IEA Bioenergy Countries' Report – update 2021

Implementation of bioenergy in the IEA Bioenergy member countries

IEA Bioenergy ExCo

November 2021

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Luc Pelkmans, Technical Coordinator, IEA Bioenergy TCP

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November 2021

ISBN: 978-1-910154-93-9

Published by IEA Bioenergy

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Introduction

This report, together with the separate country reports, was prepared from IEA statistical data[1], combined with data and information provided by the IEA Bioenergy Executive Committee. All individual country reports were reviewed by the national delegates to the IEA Bioenergy Executive Committee, who have approved the content.

The individual country reports are available as separate reports. Reports are available for Australia, Austria, Belgium, Brazil, Canada, China, Croatia, Denmark, Estonia, Finland, France, Germany, India, Ireland, Italy, Japan, the Republic of Korea, the Netherlands, New Zealand, Norway, South Africa, Sweden, Switzerland, the United Kingdom, the United States, as well as the EU28[2]. All individual country reports are available at: https://www.ieabioenergy.com/iea-publications/country-reports/2021-country-reports/

Most data are taken from IEA statistics up to the year 2019, for which complete statistics and underlying data are available for all mentioned countries. While data for 2020 are starting to become available at national level, it was decided to consider trends up to 2019 for good comparability and benchmarking between the different countries. Care should also be taken when using 2020 data for analysing trends as these data are distorted by the COVID19 Pandemic.

This report presents a comparative overview of the results for the different countries for the role of bioenergy in total energy supply (TES), in electricity use, total fuel/heat consumption, and in transport energy consumption. A first chapter will go into country profiles, indicating relevant characteristics that impact the potential role of bioenergy in the energy system.

[1] IEA (2021) World Energy Balances and Renewables Information
The IEA collects, assesses, and disseminates energy statistics on supply and demand, compiled into energy balances. The time series stretches back to 1971, and currently covers up to 95% of global energy supply and over 150 countries. The focus is on quality, comparability, and alignment with internationally agreed definitions and methodologies, and close collaboration with national offices responsible for energy statistics and other relevant stakeholders.
https://www.iea.org/areas-of-work/data-and-statistics

[2] European Union with 28 member countries up to 2019 (including the United Kingdom)

Highlights

The IEA Bioenergy member countries have distinct characteristics that impact their renewable energy and bioenergy potential. Country size and population density, as well as topography, climatic conditions and land use distribution are particularly important. Countries with low population density tend to have higher potential availability of domestic biomass resources, while countries with high population density tend to rely much more on imports for their energy and resource requirements.

Energy mix

In the overall energy supply, **coal, oil, and natural gas still play a dominating role in most countries**. Only in Brazil, Finland, France, Norway, Sweden, and Switzerland do renewable energy and nuclear energy represent more than half of total energy supply.

- There is a **strong decreasing trend of coal in many countries**, particularly in Europe and North America. Nevertheless, coal still represents a major part of the energy mix in Asian countries, Australia, and South Africa.
- Oil has a substantial and relatively stable role in all countries, particularly in relation to its use in transport.
- Natural gas also has a substantial role and has reached similar or higher levels than oil in several countries. **Since 2015, most of the countries had an increase of natural gas use** - in several cases the increase in natural gas compensated (part of) the reduction of coal.
- Apart from countries with elevated levels of hydropower (Norway, Canada, New Zealand and Switzerland), **bioenergy represents more than half of renewable energy supply in most countries**.

Biomass types

Solid biomass remains the dominating type of biomass used for energy in all countries, but liquid biofuels, renewable waste and biogas/biomethane are also relevant.

- Countries with the highest use of ***solid biomass*** for energy tend to have a high domestic forest area per capita and important wood processing industries, while their forests are still expanding.
- A few countries with limited domestic forest biomass potential (the Netherlands, the UK, Belgium, and Denmark) rely on solid biomass imports for energy - these countries have imposed sustainability requirements to (large scale) biomass use to mitigate some of the risks related to biomass sourcing from outside the country (which they cannot control with domestic forest policies).
- The amount of ***MSW*** used for power and/or heat production is clearly linked to the stage of waste management development in a country, which is quite advanced in Scandinavia and West Europe where performant collection systems have been implemented and landfill is almost completely phased out.
- Germany is most advanced in ***biogas/biomethane*** use. Nevertheless, other countries are catching up; particularly Denmark has taken major steps in biogas/biomethane lately. Biogas used to be primarily used directly for CHP generation; the raw gas is now more and more upgraded and fed into the gas grid. While biogas/biomethane use peaks above 25% of natural gas use in Denmark, it tends to be equivalent to 1-5% of natural gas use in most countries, showing that major steps will still be needed to phase out fossil gas.
- ***Liquid biofuels*** are on the rise, particularly as transport fuel. In Brazil and Sweden, the use of liquid biofuels is already equivalent to more than 15% of fossil oil use (for transport and heat production). In most other countries liquid biofuel use is equivalent to between 2 and 5% of fossil oil use, showing that major steps will still be needed to phase out fossil oil.

