, which are in high demand (1,709,700 Mg/year; an estimate for the year 2015) (de Jong et al., 2012). The market demand for bio-based products, efficient technologies, large-scale implementation of technologies, integrated production and proper selection of local feedstocks ensure the feasibility and economic viability of these systems. The overall costs of production can be lowered by 5-27%, which should lead to a decrease in the costs of biofuel production to 42–119 EUR/MWh (12–33 EUR/GJ) for fuels derived from biomass raw materials, and to 29–79 EUR/MWh (8–22 EUR/GJ) for biowaste-based fuels (Brown et al., 2020).

The challenge of climate change and depletion of fossil resources is increasingly serious. The calculations reported by the IEA Bioenergy show that a wood bioethanol biorefinery system releases 48 kt CO_2 eq./year, while the lowest emission of greenhouse gases from fossil fuels in an analogous system releases 408 kt CO_2 eq./year, which translates into a reduction in GHG emission by around 88% (de Jong et al., 2012).

Classification of biorefineries

The whole spectrum of various biorefinery processes is currently the subject of research which shows that some are already competitive on the market while others are at the stage of development. The standard classification of various existing and emerging biorefinery systems has not been completely developed yet, although the International Energy Agency (IEA) Bioenergy has made an attempt to classify all systems (Task 42; „Biorefining is the sustainable processing of biomass to a spectrum of market products and energy”). The IEA Bioenergy has classified biorefinery plants by taking into consideration four parameters: platforms, products, feedstocks, and processes (Cherubini et al., 2009).

A biorefinery system has been described as a pathway for conversion of raw material to final product using platforms and processes. Platforms are semi-products from which final products are derived, and these are the most important characteristics to define the type of a biorefinery plant.

Platforms

Platforms are considered to be the main 'pillars' supporting the classification of biorefineries, because they can be obtained through a variety of different conversion processes, applied to different feedstocks. The most important planforms are:

- biogas (a mixture of mainly CH_4 and CO_2) from anaerobic digestion,
- synthetic gas (a mixture of CO and H_2) from gasification,
- hydrogen (H_2) from the reaction of carbon monoxide with water vapour, steam reforming, electrolysis of water and digestion,
- C_6 sugars (e.g. glucose, fructose. galactose: $C_6H_{12}O_6$) from the hydrolysis of sucrose, starch, cellulose and hemicellulose,
- C_5 sugars (e.g. xylose, arabinose: $C_5H_{10}O_5$), from the hydrolysis of hemicellulose and food and fodder side streams,
- lignin (phenylpropane-based materials for building industry: $C_9H_{10}O_2\ (OCH_3)n$), from conversion of lignocellulose biomass,
- pyrolytic liquid (a multi-component mixture of molecules of different size), from pyrolysis,
- oil (triglycerides: RCOO-CH2CH (-OOCR ') CH2-OOCR") from oil-seed plants, algae and residues of oil-based substances,
- organic juice (from different chemicals), which is the liquid phase extracted after cold-pressing of wet biomass (e.g. grass),
- electric and heating energy, which can be used internally to satisfy the biorefinery plant's demand for energy or can be sold to a power grid.

Products

Biorefinery plants produce products which can be divided into two classes:

1. Energy generating biorefinery systems, where biomass is used mainly to produce secondary energy carriers (biofuels for transport, electricity or heat); products in the form of feeds are also made and sold (the current situation) but as side products, to optimise the economic and ecological outputs of the entire chain of biomass supplies.
2. Biorefinery systems based on materials which generate mainly biotechnology-based products (biomaterials, greases, chemicals, food, feeds, etc.) and process residues, which can be further processed or used to make energy (for internal use or to be sold).

In this approach, biorefinery products are divided into energy products and material products. Some products, such as bio-hydrogen and bioethanol, can be used for both energy purposes or as a marketable product. The category to which a given biorefinery is classified depends on the fact whether its product is intended for the energy or for the chemical market.

Energy products comprise electricity and heat as well as promising transport biofuels, i.e. bioethanol, biodiesel, synthetic biofuels (fuels from the Fisher-Tropsch synthesis and others) and biomethane.

Products based on materials encompass small chemicals (such as amino acids, organic acids and extracts) used in the food processing, chemical or pharmaceutical industries, as well as animal feeds and textile products. Some sub-groups of material products are: fertilisers, bio-hydrogen, glycerine (from triglyceride transesterification), chemicals and building materials (e.g. small chemicals, flavours, amino acids, xylitol, polyols, succinic, lactic, levulinic and itaconic acids, phenols, furanodicarboxylic acid, furfural, etc.), polymers and resins (produced through the (bio)chemical conversion of biomass with monomeric intermediate compounds (e.g. PHA, resins, PLA), food, animal feeds, biomaterials (fibre products, polysaccarides, pulp and paper), panels.

Raw materials

The raw material is composed of biomass. Biomass feedstocks can be divided into the primary, secondary and tertiary materials. Currently, substrates are delivered to a biorefinery plant from four different sectors:

- Agriculture (dedicated plantations and harvest residues),
- Forestry (wood and logging residues),
- Industry (processing residues and waste) and household (organic waste),
- Aquaculture (algae, seaweeds).

Another division is based on the origin of raw materials, that is ones that come from dedicated plantations, produced on farmland or woodland or in water systems, versus these which are waste materials from agriculture, forestry or industries. Biomass raw materials are also different in terms of their basic composition (cellulose, hemicellulose, lignin, starch, triglycerides and protein) and three chemical elements: carbon, oxygen and hydrogen (and S, N and ash). Other important characteristics are: the content of water, calorific value and specific density. In this approach, the following sub-groups of raw materials can be distinguished:

1. Dedicated raw materials: sugar crops (e.g. sugar beet, sugar cane), starch crops (e.g. wheat, maize, sorghum), lignocellulose crops (e.g. willow, poplar, grasses, e.g. miscanthus), oilseed crops (e.g. oilseed rape, soybean, palm oil, jatropha curcas), grasses (e.g. green plant materials, grass silage, unripe cereals and plant shoots), marine biomass (e.g. micro- and macroalgae, seaweeds).
2. Residues: oil-based residues (animal fat from the food processing industry, used cooking oil from restaurants, households, and others), lignocellulose residues (harvest residues, by-products from sawmills, etc.), organic waste and others (e.g. municipal organic waste, manure, wild fruit, cultivated plants).

Processes

Biorefining systems employ different conversion processes. Depending on the final products (e.g. fuels, chemicals, materials, food, feeds), biorefinery plants can be divided into the systems in which operations such as fractionating/dividing into polymer products (food, feeds, biomaterials) are the main processes and systems of biofuels and biochemicals, in which depolymerisation and chemical, thermochemical and/ore biochemical conversion are the principal processes. The aim of biofuel processes is both depolymerisation and deoxidation of biomass. Deoxidation is particularly important, especially when producing transport biofuels because the presence of oxygen can decrease the energy value in molecules and typically endows them with greater polarity, thus restraining their capacity to mix with the existing fossil fuels. On the other hand, the presence of oxygen in chemical products (e.g. polyols and organic acids) often provides the compounds with valuable physical and chemical properties. There are several technological processes that can be employed in biorefining systems to convert biomass substrates into market products. This approach to classification of biorefinery plants distinguishes four major sub-groups of processes:

- Mechanical/physical processes, which do not change the chemical structure of biomass components, but only change the size of particles or separate elements of a substrate (e.g. pressing, pretreatment, milling, separation, distillation).
- Thermochemical processes, in which raw material is submitted to extreme conditions (high temperature and/or pressure, with or without catalytic agents) (e.g. pyrolysis, gasification, hydrothermal upgrading, incineration).
- Chemical processes, in which chemical conversion of a substrate occurs (e.g. hydrolysis, transesterification, hydrogenation, oxidation, digestion).
- Biochemical processes, which proceed under mild conditions (lower temperature and pressure), with the use of microorganisms or enzymes (e.g. anaerobic decomposition, aerobic and anaerobic fermentation, enzymatic conversion).

All processes require additional energy inputs and additional materials. Considering the above classification, it is possible to distinguish the following biorefinery plant models:

- 2-platform biorefinery plant (electricity and heat, synthetic gas) using wood chips to produce FT biofuels, electricity, heat and waxes.
- 3-platform biorefinery plant (C_6 and C_5 sugars, electricity and heat, lignin) using wood chips to produce bioethanol, electric power, heat and phenols.
- 4-platform biorefinery plant (biogas, fibre and juice, electric power and heat) biorefinery plant using grass silage and food waste to produce bioplastics, insullation material, fertilisers, electric power.