Renewables and bioenergy in different sectors

Bioenergy plays a role in the three main energy sectors: electricity, fuel/heat consumption and transport energy consumption. **Particularly for heat and transport bioenergy/biofuels are the dominant renewable energy type.**

- The main growth of ***renewable electricity*** in the past decade has been in wind power, followed by solar power and biomass-based power. In Denmark, Finland and Estonia, bioenergy represents more than 15% of electricity production (predominantly through combined heat and power - CHP), followed by the UK, Sweden, Germany and Brazil. In other countries, typical levels of biomass-based electricity are 2-5%.
- For most countries solid biomass is the dominant fuel to produce bioelectricity. However, in Germany, Italy and Croatia bioelectricity is mainly produced from biogas. In Switzerland renewable MSW is the dominant fuel for bioelectricity.
- The ***main support systems*** for renewable power have been feed-in tariff systems and obligations connected with tradable green certificates. Recently there is a trend to work with tender systems on a competitive basis. A point of attention is that, apart from the production cost per MWh, policy actions also need to reflect the multiple benefits of using bioenergy for electricity, including rural development, waste management and dispatchability.

- In most of the analysed countries fossil fuels still dominate in ***fuel/heat provision***, typically exceeding 75% of total fuel/heat provision. Biomass is the dominant type of renewable heat. The most important progress in renewable heat has been made in countries with important shares of district heating (Denmark, Estonia, Sweden, Finland), particularly through the replacement of fossil fuels by biomass for centralised heat production.
- The ***main support systems*** for renewable heat have been subsidies for renewable heat projects and financial support for domestic renewable heat instalment. Several countries (particularly in Scandinavia) have implemented a CO_2 tax on fossil fuels which was an important driver for industries (and heat producers) to move from fossil fuels to bioenergy.

- Fossil fuels still represent over 95% of ***transport*** energy in most countries. This reflects the challenge to displace fossil fuels in the transport sector. Brazil and Sweden have achieved a renewable energy share in transport of 25% and 21%, respectively, with Norway and Finland also reaching more than 10%. Most other countries have renewable shares of 4 to 6% or lower.
- Biodiesel (including an increasing share of HVO) and bioethanol are the dominant biofuel types. Bioethanol is mainly important in countries with high shares of gasoline cars (Brazil, USA, Canada). Biodiesel gains attention with the increased focus on heavy duty transport, which relies on diesel fuel. There is an increasing trend to advanced (residue based) biofuels and drop-in biofuels to avoid blend walls (ethanol limits in gasoline and FAME limits in diesel).
- The ***main support systems*** for biofuels are tax incentives for biofuels and blending obligation systems. More systems start to be based on the carbon intensity of the fuels, e.g., the Californian Low Carbon Fuel Standard, or RenovaBio in Brazil. There is also support for (advanced) biofuel production facilities to move from pilot to commercial production.
- Renewable electricity is considered as an important option in transport, particularly towards the coming decades and mainly in the light duty segment. As of today, electricity use only represents between 0.1 and 4% of transport energy (currently mostly in rail), with the renewable share depending on the national electricity mix. Sales of electric cars are substantially increasing in recent years and several regions put high targets on EV sales. Nevertheless, with different EV introduction speeds in different regions and considering typical vehicle lifetimes of over 10 years, the replacement of the car fleet will take time so fuels will still be needed for the car sector in the next few decades; moreover, the heavy-duty sector will still remain dependent on (predominantly diesel type) fuels for quite some time. So **renewable fuels will remain an important option to displace fossil fuels in transport.**

Country profiles

The countries involved may have quite different characteristics. There are major differences in population (from 1.3 million up to 1.4 billion people), size of the country's land area (from 30,000 km² to 9.6 million km²), as well as topography, climatic conditions, and distribution of land use (forests, arable land, permanent meadows and pastures, artificial areas[3], deserts, arctic regions).

Population density between the countries varies from 3 - 4 persons per km² in Australia and Canada, to more than 500 persons per km² in the Netherlands and Korea. Countries with low population density tend to have higher potential availability of domestic biomass resources, while countries with high population density tend to rely much more on imports for their energy and resource requirements.

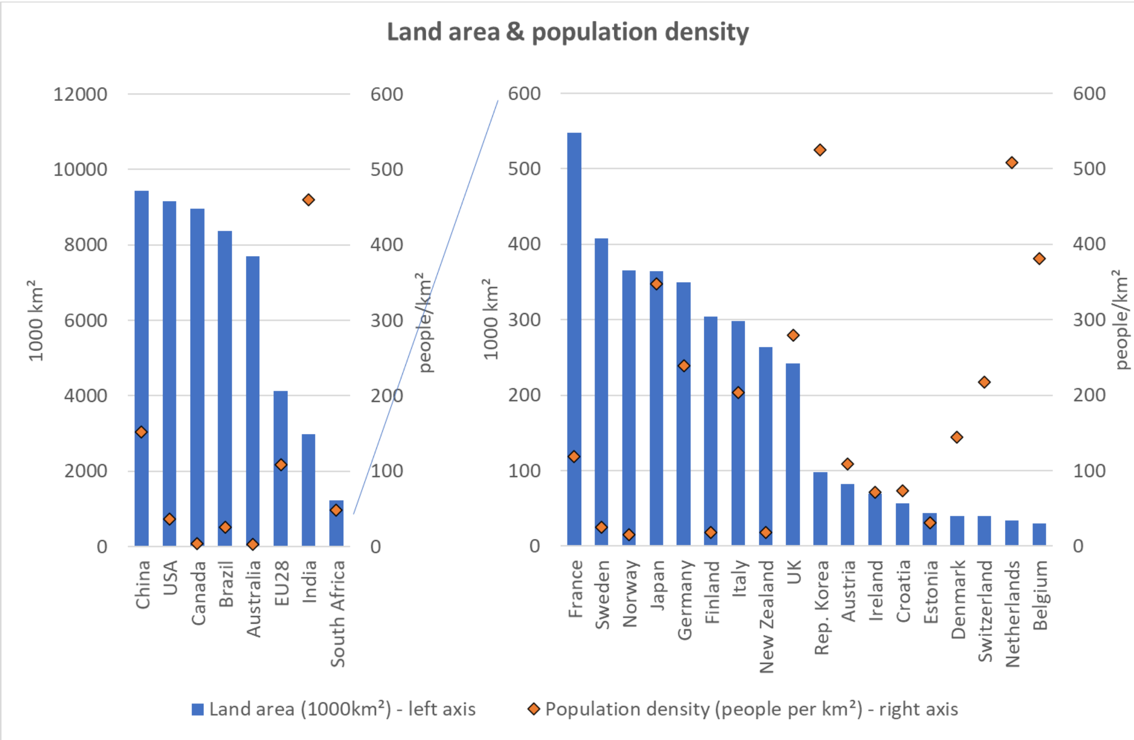

Figure 1: land area and population density of the IEA Bioenergy member countries (2018 data, source: FAOStat)

There are also wide differences in final energy consumption, when expressed per capita. Developing countries and emerging economies tend to be on the low end of the spectrum and are expected to further increase their energy consumption in the coming decades as their economies develop further. Energy consumption in more developed regions has largely stabilized, on average between 2 and 3.5 toe per capita per year in 2019 and may come down with energy efficiency measures.

- There are major differences in industrialisation, which is also reflected in the role of industries in total energy consumption (direct energy use, as well as non-energy uses of fossil energy carriers, e.g., in chemical industries). The role of industries varies from 0.5 toe/capita/year in countries with less energy-intensive industries (like the UK, Denmark) up to more than 2 toe/capita/year in Finland.
- Transport energy use is low (but increasing) in most emerging economies. Most developed countries have a transport energy use between 0.5 and 0.8 toe/capita per year, but there are outliers up to 2 toe/capita, particularly in the USA and Canada. Size of the country (and low population density) plays a role as higher distances need to be covered in larger countries, including more domestic aviation.

[3] Such as urban areas, industry areas, roadworks

Nevertheless, the preference for bigger vehicle sizes (such as SUVs and pick-up trucks) also plays a role, as well as a more or less extensive roll-out of public transport.

- Energy requirements in the residential sector and commercial/public services are also the lowest in emerging economies. Highest levels can be found in Canada, Finland, Norway, Sweden, and the USA, which in most cases tends to be related to climatic circumstances (higher heating requirements).