Biorefinery plants in the BSR

The inventory of biorefinery plants (Fig. 51) in the BSR has been made on the basis of data collected by the BIO-based Industries Consortium and Nova (Biorefineries in Europe 2017). The presence of biorefineries in the BSR countries is highly diverse. Most biorefinery plants operate in Germany, and these are mostly oil/fat-based biorefineries producing biodiesel (ca 50%) and oleochemistry products (30%). Apart from these, there are also biorefineries in Germany producing ethanol and other chemicals from sugar/starch-based substrates. There are also a few biowaste-based biorefineries. The second BSR country in terms of the number of biorefineries is Finland, where most biorefineries are wood-based ones, although there are three bio-waste based biorefineries, four oil/fat based biorefineries (two producing biodiesel and two producing oleochemicals) as well as two sugar/starch-based biorefineries making bioethanol and other chemicals. The third country with the highest number of biorefineries is Sweden, where the most numerous biorefineries are also wood-based ones, but there are four oil/fat biorefinery plants and single waste-based and sugar/starch-based biorefineries. Among the BSR countries, Denmark, Poland and Norway also have wood-based biorefineries. Additionally, there is one biowaste-based biorefinery and one oil/fat-based biorefinery producing biodiesel. In Poland, there are three biorefineries, two of which are sugar/starch-based ones producing bioethanol and other chemicals, and one oil/fat-based biorefinery producing biodiesel. The type of a biorefinery plant clearly depends on local biomass. There are wood-based biorefineries, mostly in the northern part of the BSR region, whereas oil/fat i sugar/starch biorefineries dominate in the southern regions. No active biorefinery plants have been noted in Lithuania, Latvia and Estonia.

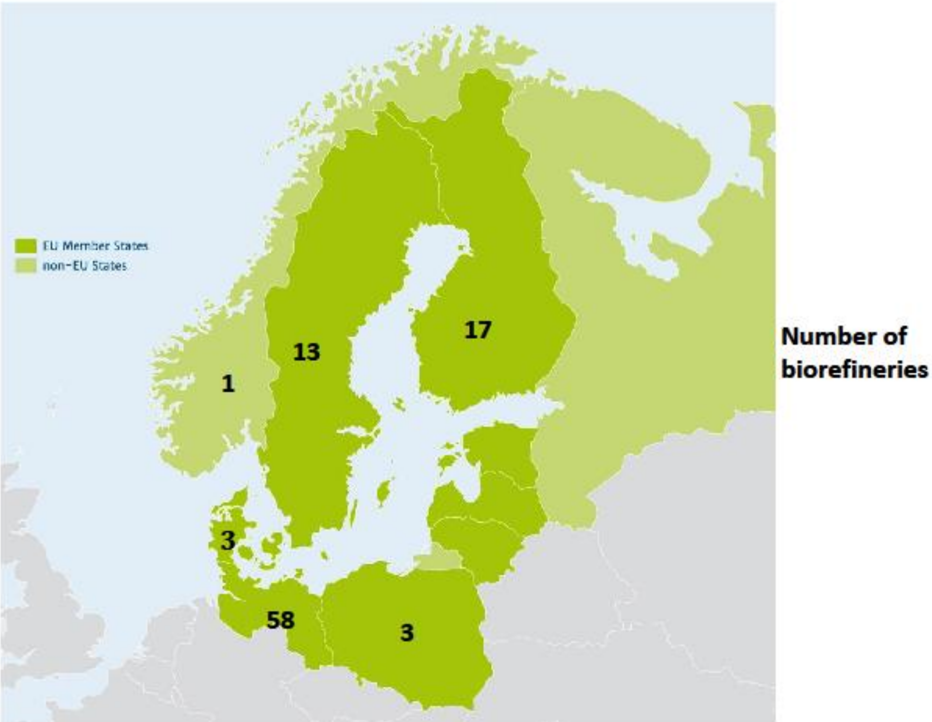

Fig 51. Biorefineries in the BSR in 2017
Source: Biorefineries in Europe 2017.

Biorefinery mapping was also carried out by IEA Bioenergy, and presented in Bioeconomy and biorefining strategies in EU Members States and beyond (Motola et al., 2018). The products covered by the analysis are: bio-based chemicals, including: platform chemicals, solvents, polymers, paints, coatings, inks, surfactants, cosmetics, adhesives, lubricants, plasticizers, stabilizers, enzymes and agrochemicals; liquid biofuels, including: bioethanol, biodiesel and aviation biofuel; biological-based composites and fibers, including: wood-plastic composites, composites of natural fibers and various types of fabrics; bioenergy and bio-heat. The analysis included a grouping approach based on the level of technological readiness of identified plants and installations. According to data of the IEA Bioenergy, in Denmark there are 4 biorefineries, and all of them are commercial establishments (but there is no data on their production profile). Such commercial biorefineries are in Sweden (3) (all produce biofuel), Germany (2) (1 producing biofuel and 1 producing composites and fibers) and Poland (1) (producing biofuel). In addition, there are two biorefineries producing biofuels in Sweden (TRL 8 - i.e. installations producing economically justified scale, research and demonstration completed.) According to the IEA

Bioenergy there are several biorefineries in the demo-plant stage (TRL 5) at the moment: 3 in Denmark (1 producing biofuels and 2 for which there is no product data), 4 in Germany (2 producing biofuels and 2 producing chemicals), 3 in Poland (1 producing biofuels, 1 comopsites and fibers and 1 for which has data on products), and 2 in Sweden (for producing biofuels) (Motola et al., 2018).

6. Conclusions

The analysed Baltic Sea region countries were characterised by a high share of woodlands and agricultural land. They have high wood production and large areas of cropped farmland, particularly Germany and Poland. Because of the large area of forests and the timber industry in the BSR countries, they produced most pellet among all the EU states. The technical potential of straw in the BSR countries corresponded to around 34% of the potential owned by the entire EU-28, and the area used for growing dedicated perennial crops reached almost 65 thousand ha (55% of the total area of these crops in the EU-28). The potential of obtaining manure and slurry was also high, making up 25% and 30% of the potential of the whole European Union, respectively.

The above conditions allow the use of biomass for various purposes and in many bioenergy technologies, i.e. direct combustion, biofuels or biogas production. There are large reasons for this presented below. The share of heating and cooling (but mainly heating) corresponded to over half of the final energy consumption in the BSR countries. The analysed countries were also distinguished by a high share of gross electricity production, which corresponded to half the value of the whole EU-28. Thus, the high level of development of bioenergy technologies and national bioenergy resources justifies the recommendation to propose a strategy for the development of bioenergy and to share the best technologies and the best practices in order to increase the contribution of bioenergy in the BSR countries.

The global increase in human population, decreasing resources of fossil fuels and the progressing climate change are the challenges that economy must face. Search for solutions is associated with the development of smart solutions in line with resource-efficient and sustainable economy. The concept of a biorefinery seems to be a solution to the current problems. A biorefinery understood as a component of bio-based economy that is a promising technology for the management of biomass, efficient conversion ways and pathways towards the use of biomass for production of energy and materials, is a crucial element in the concept of cascade-like use of biomass.

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Appendix 1

In Appendix 1. we provide data in tables from the figures of this study. Empty cells means that the data were no available.

Total BSR means the total value for 9 Baltic Sea Region Countries.

% of the EU-28 means the share the total value for 9 Baltic Sea Region Countries in the relation to the total value for the whole 28 European Union countries.

Table 1. Data shown in Fig. 1. Characterisation of land use (1000 ha) and populations (mln people) in the Baltic Sea Region countries in 2017. Source: Eurostat. 2019.

Table 2. Data shown in Fig. 2. Forest area, forests available for wood supply (1000 ha) and % of private forest ownership in 2017. Source: Eurostat. 2019.

Table 3. Data shown in Fig. 3. Fuel and industrial wood removals from forests and fuel wood import and export (including wood for charcoal) (1000 m3) in BSR countries in 2017. Source: Eurostat. 2019.

Table 4. Data shown in Fig. 4. Area cultivation of major agricultural crops in the BSR countries in 2017 (1000 ha). Source: Eurostat. 2019.

Table 5. Data shown in Fig. 5. Major crop production in the BSR countries in 2017 (1000 Mg). Source: Eurostat. 2019.

Table 6. Data shown in Fig. 6. Plants harvested green from arable land in the BSR countries in 2017 (1000 Mg). Source: Eurostat. 2019.

Table 7. Data shown in Fig. 7. Cereals and oil seeds for the production of seed in the BSR countries in 2017 (1000 Mg). Source: Eurostat. 2019.

Table 8. Data shown in Fig. 8. Root crops production in BSR countries in 2017 (1000 Mg). Source: Eurostat. 2019.

Table 9. Data shown in Fig. 9. Vegetable production in the BSR countries in 2017 (1000 Mg). Source: Eurostat. 2019.

Table 10. Data shown in Fig. 10. Fruit production in the BSR countries in 2017 (1000 Mg). Source: Eurostat. 2019.

Table 11. Data shown in Fig. 11. Theoretical straw potential from cereals and oil seeds production in the BSR countries in 2017 (1000 Mg/year). Source: own calculations.

Table 12. Data shown in Fig. 12. Technical straw potential for energy purposes from cereals and oil seeds in the BSR countries in 2017 (1000 Mg/year). Source: own calculations.

Table 13. Data shown in Fig. 13. Area cropped with perennial energy crops in the BSR countries in 2017 (ha). Source: Bioenergy Europe. 2019e.

Table 14. Data shown in Fig. 14. Theoretical potential of biomass from perennial energy crops in the BSR countries in 2017 (1000 Mg/year). Source: own calculations.

Table 15. Data shown in Fig. 15. Animals in the BSR countries in 2017 (1000 heads). Source: FAO. 2019.

Table 16. Data shown in Fig. 16. Theoretical manure potential in the BSR countries in 2017 (1000 Mg/year). Source: own calculations

Table 17. Data shown in Fig. 17. Theoretical slurry potential in the BSR countries in 2017 (1000 m3/year at 8-10% DM). Source: own calculations.

Table 18. Data shown in Fig. 18. Municipal waste by waste operation in the BSR countries in 2017 (1000 Mg/year). Source: Eurostat. 2019.

Table 19. Data shown in Fig. 19. Sludge disposal from wastewater treatment plants in the BSR countries in 2015 (1000 Mg/year DM). Source: Eurostat. 2019.

Table 20. Data shown in Fig. 20. Catches - major fishing areas and production from aquaculture excluding hatcheries and nurseries in 2017 (Mg live weight) *data for 2016 (Mg). Source: Eurostat. 2019.

Table 21. Data shown in Fig. 21. Estimated amount of processing waste (tonnes) and estimated potential of biogas generation (ktoe/year) from aquatic biomass resources (imported fish & seafood, capture fisheries and aquaculture). Source: Calculations based on:
https://datam.jrc.ec.europa.eu/datam/public/pages/previousFilters.xhtml?dataset=34178536-7fd1-4d5e-b0d4-116be8e4b124
https://datam.jrc.ec.europa.eu/datam/mashup/BIOMASS_FLOWS/index.html

Table 22. Data shown in Fig. 22. Technical biomass potential from different sources in the BSR countries based on the results of project BioBoost (1000 Mg). Source: http://bioboost.eu

Table 23. Data shown in Fig. 23. Share of renewable energy in gross final energy consumption in BSR countries in 2017 and target for 2020 (%). Source: Eurostat. 2019.

Table 24. Data shown in Fig. 24. Share of different types of renewable energy sources in gross inland consumption of total renewable energy sources in BSR countries in 2017 (%). Source: Eurostat. 2019.

Table 25. Data shown in Fig. 25. Pellet capacity. production (Mg) and number of pellet manufacturing plants in the BSR countries in 2017. Source: Bioenergy Europe. 2018.

Table 26. Data shown in Fig. 26. Pellet consumption (Mg) in the BSR countries in 2017. Source: Bioenergy Europe. 2018.

Table 27. Data shown in Fig. 27. Pellet production and consumption (Mg) in the BSR countries in 2017. Source: Bioenergy Europe. 2018.

Table 28. Data shown in Fig. 28. Distribution of population by degree of urbanisation in the BSR countries in 2017 (%). Source: Eurostat. 2019.

Table 29. Data shown in Fig. 31. Distribution of population by degree of urbanisation in the BSR countries in 2017. Source: own calculations based on Eurostat. 2019.

Table 30. Data shown in Fig. 32 Distribution of population by dwelling types in the BSR countries in 2017. Source: Eurostat. 2019.

Table 31. Data shown in Fig. 33. Residential heat production by fuel in the BSR countries in 2017 (ktoe). Source: Bioenergy Europe. 2019d.

Table 32. Data shown in Fig. 34. Structure of residential heat production by fuel in the BSR countries in 2017 (%). Source: Bioenergy Europe. 2019d.

Table 33. Data shown in Fig. 35. Heating and cooling consumption (ktoe) compared with total final energy consumption (%) in the BSR countries in 2017. Source: Bioenergy Europe. 2019d.

Table 34. Data shown in Fig. 36. Gross production of derived heat (ktoe) by type of fuels in the BSR countries in 2017. Source: Bioenergy Europe. 2019d.

Table 35. Data shown in Fig. 37. Share of solid biomass. biogas. renewable waste and liquid biofuels in gross production of derived bioheat in the BSR countries in 2017 (%). Source: Bioenergy Europe. 2019d.

Table 36. Data shown in Fig. 39. Gross electricity production (ktoe) in the BSR countries in 2017. Source: Eurostat. 2019.

Table 37. Data shown in Fig. 41. Share of solid biomass. biogas. renewable municipal waste and liquid biofuels in gross electricity generation from biomass and share of bioelectricity in total gross electricity generation in the BSR countries in 2017 (%). Source: Bioenergy Europe. 2019a.

Table 38. Data shown in Fig. 42. Biofuels capacity in the BSR countries in 2017 (1000 Mg/year). Source: Bioenergy Europe. 2019b.

Table 39. Data shown in Fig. 44. Primary bioethanol production and final energy consumption in the transport sector in the BSR countries in 2017 (ktoe). Source: Bioenergy Europe. 2019b.

Table 40. Data shown in Fig. 45. Primary biodiesel production and final energy consumption in the transport sector in the BSR countries in 2017 (ktoe). Source: Bioenergy Europe. 2019b.

Table 41. Data shown in Fig. 47. Feedstock use for biogas production (excluding landfill - expressed as a mass percentage) in the BSR countries in 2017. Source: Bioenergy Europe. 2019c.

Table 42. Data shown in Fig. 48. Primary energy production of biogas by biogas plant type in the BSR countries in 2017 (%). Source: Bioenergy Europe. 2019c.

Table 43. Data shown in Fig. 49. Gross final energy consumption from biogas by end-use in the BSR countries in 2017 (%). Source: Bioenergy Europe. 2019c.

Appendix 1

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Table 1. Data shown in Fig.. 1. Characterisation of land use (1000 ha) and populations (mln people) in the Baltic Sea Region countries in 2017. Source: Eurostat. 2019.

	DK	DE	EE	FI	LV	LT	PL	SE	NO	Total BSR	% of the EU-28
Total land cover	4316.2	35832.7	4534.7	33754.7	6551.9	6541.2	31385.1	44989.6	32380.9	200287.0	45.7
Artificial land	296.8	2640.4	89.7	553.1	104.9	179.5	1077.0	729.5	547.3	6218.2	34.0
Cropland	2184.0	11543.6	611.2	1977.2	923.3	1911.1	10356.1	1880.5	1116.7	32503.7	33.5
Woodland	793.5	12087.7	2584.2	22940.0	3481.5	2459.4	11143.5	28881.8	12106.1	96477.7	58.6
Shrubland	84.4	379.3	72.9	1442.6	119.8	52.0	315.3	2504.9	274.0	5245.2	16.9
Grassland	757.3	7828.4	720.9	1471.0	1453.5	1616.6	7047.0	2429.7	12186.7	35511.1	39.2
Bare land	54.2	440.9	40.2	300.3	79.9	69.8	520.6	2119.0	2398.3	6023.2	41.2
Water	64.0	649.6	215.7	3386.0	143.4	131.9	529.6	4012.7	2015.3	11148.2	84.3
Wetland	82.0	204.6	199.9	1684.6	152.2	69.7	203.6	2413.7	1736.5	6746.8	92.6
Average population	5.76	82.66	1.32	5.51	1.94	2.83	37.97	10.06	5.28	199874.1	45.7

Table 2. Data shown in Fig. 2. Forest area. forests available for wood supply (1000 ha) and % of private forest ownership in 2017. Source: Eurostat. 2019.

	DK	DE	EE	FI	LV	LT	PL	SE	NO	Total BSR	% of the EU-28
% of private forest ownership	76	48	53	70	48	39	18	76	77	Average 56.1	
Forests	612	11419	2232	22218	3356	2180	9435	28073	12145	91670	56.9
Forests available for wood supply	572	10888	1994	19465	3151	1924	8234	19832	8582	74642	55.5

Table 3. Data shown in Fig. 3. Fuel and industrial wood removals from forests and fuel wood import and export (including wood for charcoal) (1000 m^3) in BSR countries in 2017. Source: Eurostat. 2019.

	DK	DE	EE	FI	LV	LT	PL	SE	NO	Total BSR	% of the EU-28
Fuel wood	2014.6	9929.0	3106.0	7949.0	2200.0	2085.0	5248.0	7500.0	1829.0	41860.6	38.4
Industrial wood	1468.2	43562.0	6842.0	55330.0	10696.0	4662.0	40099.0	65380.0	10491.0	238530.2	66.0
Imports total	101.8	394.0	18.0	11.0	32.0	46.5	58.0	158.0	113.0	932.3	24.1
Exports total	166.6	134.0	267.0	61.0	348.0	165.0	170.0	18.0	28.0	1357.6	34.2

Table 4. Data shown in Fig. 4. Area cultivation of major agricultural crops in the BSR countries in 2017 (1000 ha). Source: Eurostat. 2019.

	DK	DE	EE	FI	LV	LT	PL	SE	NO	Total BSR	% of the EU-28
Cereals	1442.7	6276.2	330.7	864.5	633.4	1199.5	7602.0	993.1	285.9	19628.0	35.3
Dry pulses and protein crops	20.6	178.1	65.6	20.3	48.2	236.2	272.4	55.1	0.0	896.5	34.7
Root crops	88.5	662.5	3.5	33.0	21.7	37.0	560.8	55.6	11.7	1462.6	40.3
Industrial crops	177.6	1398.7	85.5	76.4	115.4	195.2	1003.2	118.8	0.0	3170.8	
Plants harvested green	492.1	2753.8	170.8	780.9	294.0	228.9	1037.7	1119.2	0.0	6877.3	33.0
Fresh vegetables	11.3	125.0	2.4	12.3	2.4	10.1	192.0	10.8	0.0	366.2	17.3
Fruits. berries and nuts	3.2	59.0	1.9	3.2	5.5	21.6	323.5	2.0	0.0	419.8	
Strawberries	1.2	14.2	0.5	6.9	0.5	0.8	49.8	2.0	1.5	77.4	71.4
Total	2237.1	11467.4	660.8	1797.5	1121.1	1929.4	11041.4	2356.5	299.1	32910.4	

Table 5. Data shown in Fig. 5. Major crop production in the BSR countries in 2017 (1000 Mg). Source: Eurostat. 2019.