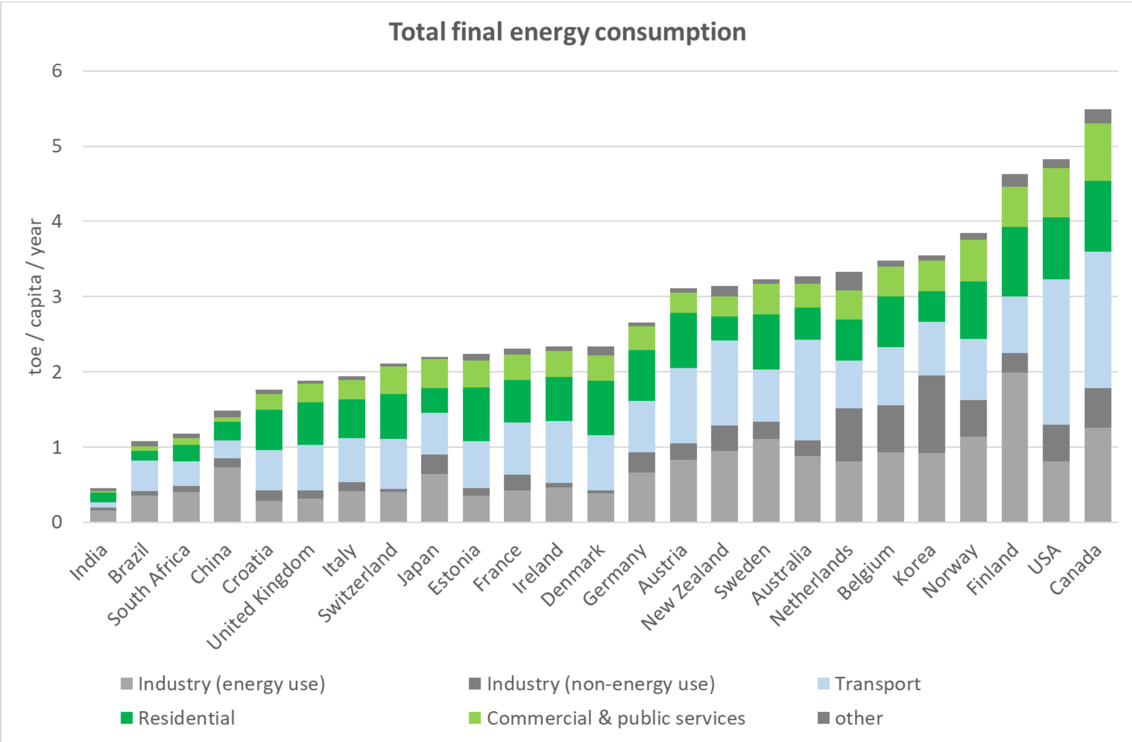

Figure 2: total final energy consumption in the IEA Bioenergy member countries, split up in sectors (2019 figures - Source: IEA (2021) World Energy Balances and Renewables Information)

Final energy consumption is an important factor in the decarbonisation of the energy sector. The higher the energy consumption per capita, the more efforts will be required to displace fossil fuels in these sectors.

Total energy supply (TES)

Total energy supply (TES) is defined as production plus imports minus exports and plus/minus stock changes of the different energy carriers (see definition section). Thus, according to the IEA definition of TES, because of imports, both primary and secondary energy carriers are displayed. Resource categories displayed include coal and coal products; peat and peat products; crude oil, natural gas liquid (NGL) and oil products; natural gas; nuclear[4]; waste (non-renewable share); hydropower; bioenergy (including all categories of bioenergy/biofuels); and other renewables (which include wind energy; solar energy; geothermal energy and wave/tidal energy). Net electricity imports (imports minus exports) are also included in TES.

Figure 3 depicts the contribution of the different energy carriers in the countries' energy mix[5] (expressed per capita for comparison) and how these have evolved since 2005.

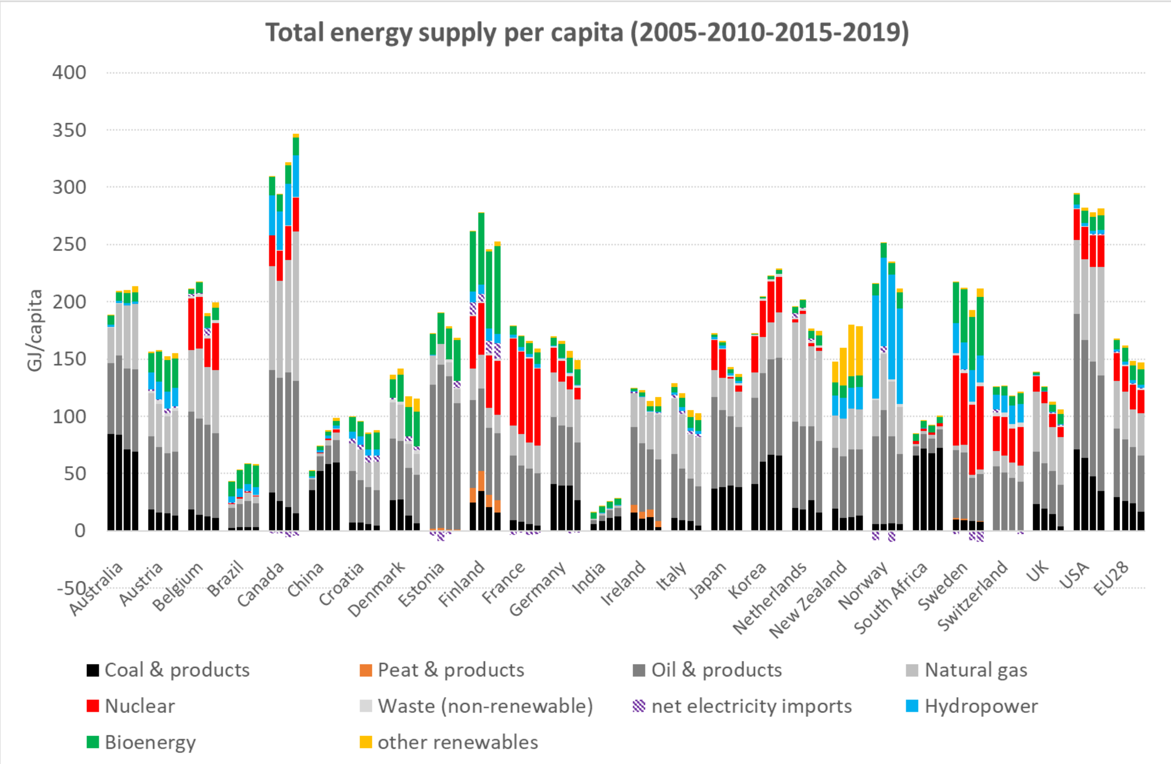

Figure 3: evolution of total energy supply per capita in the IEA Bioenergy member countries (Data source: IEA (2021) World Energy Balances and Renewables Information)