	DK	DE	EE	FI	LV	LT	PL	SE	NO	Total BSR	% of the EU-28
Cereals	9883.0	45593.2	1311.9	3462.1	2692.5	5074.2	31331.0	5958.4	1205.8	106512.1	34.4
Dry pulses and protein crops	88.1	571.0	75.3	42.7	170.7	707.4	598.0	190.5	0.0	2443.6	39.4
Root crops	4920.1	46231.6	63.9	1042.3	214.2	1202.2	25041.8	2816.0	314.5	81532.1	
Industrial crops	742.3	4398.5	168.9	92.3	328.2	553.7	2657.8	385.1	0.0	9326.6	
Plants harvested green	32751.2	115147.1	0.0	7877.5	0.0	5440.8	22626.4	15244.3	0.0	199087.3	

Table 6. Data shown in Fig. 6. Plants harvested green from arable land in the BSR countries in 2017 (1000 Mg). Source: Eurostat. 2019.

	DK	DE	EE	FI	LV	LT	PL	SE	NO	Total BSR	% of the EU-28
Temporary grasses and grazings	20417.9	5989.1	0.0	6794.7	0.0	3920.8	3019.4	13890.0	0.0	54031.9	
Leguminous plants harvested green	192.3	6569.1	0.0	13.3	0.0	711.6	2374.9	0.0	0.0	9861.3	
Green maize	10141.8	99473.4	208.7	0.0	689.3	643.7	16582.8	537.7	0.0	128277.4	48.7
Other cereals harvested green	2126.7	2825.0	88.1	1034.6	30.8	80.4	522.6	494.3	0.0	7202.5	64.6
Other plants harvested green	0.0	0.0	0.0	0.0	0.0	6.9	126.7	322.3	0.0	455.9	

Table 7. Data shown in Fig. 7. Cereals and oil seeds for the production of seed in the BSR countries in 2017 (1000 Mg). Source: Eurostat. 2019.

	DK	DE	EE	FI	LV	LT	PL	SE	NO	Total BSR	% of the EU-28
Wheat and spelt	4777.9	24481.6	713.3	812.2	2138.8	3917.4	11448.7	3298.6	0.0	51588.4	34.0
Rye and winter cereal mixtures	714.8	2737.4	52.4	115.2	129.4	63.1	2869.4	141.8	42.5	6866.0	89.7
Barley	3945.9	10853.4	425.7	1477.1	240.9	519.7	3722.5	1635.2	527.8	23348.1	39.8
Oats	318.4	576.5	89.4	1028.1	134.0	195.9	1437.4	676.4	260.9	4717.0	57.6
Spring cereal mixtures	27.7	43.3	1.4	28.6	6.3	20.3	2548.9	41.1	0.0	2717.6	88.9
Grain maize and corn-cob-mix	38.5	4547.6	0.0	0.0	0.0	57.0	3946.8	8.8	0.0	8598.6	13.3
Triticale	59.8	2317.0	26.5	0.0	26.0	247.5	5213.2	156.5	0.0	8046.5	69.4
Other cereals (buckwheat. millet...)	0.0	0.0	3.4	0.0	17.1	53.3	144.2	0.0	0.0	218.0	30.6
Oilseeds	742.3	4398.5	165.3	92.3	327.9	553.5	2648.2	385.1	0.0	9312.9	

Table 8. Data shown in Fig. 8. Root crops production in BSR countries in 2017 (1000 Mg). Source: Eurostat. 2019.

	DK	DE	EE	FI	LV	LT	PL	SE	NO	Total BSR	% of the EU-28
Potatoes	2171.0	11720.0	63.2	611.9	209.3	231.7	8956.0	852.5	314.5	25130.2	40.5
Sugar beet	2454.6	34059.9	0.0	430.3	0.0	957.0	15733.0	1963.5	0.0	55598.2	38.8

Table 9. Data shown in Fig. 9. Vegetable production in the BSR countries in 2017 (1000 Mg). Source: Eurostat. 2019.

	DK	DE	EE	FI	LV	LT	PL	SE	NO	Total BSR	% of the EU-28
Brassicas	53.7	922.8	10.1	32.1	20.5	47.6	1400.6	30.9	0.0	2518.4	35.4
Leafy and stalked vegetables (excluding brassicas)	32.7	693.9	0.0	19.5	0.7	3.1	263.3	37.0	0.0	1050.1	14.3
Vegetables cultivated for fruit (including melons)	28.5	525.7	6.8	92.9	13.2	33.2	1705.1	58.4	28.3	2492.0	8.0
Root. tuber and bulb vegetables	198.7	1660.6	12.4	115.6	25.8	91.3	2156.3	202.4	70.2	4533.4	28.6
Fresh pulses	15.4	87.1	0.7	7.2	0.0	0.7	128.3	12.4	0.0	251.6	11.0

Table 10. Data shown in Fig. 10. Fruit production in the BSR countries in 2017 (1000 Mg). Source: Eurostat. 2019.

	DK	DE	EE	FI	LV	LT	PL	SE	NO	Total BSR	% of the EU-28
Apples	20.5	596.7	1.0	6.8	7.5	73.4	2441.4	22.1	12.7	3181.9	31.7
Pears	4.5	23.4	0.0	0.2	0.4	2.0	55.1	2.1	0.3	87.9	3.6
Plums	0.4	26.6	0.0	0.0	0.1	0.3	58.4	0.3	1.2	87.2	6.7
Cherries	4.2	24.8	0.0	0.0	0.1	0.5	91.3	0.1	0.6	121.5	16.4
Currants	3.3	12.5	0.2	1.9	0.4	3.8	128.8	0.4	0.0	151.2	79.6
Raspberries	0.1	6.4	0.1	1.1	0.2	1.7	104.5	0.4	3.0	117.5	54.6
Blueberries	0.1	13.8	0.0	0.1	0.3	0.1	16.3	0.1	0.0	30.9	35.7
Strawberries	6.7	135.3	1.1	12.0	1.4	2.1	189.1	15.7	8.5	371.9	29.4
Grapes	0.0	0.0	0.0	0.0	0.0	0.0	2.8	0.1	0.0	2.8	0.0
Nuts	0.0	0.0	0.0	0.0	0.0	0.1	8.4	0.0	0.0	8.4	0.9

Table 11. Data shown in Fig. 11. Theoretical straw potential from cereals and oil seeds production in the BSR countries in 2017 (1000 Mg/year). Source: own calculations.

	DK	DE	EE	FI	LV	LT	PL	SE	NO	Total BSR	% of the EU-28
Wheat and spelt	4300.1	22033.4	641.9	731.0	1924.9	3525.6	10303.8	2968.7	0.0	46429.6	34.0
Rye and winter cereal mixtures	643.3	2463.7	47.1	103.7	116.5	56.8	2582.5	127.6	38.3	6179.4	89.7
Barley	3551.3	9768.1	383.1	1329.4	216.8	467.8	3350.2	1471.7	475.0	21013.3	39.8
Oats	286.6	518.9	80.5	925.2	120.6	176.3	1293.6	608.8	234.8	4245.3	57.6
Spring cereal mixtures	25.0	39.0	1.2	25.7	5.7	18.3	2294.0	37.0	0.0	2445.8	88.9
Grain maize and corn-cob-mix	34.6	4092.8	0.0	0.0	0.0	51.3	3552.1	7.9	0.0	7738.7	13.3
Triticale	53.8	2085.3	23.8	0.0	23.4	222.8	4691.9	140.9	0.0	7241.8	69.4
Other cereals (buckwheat. millet...)	0.0	0.0	3.1	0.0	15.4	48.0	129.8	0.0	0.0	196.2	30.6
Oilseeds	668.0	3958.7	148.7	83.0	295.1	498.1	2383.3	346.6	0.0	8381.6	
Total	9562.7	44959.8	1329.4	3198.1	2718.4	5064.9	30581.2	5709.2	748.1	103871.7	

Table 12. Data shown in Fig. 12. Technical straw potential for energy purposes from cereals and oil seeds in the BSR countries in 2017 (1000 Mg/year). Source: own calculations.

	DK	DE	EE	FI	LV	LT	PL	SE	NO	Total BSR	% of the EU-28
Wheat and spelt	716.7	3672.2	107.0	121.8	320.8	587.6	1717.3	494.8	0.0	7738.3	34.0
Rye and winter cereal mixtures	107.2	410.6	7.9	17.3	19.4	9.5	430.4	21.3	6.4	1029.9	89.7
Barley	591.9	1628.0	63.9	221.6	36.1	78.0	558.4	245.3	79.2	3502.2	39.8
Oats	47.8	86.5	13.4	154.2	20.1	29.4	215.6	101.5	39.1	707.5	57.6
Spring cereal mixtures	4.2	6.5	0.2	4.3	0.9	3.0	382.3	6.2	0.0	407.6	88.9
Grain maize and corn-cob-mix	5.8	682.1	0.0	0.0	0.0	8.5	592.0	1.3	0.0	1289.8	13.3
Triticale	9.0	347.6	4.0	0.0	3.9	37.1	782.0	23.5	0.0	1207.0	69.4
Other cereals (buckwheat. millet...)	0.0	0.0	0.5	0.0	2.6	8.0	21.6	0.0	0.0	32.7	30.6
Oilseeds	111.3	659.8	24.8	13.8	49.2	83.0	397.2	57.8	0.0	1396.9	
Total	1593.8	7493.3	221.6	533.0	453.1	844.1	5096.9	951.5	124.7	17312.0	

Table 13. Data shown in Fig. 13. Area cropped with perennial energy crops in the BSR countries in 2017 (ha). Source: Bioenergy Europe. 2019e.

	DK	DE	EE	FI	LV	LT	PL	SE	NO	Total BSR	% of the EU-28
Short Rotation Coppice	8896	6600		26	666	4063	16832	10932		48015	75.1
Grasy energy crops	66	9200		5452	253		992	691		16654	31.1
Total	8962	15800		5478	919	4063	17824	11623		64669	55.1

Table 14. Data shown in Fig. 14. Theoretical potential of biomass from perennial energy crops in the BSR countries in 2017 (1000 Mg/year). Source: own calculations.

	DK	DE	EE	FI	LV	LT	PL	SE	NO	Total BSR	% of the EU-28
Short Rotation Coppice	62.3	46.2	0.0	0.2	4.7	28.4	117.8	76.5	0.0	336.1	
Grasy energy crops	0.5	64.4	0.0	38.2	1.8	0.0	6.9	4.8	0.0	116.6	
Total	62.7	110.6	0.0	38.3	6.4	28.4	124.8	81.4	0.0	452.7	

Table 15. Data shown in Fig. 15. Animals in the BSR countries in 2017 (1000 heads). Source: FAO. 2019.

	DK	DE	EE	FI	LV	LT	PL	SE	NO	Total BSR	% of the EU-28
Cattle	1545	12281	248	893	412	695	6143	1449	861	24528	27.3
Pigs	12308	27578	266	1136	336	664	11353	1382	811	55833	37.8
Sheep	154	1580	86	156	107	164	261	606	2393	5506	5.5
Horses	52	448	6	74	9	16	185	103	34	928	27.5
Goats	0	140	5	5	13	13	44	0	62	284	1.9
Chickens	20733	160000	2054	8047	2171	9917	177640	9075	14480	404117	29.0
Turkeys	304	12875	10	292	18	146	12228	100	638	26611	29.5
Ducks	174	2417	9	0	0	16	3181	0	121	5918	13.7
Geese and guinea fowls	4	301	8	0	0	13	4173	0	0	4499	40.1
Total	35274	217620	2692	10603	3067	11644	215209	12714	19401		

Table 16. Data shown in Fig. 16. Theoretical manure potential in the BSR countries in 2017 (1000 Mg/year). Source: own calculations

	DK	DE	EE	FI	LV	LT	PL	SE	NO	Total BSR	% of the EU-28
Cattle	13 494.6	107 239.4	2 167.6	7 799.2	3 600.3	6 066.6	53 641.4	12 649.1	7 518.4	214176.5	27.3
Pigs	2 953.8	6 618.6	63.8	272.5	80.7	159.3	2 724.7	331.8	194.7	13 399.9	37.8
Sheep	185.0	1 895.8	102.6	187.1	128.0	196.3	313.5	727.3	2 872.0	6607.5	5.5
Horses	257.9	2 240.7	31.5	372.0	46.4	81.6	927.5	512.6	169.9	4640.1	27.
Goats	0.0	140.0	5.1	5.3	13.2	13.4	44.2	0.0	62.4	283.5	1.9
Chickens	725.7	5 600.0	71.9	281.6	76.0	347.1	6 217.4	317.6	506.8	14144.1	29.
Turkeys	18.2	772.5	0.6	17.5	1.1	8.8	733.7	6.0	38.3	1596.7	29.
Ducks	10.4	145.0	0.5	0.0	0.0	1.0	190.9	0.0	7.3	355.1	13.
Geese and guinea fowls	0.2	12.0	0.3	0.0	0.0	0.5	166.9	0.0	0.0	180.0	40.
Total	17 645.8	124 664.1	2 444.0	8 935.3	3 945.6	6 874.6	64 960.1	14 544.3	11369.7	255383.4	24.8

Table 17. Data shown in Fig. 17. Theoretical slurry potential in the BSR countries in 2017 (1000 m^3/year at 8-10% DM). Source: own calculations.

	DK	DE	EE	FI	LV	LT	PL	SE	NO	Total BSR	% of the EU-28
Cattle	14573.3	115811.7	2340.9	8422.7	3888.1	6551.5	57929.3	13660.2	8119.3	231296.9	27.3
Pigs	19643.0	44013.8	424.4	1812.4	536.9	1059.6	18118.9	2206.2	1294.4	89109.6	37.8
Total	34216.3	159825.5	2765.3	10235.1	4425.0	7611.1	76048.2	15866.4	9413.8	320406.6	29.6

Table 18. Data shown in Fig. 18. Municipal waste by waste operation in the BSR countries in 2017 (1000 Mg/year). Source: Eurostat. 2019.

	DK	DE	EE	FI	LV	LT	PL	SE	NO	Total BSR	% of the EU-28
Disposal - landfill and other	38.0	451.0	98.0	26.0	518.0	421.0	5000.0	20.0	137.0	6709.0	11.5
Disposal - incineration	0.0	612.0	0.0	0.0	0.0	0.0	198.0	0.0	0.0	810.0	35.7
Recovery - energy recovery	2355.0	15946.0	217.0	1646.0	21.0	236.0	2724.0	2400.0	2088.0	27633.0	40.3
Recycling - material	1282.0	25355.0	127.0	771.0	141.0	311.0	3199.0	1426.0	1138.0	33750.0	45.7
Recycling - composting and digestion	834.0	9429.0	19.0	369.0	57.0	308.0	848.0	704.0	395.0	12963.0	31.3
Total	4509.0	51790.0	492.0	2812.0	737.0	1275.0	11969.0	4551.0	3949.0	82084.0	33.4

Table 19. Data shown in Fig. 19. Sludge disposal from wastewater treatment plants in the BSR countries in 2015 (1000 Mg/year DM). Source: Eurostat. 2019.

	DK	DE	EE	FI	LV	LT	PL	SE	NO
Agricultural use		427.7	0.3		4.706	11.218	126.6	59.5	70.9
Compost and other applications		223.674	16.44		6.074	15.565	48.2	0	20.5
Landfill		0	2.4		0.396	0	131.5	0	19.6
Incineration		1148.679	0		0	0	165.4	0	0
Other		2.998	14.43		11.618	0	479.8	0	3.3
Total		1803.1	33.6		22.8	26.8	951.5	59.5	114.4

Table 20. Data shown in Fig. 20. Catches - major fishing areas and production from aquaculture excluding hatcheries and nurseries in 2017 (Mg live weight) *data for 2016 (Mg). Source: Eurostat. 2019.

	DK	DE	EE	FI	LV	LT	PL	SE	NO	Total BSR	% of the EU-28
Catches. major fishing areas (all aquatic. Mg live weight) - LV*	904450	229406	162017	79647	114655	72145	207139	221823	2221036	4212318.0	81.9
Production from aquaculture excluding hatcheries and nurseries (Mg live weight) - DE*. LV*. PL*. SE/. NO*	34327	36142	14584	870	779	3459	35419	14848	1308485	1448913.6	115.0
Total	938777	265548	176601	80518	115434	75604	242558	236671	3529521		

Table 21. Data shown in Fig. 21. Estimated amount of processing waste (tonnes) and estimated potential of biogas generation (ktoe/year) from aquatic biomass resources (imported fish & seafood, capture fisheries and aquaculture). Source: Calculations based on: https://datam.jrc.ec.europa.eu/datam/public/pages/previousFilters.xhtml?dataset=34178536-7fd1-4d5e-b0d4-116be8e4b124
https://datam.jrc.ec.europa.eu/datam/mashup/BIOMASS_FLOWS/index.html
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	DK	DE	EE	FI	LV	LT	PL	SE	NO
Estimated potential of biogas generation (ktoe/year)	2684.9	3638.0	210.2	771.6	369.3	790.4	1514.2	600.6	n.d.
Estimated amount of processing waste (tonnes)	43707.1	59223.5	3422.0	12561.7	6012.6	12867.1	24649.7	9777.9	n.d.

Table 22. Data shown in Fig. 22. Technical biomass potential from different sources in the BSR countries based on the results of project BioBoost (1000 Mg). Source: http://bioboost.eu

	DK	DE	EE	FI	LV	LT	PL	SE	NO
Straw	4645.9	19911.5	206.5		593.2	1612.0	12568.5	2750.1	
Residuals of pruning	0.5	214.2	1.5		2.3	6.4	124.1	1.6	
Livestock Residues	0.0	3336.1	0.0		0.0	0.0	0.0	0.0	
Hay from permanent grassland	7.5	0.0	0.0		256.5	0.0	22.0	0.0	
Forestry residues	695.8	15862.1	1590.5		2485.1	1391.7	9572.6	13717.7	
Green urban areas	63.2	128.5	3.1		4.9	7.1	57.4	53.8	
Perennial crops	749.9	3022.9	98.9		340.6	575.6	5971.0	991.8	
Roadside vegetation	25.9	472.1	10.2		10.7	24.5	143.7	62.9	
Biodegradable municipal waste	614.0	12313.1	126.9		112.7	86.2	3519.8	993.8	
Bio-waste of food industry	0.0	149.4	0.0		0.0	0.0	0.4	0.0	
Total	6802.7	55200.3	2037.6		3805.9	3703.4	31979.5	18571.7	

Table 23. Data shown in Fig. 23. Share of renewable energy in gross final energy consumption in BSR countries in 2017 and target for 2020 (%). Source: Eurostat. 2019.