As indicated earlier, there is a substantial spread in total energy supply between the different countries – even when considered per capita - with emerging economies at relatively low level but increasing; while developed countries have higher levels of energy use, but in most cases, there is a (slight) decreasing trend. In the overall mix, coal, oil, and natural gas still play a dominating role in most countries. Only in Brazil, Finland, France, Norway, Sweden and Switzerland renewable energy and nuclear energy represent

[4] Nuclear energy supply shows the primary heat equivalent of the electricity produced by a nuclear power plant with an average thermal efficiency of 33%.

[5] In terms of the role in the energy system care should be taken as this distribution overestimates the role of resources producing electricity with a high share of unused waste heat (like nuclear plants or other condensing power plants), while for solar, wind and hydropower only the final electricity produced is considered. In that sense it is important to look at the final consumption in the different sectors (see further on in this report).

more than half of total energy supply. The differences between 2015 and 2019 are depicted in Figure 4.

- There is a strong decreasing trend of *coal* in many countries, particularly in Europe and North America. Nevertheless, coal still represents a major part of the energy mix in Australia, China, India, Japan, South Korea, and South Africa.
- *Oil* has a substantial role in all countries, particularly in relation to its use in transport. Its consumption is (slightly) decreasing in several countries, with highest decreases in Estonia, Norway, Japan, and Belgium. Nevertheless, average levels of oil supply in the EU28 and the USA are actually stable. Emerging economies have an increasing demand for oil, linked to increasing transport activities.
- *Natural gas* also has a substantial role and has reached similar or higher levels than oil in several countries, for instance in Canada, Italy, the Netherlands, the UK and the USA. When looking at the trends since 2015, we see that most of the countries had an increase of natural gas use, which was particularly large in Canada, the USA, the Netherlands, South Korea and Ireland. In several cases the increase in natural gas compensated (part of) the reduction of coal. For example, in the USA the decrease of coal was almost exactly matched by an increase of natural gas; in the EU28 the increase of natural gas use covered 54% of the decrease in coal.
- *Nuclear energy* is particularly important in France, but also plays a strong role in Sweden, Finland, Switzerland, and Belgium. Overall levels of nuclear energy were relatively stable in most countries, apart from some temporary fluctuations, e.g., in Belgium and Sweden.

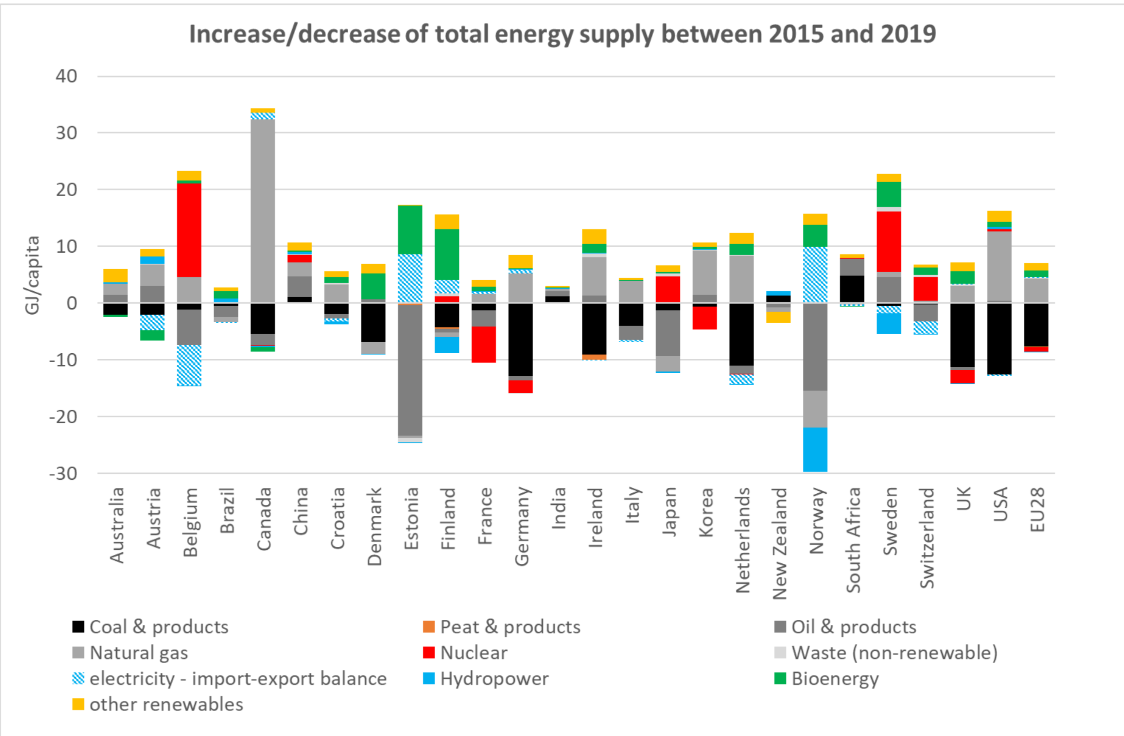

Figure 4: Difference in TES between 2015 and 2019 (Data source: IEA (2021) World Energy Balances and Renewables Information)

The highest shares of renewable energy in total energy supply in 2019 are reached in Norway (48%), Brazil (46%), Sweden (41%), New Zealand (40%), Denmark (36%), Finland (35%), Austria (30%), Croatia (25%), Switzerland (22%) and Estonia (22%). Apart from countries with prominent levels of hydropower (Norway, Canada, New Zealand and Switzerland), bioenergy represents more than half of renewable energy supply.

Levels of hydropower were fairly stable (with temporary fluctuations), while bioenergy and other renewables - particularly wind and solar - generally saw substantial increases. Wind and solar energy together increased by more than 1 GJ/capita since 2015 in 17 out of 25 IEA Bioenergy member states. This will be discussed further in the electricity chapter.

12 out of 25 IEA Bioenergy member countries had an increase in bioenergy of more than 1 GJ/capita since 2015, with the biggest increases in Finland, Estonia, Denmark, Sweden and Norway.

Figure 5 shows the evolution of bioenergy since 2005, with distinction made between the different types of bioenergy resources. Overall bioenergy levels vary widely between the different countries, from 3 GJ/capita in South Korea, Japan, and China to 70 GJ/capita in Finland, with most countries situated between 8 and 15 GJ/capita. When putting these figures in perspective of total energy supply, Brazil and Finland reach bioenergy levels of more than 30% of TES, while Denmark, Sweden and Estonia reach more than 10% of TES. Most other countries reach a bioenergy share between 5 and 10% of TES.

Solid biomass was and remains the dominating type of biomass used for energy in all countries, but liquid biofuels, renewable waste and biogas/biomethane are also relevant. In the next paragraphs we will consider the different types of bioenergy resources with their evolution in the past decade, but also put in perspective compared to relevant reference points.

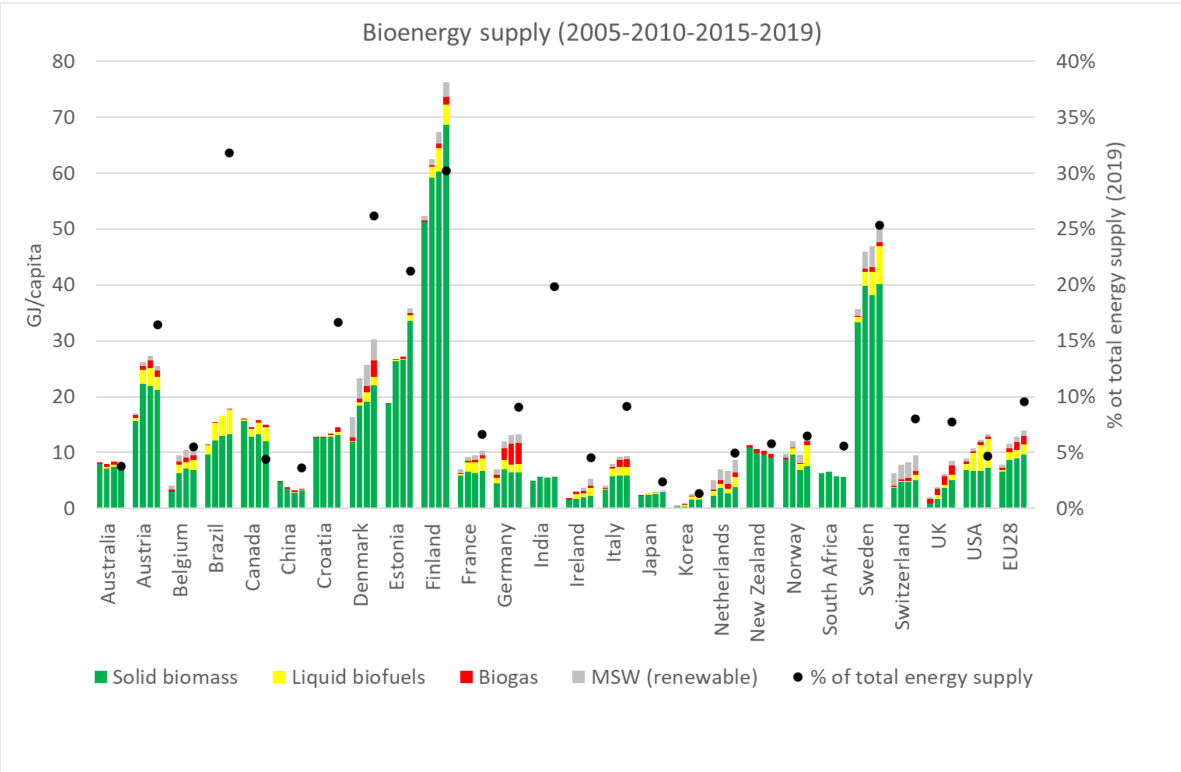

Figure 5: evolution of bioenergy supply per capita in the IEA Bioenergy member countries (Data source: IEA (2021) World Energy Balances and Renewables Information)