	EU-28	DK	DE	EE	FI	LV	LT	PL	SE	NO
2017	17.5	35.8	15.5	29.2	41.0	39.0	25.8	10.9	54.5	71.2
Target 2020	20.0	30.0	18.0	25.0	38.0	40.0	23.0	15.0	49.0	

Table 24. Data shown in Fig. 24. Share of different types of renewable energy sources in gross inland consumption of total renewable energy sources in BSR countries in 2017 (%). Source: Eurostat. 2019.

	DK	DE	EE	FI	LV	LT	PL	SE	NO
Solid biofuels	53.78	29.50	92.63	73.41	73.40	80.92	70.52	45.54	6.42
Liquid biofuels for transport	3.98	6.65	0.09	3.76	0.56	3.90	6.80	7.87	3.46
Biogas	6.51	18.37	1.21	1.06	4.82	2.06	3.15	0.85	0.25
Municipal waste (renewable)	8.71	7.53	0.00	2.78	1.04	1.88	1.04	4.18	1.35
Hydro	0.03	4.06	0.21	10.79	19.46	3.31	2.47	26.77	84.05
Geothermal	0.06	0.60	0.00	0.00	0.00	0.05	0.25	0.00	0.00
Wind	21.25	21.28	5.85	3.50	0.67	7.50	14.37	7.24	1.69
Solar	2.01	9.51	0.00	0.05	0.00	0.37	0.77	0.15	0.00
Ambient heat (heat pumps)	3.68	2.50	0.00	4.66	0.05	0.00	0.63	7.41	2.79

Table 25. Data shown in Fig. 25. Pellet capacity. production (Mg) and number of pellet manufacturing plants in the BSR countries in 2017. Source: Bioenergy Europe. 2018.

	DK	DE	EE	FI	LV	LT	PL	SE	NO	Total BSR	% of the EU-28
Number of operating production plants	5	55	23	29	27	17	55	64	4	279	42.5
Production capacity (tonnes)	300000	3400000	1612000	630000	1950000	400000	1200000	2300000	105000	11897000	52.2
Actual production (tonnes)	180000	2250000	1057000	324000	1466000	350000	1000000	1678929	57368	8363297	54.6

Table 26. Data shown in Fig. 26. Pellet consumption (Mg) in the BSR countries in 2017. Source: Bioenergy Europe. 2018.

	DK	DE	EE	FI	LV	LT	PL	SE	NO	Total BSR	% of the EU-28
Residential	800000	1420000	30000	62000	129000	47500	233000	586816	46180	3354496	34.4
Commercial	160000	620000	10000	188000	9000	12500	50000	545555	24866	1619921	48.1
CHP	2300000	60000	0	100000	0	0	30000	395795	0	2885795	98.0
Power only	0	0	0	0	0	0	30000	0	0	30000	0.4

Table 27. Data shown in Fig. 27. Pellet production and consumption (Mg) in the BSR countries in 2017. Source: Bioenergy Europe. 2018.

	DK	DE	EE	FI	LV	LT	PL	SE	NO	Total BSR	% of the EU-28
Actual production (tonnes)	180000	2250000	1057000	324000	1466000	350000	1000000	1678929	57368	8363297	54.6
Actual consumption (tonnes)	3260000	2100000	40000	350000	138000	60000	343000	1528166	71046	7890212	32.7

Table 28. Data shown in Fig. 30. Distribution of population by degree of urbanisation in the BSR countries in 2017 (%). Source: Eurostat. 2019.

	DK	DE	EE	FI	LV	LT	PL	SE	NO	EU-28
Cities	32.3	36.6	43.9	37.8	43.5	42.9	33.9	39.6	29.3	41.7
Towns and suburbs	34.6	40.4	15.3	32.9	19.4	2.2	24.4	40.0	39.0	31.0
Rural areas	33.1	23.0	40.8	29.3	37.1	54.9	41.7	20.4	31.7	27.3

Table 29. Data shown in Fig. 31. Distribution of population by degree of urbanisation in the BSR countries in 2017. Source: own calculations based on Eurostat. 2019.

	DK	DE	EE	FI	LV	LT	PL	SE	NO	Total BSR
Cities	1862089	30252463	578332	2082105	844878	1213385	12873466	3982848	1546152	55235717
Towns and suburbs	1994683	33393429	201560	1812202	376796	62225	9265858	4023079	2058018	53187849
Rural areas	1908208	19011110	537493	1613907	720574	1552793	15835502	2051770	1672799	44904157
Total	5764980	82657002	1317384	5508214	1942248	2828403	37974826	10057698	5276968	153327723

Table 30. Data shown in Fig. 32. Distribution of population by dwelling types in the BSR countries in 2017. Source: Eurostat. 2019.

	DK	DE	EE	FI	LV	LT	PL	SE	NO	Total BSR
Detached house	3118854	21821449	430785	2566828	594328	1006911	19177287	4586310	3087026	56389778
Semi-detached house	789802	12977149	64552	1024528	52441	149905	2164565	915251	1081778	19219971
Flat	1833264	46866520	814143	1889317	1289653	1660273	16594999	4546079	1092332	76586581
Others	28825	991884	7904	27541	5827	14142	75950	10058	15831	1177961

Table 31. Data shown in Fig. 33. Residential Heat Production by Fuel in the BSR countries in 2017 (ktoe). Source: Bioenergy Europe. 2019d.

	DK	DE	EE	FI	LV	LT	PL	SE	NO	Total BSR	% of the EU-28
Solid Fossil Fuels	0	500	2	4	10	57	6554	0	0	86263	35.2
Natural Gas	582	21598	55	26	111	154	3630	36	0	7127	75.7
Oil and Petroleum	216	11348	10	359	55	55	599	20	133	26192	25.2
Derived Heat	1673	4431	318	1660	372	475	3917	2614	0	12662	39.1
Electricity (for H&C)	199	5456	0	1190	50	40	565	1615	2148	15460	68.9
Biomass	1054	5984	390	1276	505	470	2621	943	613	9115	34.7
Geothermal	0	28	0	0	0	0	17	0	0	13243	30.1
Solar Thermal	12	645	0	2	0	0	49	11	0	45	47.4
Heat Pumps	152	993	0	500	0	0	40	0	122	719	36.6
Others	8	0	0	0	0	0	0	2	0	1807	40.1

Table 32. Data shown in Fig. 34. Structure of residential heat production by fuel in the BSR countries in 2017 (%). Source: Bioenergy Europe. 2019d.

	DK	DE	EE	FI	LV	LT	PL	SE	NO
Solid Fossil Fuels	0.0	1.0	0.3	0.1	0.9	4.6	36.4	0.0	0.0
Natural Gas	14.9	42.4	7.1	0.5	10.1	12.3	20.2	0.7	0.0
Oil and Petroleum	5.5	22.3	1.3	7.2	5.0	4.4	3.3	0.4	3.4
Derived Heat	42.9	8.7	41.0	33.1	33.7	37.9	21.8	49.9	0.0
Electricity (for H&C)	5.1	10.7	0.0	23.7	4.5	3.2	3.1	30.8	55.5
Biomass	27	12	50	25	46	38	15	18	16
Geothermal	0.0	0.1	0.0	0.0	0.0	0.0	0.1	0.0	0.0
Solar Thermal	0.3	1.3	0.0	0.0	0.0	0.0	0.3	0.2	0.0
Heat Pumps	3.9	1.9	0.0	10.0	0.0	0.0	0.2	0.0	3.2
Others	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table 33. Data shown in Fig. 35. Heating and cooling consumption (ktoe) compared with total final energy consumption (%) in the BSR countries in 2017. Source: Bioenergy Europe. 2019d.

	DK	DE	EE	FI	LV	LT	PL	SE	NO	Total BSR	% of the EU-28
% of the H&C Sector in the Final Energy Consumption	55.2	54.1	54.9	57.4	60.8	48.6	55.2	43.8	52.8	Average 53.6	
H&C Energy Consumption	7654	110670	1539	14142	2357	2550	38177	14163	9776	201028.1	38.3
Total Final Energy Consumption	13862	204604	2806	24640	3875	5241	69139	32370	18532	375069	35.4

Table 34. Data shown in Fig. 36. Gross production of derived heat (ktoe) by type of fuels in the BSR countries in 2017. Source: Bioenergy Europe. 2019d.

	DK	DE	EE	FI	LV	LT	PL	SE	NO	Total BSR	% of the EU-28
Solid Fossil Fuels	459	3126	0	771	2	1	5755	96	0	10210	76.3
Natural Gas	493	5241	128	495	397	238	589	76	25	7682	35.4
Oil and Petroleum Products	29	109	19	199	1	8	98	58	0	521	22.2
Non-Renewable Waste	300	936	27	137	0	19	56	551	345	2371	76.3
Biomass	1797	1600	297	1897	316	564	312	3154	187	10124	68.9
Other sources	69	30	109	651	0	7	332	492	84	1774	73.6
Total	3148	11042	579	4150	716	836	7142	4427	646	32686	56.7

Table 35. Data shown in Fig. 37. Share of solid biomass. biogas. renewable waste and liquid biofuels in gross production of derived bioheat in the BSR countries in 2017 (%). Source: Bioenergy Europe. 2019d.

	DK	DE	EE	FI	LV	LT	PL	SE	NO
Soild Biomass	75	38	100	90	92	97	89	80	0
Biogas	4	13	0	1	8	0	7	0	0
Renewable Waste	20	48	0	9	0	3	4	19	0
Liquid Biofuels	0	0	0	0	0	0	0	1	0

Table 36. Data shown in Fig. 39. Gross electricity production (ktoe) in the BSR countries in 2017. Source: Eurostat. 2019.

	DK	DE	EE	FI	LV	LT	PL	SE	NO	Total BSR	% of the EU-28
Solid Fossil Fuels	534	20802	11	742	0	0	11278	45	0	33415	58.3
Petroleum Products	24	479	863	16	0	12	174	25	2	1595	26.3
Gas	164	8476	70	334	178	51	1059	84	229	10647	17.8
Nuclear	0	6563	0	1933	0	0	0	5649	0	14144	19.8
Non-renewable waste	62	627	12	41	0	7	27	145	22	943	43.2
Renewables (excl. biomass)	1337	14739	64	1686	390	225	1557	7137	12540	39675	56.2
Total biomass	547	4379	89	1020	80	43	558	1038	21	7776	48.8
Total	2668.9	56065.00	1109.46	5771.58	647.566	338.53	14652.07	14122.96	12818.40	108194.46	38.2

Table 37. Data shown in Fig. 41. Share of solid biomass. biogas. renewable municipal waste and liquid biofuels in gross electricity generation from biomass and share of bioelectricity in total gross electricity generation in the BSR countries in 2017 (%). Source: Bioenergy Europe. 2019a.

	DK	DE	EE	FI	LV	LT	PL	SE	NO
Soild biomass	75	21	97	92	56	60	82	85	5
Biogas	11	67	3	3	44	26	17	0	10
Renewable municipal waste	14	12	0	5	0	14	1	15	86
Bioliquids	0	1	0	0	0	0	0	0	0
% Bioelectricity in total gross electricity generation	21	8	8	18	12	13	4	7	0.2

Table 38. Data shown in Fig. 42. Biofuels Capacity in the BSR countries in 2017 (1000 Mg/year). Source: Bioenergy Europe. 2019b.

	DK	DE	EE	FI	LV	LT	PL	SE	NO	Total BSR	% of the EU-28
Bioethanol	0	792	0	50	19	20	858	190	0	1929	27.3
Biodiesel	0	4153	0	490	173	140	1321	132	0	6409	29.2
Other liquid Biofuels	0	3962	0	51	0	0	0	63	0	4076	83.5
Total	0	8907	0	591	192	160	2179	385	0	12414	36.6

Table 39. Data shown in Fig. 44. Primary bioethanol production and final energy consumption in the transport sector in the BSR countries in 2017 (ktoe). Source: Bioenergy Europe. 2019b.

	DK	DE	EE	FI	LV	LT	PL	SE	NO	Total BSR	% of the EU-28
Bioethanol Production	0	406	0	0	6	9	123	119	0	663	27.4
Bioethanol Consumption	0	733	1	81	8	7	176	99	28	1133	40.8

Table 40. Data shown in Fig. 45. Primary biodiesel production and final energy consumption in the transport sector in the BSR countries in 2017 (ktoe). Source: Bioenergy Europe. 2019b.

	DK	DE	EE	FI	LV	LT	PL	SE	NO	Total BSR	% of the EU-28
Biodiesel Production	0	2841	0	310	47	104	793	66	0	4161	34.0
Biodiesel Consumption	215	1827	0	310	1	54	429	1421	462	4719	39.5

Table 41. Data shown in Fig. 47. Feedstock use for biogas production (excluding landfill - expressed as a mass percentage) in the BSR countries in 2017. Source: Bioenergy Europe. 2019c.

	DK	DE	EE	FI	LV	LT	PL	SE	NO
Energy crops	2	49		0	77		12	0	
Agricultural residues	51	45		6	5		53	7	
Biowaste. municipal waste	1	4		89	12		0	0	
Industrial (food and beverage)	26	2		0	4		35	2	
Sewage	16			6	2		0	90	
Other waste fraction	4			0	0		0	1	

Table 42. Data shown in Fig. 48. Primary energy production of biogas by biogas plant type in the BSR countries in 2017 (%). Source: Bioenergy Europe. 2019c.

	DK	DE	EE	FI	LV	LT	PL	SE	NO
Landfill	1.3	1.7	69.2	16.8	8.6	15.6	17.1	2.8	
Sewage sludge	6.7	5.9	30.8	13.6	2.2	21.9	40.9	44.1	
Agriculture	60.4	92.4	0.0	24.8	89.2	62.5	42.0	53.1	
Biogas from thermal processes	31.6	0.0	0.0	44.8	0.0	0.0	0.0		

Table 43. Data shown in Fig. 49. Gross final energy consumption from biogas by end-use in the BSR countries in 2017 (%). Source: Bioenergy Europe. 2019c.

	DK	DE	EE	FI	LV	LT	PL	SE	NO
Electricity	25.7	62.9	33.3	43.2	52.2	52.4	47.5	0.4	
Direct used (industry. household. commercial etc.)	41.7	31.6	58.3	30.9	11.9	38.1	41.9	54.6	
Heat	32.6	4.6	8.3	25.9	35.8	9.5	10.6	3.7	
Transport	0.1	0.8	0.0	0.4	0.0	0.0	0.0	41.3	

Appendix 2

Information on algae situation in the BSR countries

Country	Industrial algae cultivation	Usage of algae biomass for energy purposes	Usage of algae biomass for other bio-based products
Estonia	In Estonia there is only one extensive cultivated large algae species - the unattached form of the red alga Furcellaria lumbricalis (agaric). Its natural assemblage in the Kassari bay has been used since the 1960s. The most promising seaweed species in Estonia are aquaculture species Fucus vesiculosus, Furcellaria lumbricalis, Ulva intestinalis and Cladophora glomerata[1].	-	*Est-Agar AS is the only producer of the unique texturant – furcellaran from the red seaweed Furcellaria lumbricalis in the world. Est-Agar AS main business areas are: – Production and sale of gelling agent furcellaran; – Trawling, gathering, buying up, processing and sale of red seaweed Furcellaria lumbricalis[2]. *Estonian company Numami prepares crispbread, pesto and freeze-dried algae flakes from different algae (Dulse, Wakame and Kombu). Algae is grown in cooperation with a Norwegian research farm, but the company hopes to get some part of raw material from Estonia in the future[3].
Germany	Micro- and macroalgae are grown industrially in Germany.	There is no such practice	Vegan Food products from macroalgae (e.g. Algae-Pasta; Algae-sauces, Algae-mustard, Algae-herb, Algae-sausages,

[1]Vesiviljeluse piirkondlike kavade koostamine võimaliku keskkonnasurve ohjamiseks. Lõpparuanne, Tartu Ülikool (2019) (in Estonian): https://www.envir.ee/sites/default/files/2019_11_01_lopparuanne_pikk_versioon.pdf

[2] http://estagar.ee/

[3] In Estonian: https://maaelu.postimees.ee/6539216/vetikatootja-numami-polluks-on-meri; https://numami.ee/meist/

Country	Industrial algae cultivation	Usage of algae biomass for energy purposes	Usage of algae biomass for other bio-based products
	The following list shows some of the companies which cultivate algae: - RO-V-AL gbr: Microalgea chlorella vulgaris from Rockstedt since 2016 - Algomed: Cultivation of the microalgae Chlorella vulgaris in Klötze since 2000 - IGV: Microalgae Chlorella and Spirulina - Blue Biotech: Nannochloropsis - Phytolutions: Microalgea - Algenland GmbH: Microalgae - Viva Maris: Macroalgae brown algae Saccharina latissima and red algae Dulse/Palmaria Malmata - Algamar: red algae Dulse and Nori/Porphyra		Algea-bred) made by Viva Maris/made by Algamar Phytolutions installed a 200 square meter outdoor microalgae plant at a sewage plant in central Germany. This algae plant will be used to reduce phosphate from wastewater while the biomass will be converted into bioplastics and fuels. Aquaflor: innovative algae cosmetics, manufactured by IGV cosmetic manufactory. In the manufacture in Brandenburg, creams, lotions and other high-quality cosmetic products are produced by hand. They combine the natural potential of the microalgae **Spirulina platensis** and the macroalgae **Ascophyllum nodosum** in the sense of holistic skin care - Made in Germany. Additionally to the cosmetic products IGV offers algae food supplements (tablets and powder) under the brand aquaflor as well. Algomed also produces algae food supplements, as well as algae food/beverage and also pellets for animals.

Country	Industrial algae cultivation	Usage of algae biomass for energy purposes	Usage of algae biomass for other bio-based products
	umbilicalis; brown algae undaria pinnatifida and Himanthalia elongate - Sylter Algenfarm: red and brown algae		Oceanwell: innovative algae cosmetics by oceanBASIS. The company also develops medical ingredients and products from natural marince substances with the focus on anti-infectives from algae extracts and collagen from marine invertebrates four wound healing and orthopaedics.
Latvia	Algae are not grown industrially in Latvia.	The algae are not in usage for any purposes in Latvia. Aggregated data on the potential of algae on the coast of the Baltic Sea in the territory of Latvia: 1. Total algae biomass potentials 86271 tons based on theoretical research[4]. 2. Under EU Directive 2006/7/EC, algae should BE COLLECTED IN recreational areas during the swimming season. According to the information provided by local authorities, 100 tons of algae are collected per year[5]. 3. The distribution of washed algae on the coast is very uneven and difficult to predict. Volumes of macro-algae washed in weight from > 200 m3/100 m to 0,002 m3/100 m[5].	SpirulinaNord is a start-up company that has developed an efficient microalga growing technology and has started production at premises in Latvia. The idea is based on the idea and understanding of two researchers at Riga Technical University, how fresh greens are tempting in the winter and the first sunshine of spring[6].
Lithuania	Microalgae are not grown industrially in Lithuania.	The EU LIFE project "*AlgaeService for LIFE – ALGAE – ECONOMY BASED ECOLOGICAL SERVICE OF AQUATIC*	Lithuanian start-up has developed an algae-based food packaging material.