SOLID BIOMASS

The solid biomass category comprises wood logs, wood chips, wood pellets, bark, sawmill by-products, pulp & paper mill by-products, wood waste, but also agricultural crop residues such as bagasse (in Brazil) and straw (in Denmark and India).

Figure 6 shows the evolution of solid biomass use for energy since 2005. The highest levels of solid biomass use (per capita) are reached in Finland, Sweden, Estonia, Austria, and Denmark. With exception of Denmark - which also uses straw and wood imports - these countries have a high domestic forest area per capita and important wood processing industries. To indicate this importance, the right axis in Figure 6 puts the amount of solid biomass used for energy in 2019 in relation to the domestic forest area (protected forest areas excluded). Considering that the typical calorific value of wood is 19 GJ/ton dry mass, most countries (including Finland, Sweden, Estonia) consume less than 1.5 tons of solid biomass (dry mass wood equivalent) per hectare domestic forest, which is below the annual increment in their forests. Mind that some of these countries (e.g., USA, Canada, Estonia) are also exporters of solid biomass to other countries, but these exports are still fairly modest compared to their domestic potential. Countries like Germany, Austria and Italy reach somewhat higher levels of solid biomass use compared to their domestic forest area, which is partly related to higher increments in their forests (better climatic conditions compared to e.g., Nordic countries) and can partly also be related to direct and indirect[6] imports from neighbouring countries.

A few countries (the Netherlands, Denmark, the UK, Belgium, India) clearly exceed what they can domestically produce through their domestic forests. In the case of Denmark and India this also links to the important share of agricultural residues in the solid biomass they use. The Netherlands, the UK, Belgium (and Denmark to some extent) heavily rely on solid biomass imports for energy. These countries have imposed sustainability requirements to (large scale) biomass use to mitigate some of the risks related to biomass sourcing from outside the country (which they cannot control with domestic forest policies).

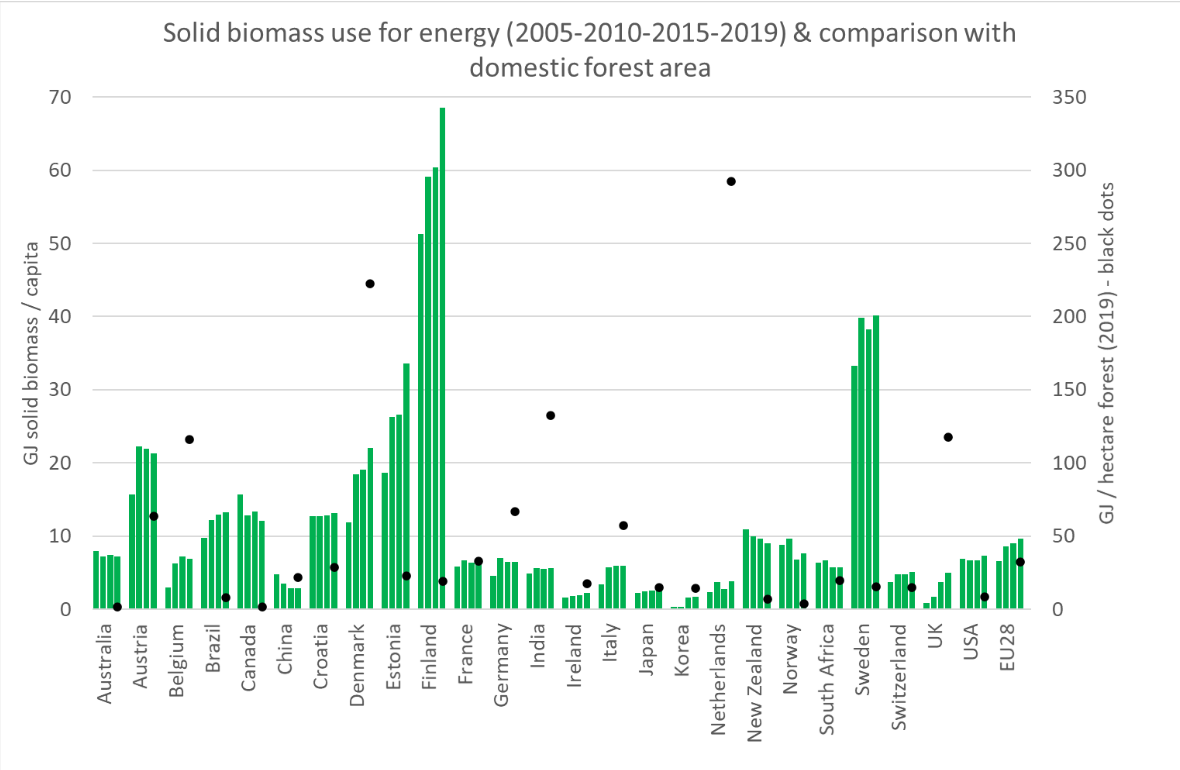

Figure 6: evolution of solid biomass use for energy in the IEA Bioenergy member countries, and comparison with the domestic forest areas (data source energy: IEA (2021) World Energy Balances and Renewables Information; data source forest area: FAOStat)