[4] Martin G. , Kukk E. , Kukk H. & Kotta J. (2004) Historical review of the literature on phytobenthic investigations in the Gulf of Riga. Proc. Estonian Acad. Sci. Biol. Ecol. , 53 , 236–250.
[5] Balode M. & Strake S. (2018) Beach Cast Algae Evaluation and Management Plan for Latvian Coast. Latvian FLAGs teamed FARNET Good Practice Project.
[6] SpirulinaNord, www.spirulinanord.eu, contacts: info@spirulinanord.eu, Agnese Stunda-Zujeva, business development manager.

Country	Industrial algae cultivation	Usage of algae biomass for energy purposes	Usage of algae biomass for other bio-based products
		ECOSYSTEMS" is working on pilot biogas production from cyanobacteria and macro-algae in Lithuania, both alone and combined with other biodegradable biomass, and plans to validate other potential uses of algae (as fertilizer, etc.)[7]. Researchers of technical universities in Vilnius and Kaunas are working on developing algal biofuel[8] and algal biogas[9].	The material uses chalk powder with algal agar as a stabilizer[10]. Lithuanian researchers are also working on using algae grown on municipal wastewaters for nutrient recovery[11].
Poland	Microalgae are not grown industrially in Poland.	Researchers from the University of Warmia and Mazury in Olsztyn, the University of Lodz, and Lodz University of Technology, Czestochowa University of Technology, University of Szczecin and the Institute of Agrophysics of the Polish Academy of Sciences in Lublin conduct research in the field of optimization of the microalgae biomass production process[12][13]and recovery of valuable energy carriers, including biooil, biogas[7][14] and biohydrogen[15]. PKN Oreln, a leader in the production of transport fuels in Poland, conducts research into the technology of producing III generation biocomponents (biofuels), obtained from oil algae. For the production of algae,	Researchers from the University of Warmia and Mazury in Olsztyn, the University of Lodz and the Lodz University of Technology are conducting research on the use of algae in cosmetics, pharmaceuticals and also as a source of natural antioxidants, food supplements, feed, natural antibacterial and antifungal compounds, as well as in natural methods of plant protection. Svanvid company in Gdansk successfully sells several raw materials

[7] https://ec.europa.eu/environment/life/project/Projects/index.cfm?fuseaction=search.dspPage&n_proj_id=6841&docType=pdf; https://algaeservice.gamtostyrimai.lt.
[8] Algal Biodiesel in Lithuania: From Promise to Reality (2016): https://www.sciencedirect.com/science/article/pii/S1877705816000497
[9] Biogas production experimental research using algae (2015): https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4391081/#idm140598787497056aff-info
[10] https://www.austejaplatukyte.com/about
[11] Green algae *Chlorella vulgaris* cultivation in municipal wastewater and biomass composition (2016): https://www.tandfonline.com/doi/abs/10.3846/16486897.2016.1245661
[12] https://www.mdpi.com/1996-1073/13/6/1432
[13] https://link.springer.com/article/10.1007/s12649-016-9667-1
[14] https://link.springer.com/article/10.1007/s41742-017-0024-4
[15] https://www.sciencedirect.com/science/article/abs/pii/S0360319918311637

Country	Industrial algae cultivation	Usage of algae biomass for energy purposes	Usage of algae biomass for other bio-based products
		post-production water and carbon dioxide from refinery processes will be used[16] Svanvid, Krajowa Spółka Cukrowa within the project Biostrateg II „Waste biomass processing in associated biological and chemical processes".	for the cosmetics and pharmaceutical industries. Their flagship product available on the free market is Ultivia. Ultivia contains DHA obtained from algae. In 2015 Svanvid received the prestigious title as second most innovative biotechnology company in Europe. The awards were organized by EuropaBio at the European Parliament.
Sweden	The development of algae cultivation is in its early development in Sweden (Hasselström et al, 2020; Tomas et al, 2019)[17] [18]. One example is the research project CirkAlg[19] that explore the potential of Swedish seaweed as a contributor to the "protein shift". The project is a	Several research projects are addressing this issue in Sweden. Research project Seafarm[20] is an interdisciplinary research project which grows and uses macroalgae for many different purposes in a closed loop system that produces zero waste[21]. The goal is to develop a sustainable system for the use of seaweeds as a renewable resource in a future, biobased Swedish society. The research programme NordAqua[22] makes use of aquatic photosynthetic organisms in production of	A few industrial products examples seaweed chips and seaweed caviar[25], sugar kelp and sea lettuce[26].

[16] https://www.orlen.pl/PL/BiuroPrasowe/Strony/PKN-ORLEN-bada-produkcj%C4%99-biokomponent%C3%B3w-z -glon% C3% B3w.aspx
[17] Hasselström, L., Thomas, J., Nordström, J. *et al.* Socioeconomic prospects of a seaweed bioeconomy in Sweden. *Sci Rep* 10, 1610 (2020). https://doi.org/10.1038/s41598-020-58389-6
[18] Thomas, J-B. E., Ramos, F. S. and Gröndahl, F. (2019) Identifying Suitable Sites for Macroalgae Cultivation on the Swedish West Coast, *Coastal Management*, 47:1, 88-106, DOI: 10.1080/08920753.2019.1540906
[19] https://www.chalmers.se/en/projects/Pages/Seaweed-as-a-vehicle-for-nutrients-in-a-circular-food-chain--.aspx
[20] http://www.seafarm.se/web/page.aspx?refid=135
[21] Sterner, M. (2018). Polymer extraction and utilisation of brown algal biomass. PhD thesis, KTH Royal Institute of Technology, 2018
[22] https://nordaqua.fi/about-nordaqua
[25] https://swemarc.gu.se/digitalAssets/1721/1721137_scary_seafood_den-nya-maten-fr--n-havet.pdf
[26] www.kosteralg.se/en/homepage/

Country	Industrial algae cultivation	Usage of algae biomass for energy purposes	Usage of algae biomass for other bio-based products
	collaboration between several Universities, companies and a government agency with the aim to develop techniques to increase the protein amount in seaweed in two steps and in ingredients made from these. In a first step the seaweed is cultivated in nutrient rich media and in a second step scalable processes will be developed to concentrate the protein from the cultivated seaweed. Other central objectives of the project include analysis of tastiness, nutrition value and food safety of the developed protein ingredients and in products containing these.	biobased chemicals, pharmaceuticals, biofuels, food and feed, as well as in the process of wastewater purification. **Algae plantations can reduce greenhouse gas emissions from the metal industry. This is shown by the results of a research project in which RISE and Boliden[23] have realistically tested carbon dioxide capture from industrial flue gases using algae. The algae are carbon** dioxide and metals from the gas and water emissions that occur in the metal **industry.** Swedish microalgae can produce biofuels while purifying water[24]	
Norway	Norway supplies more than half (65%) of the total European macroalgal biomass production (2015).	The Norwegian Seaweed Technology Center from SINTEF, works on algae development and deployment for, among other things, bioenergy[27].	From SINTEF's Norwegian Seaweed Technology Center: "Norwegian Seaweed Technology Center is a knowledge platform for technology development within

[23] https://www.ri.se/sv/press/algodlingar-vid-metallindustrier-kan-minska-vaxthuseffekten
[24] Ferro, L (2019). Wastewater treatment and biomass generation by Nordic microalgae. Growth in subarctic climate and microbial interactions. PhD thesis, Umeå Universty, Sweden.
[27] https://www.sintef.no/en/ocean/initiatives/norwegian-seaweed-technology-center/#Aboutthecentre

Country	Industrial algae cultivation	Usage of algae biomass for energy purposes	Usage of algae biomass for other bio-based products
	Source: JRC Science for policy report 2018: Biomass production, supply, uses and flows in the European Union.	There is also a NIBIO project: Algae to Future (A2F) From Fundamental Algae Research to Applied Industrial Practices; but it mostly focuses on food and feed[28].	industrial cultivation, harvesting, processing and application of seaweed in Norway. " and "Norway has the opportunity to develop the macroalgae cultivation to a new, large industry. Industrial cultivation of macroalgae gives opportunities for production of biomass that can be used as basis for many different products and that can contribute to make Norway more self-sufficient on food, feed ingredients and bioenergy. Norway has vast areas along the coast that are suitable for seaweed cultivation. Seaweeds are primary producers and can be cultivated in the sea without the use of arable land, fertilizers, fresh water, pesticides or antibiotics. " From NIBIO's A2F: "A2F's vision is to lay the foundation for industrial microalgae production in Norway, utilizing natural resources and waste streams from existing production lines within agriculture, aquaculture and process industry."

[28] https://www.nibio.no/en/projects/algae-to-future-a2f