[6] Example of indirect imports are wood processing industries in Austria importing wood from the Czech Republic and using their residues for energy production.

RENEWABLE PART OF MSW

Municipal solid waste (MSW) consists of products that can be combusted directly to produce heat and/or power. MSW comprises wastes produced by households, industry, hospitals, and the tertiary sector that are collected by local authorities for incineration at specific installations (IEA definition). As municipal waste partly – typically around half - consists of renewable/organic inputs (e.g., paper and cardboard waste, wood waste, food waste) the energy produced is then also partly considered as renewable. Mind that separately collected bio-waste (often used for biogas production) is not comprised in these figures.

Figure 7 shows the evolution of renewable MSW used for energy production in the different IEA Bioenergy member countries since 2005. Levels vary from zero in several countries with less developed waste management systems to almost 4 GJ/capita in Denmark and Sweden. The Figure also puts the amount of renewable MSW in relation with the domestic MSW generation (for 2019).

The amount of MSW used for power and/or heat production is clearly linked to the stage of waste management development in a country, which is quite advanced in Scandinavia and West Europe where performant collection systems have been implemented (often with separation of different fractions for recycling) and landfill is almost completely phased out. A further increase in recycling, e.g., chemical recycling to hydrocarbons, may reduce the need for incineration in future.

Most countries with advanced waste management systems use 3 to 5 GJ renewable MSW for energy per ton MSW generated. The level in Sweden is even higher at 8 GJ per ton, but this is also because of substantial waste imports to Sweden for energy production.

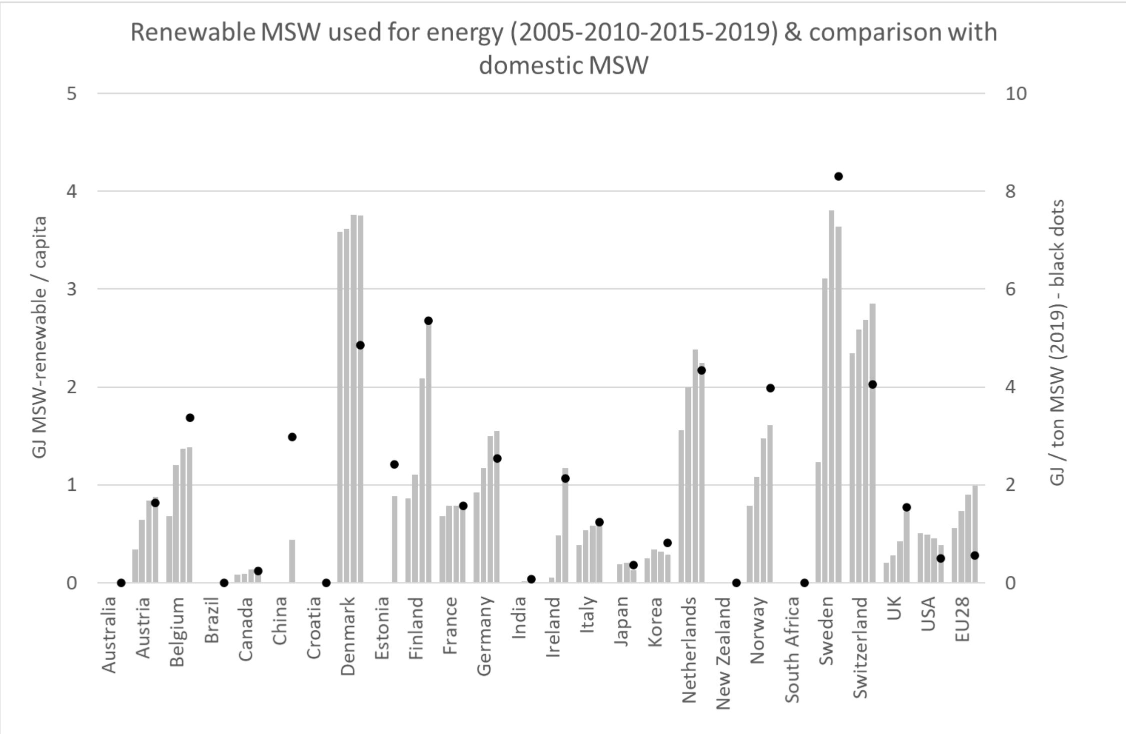

Figure 7: evolution of renewable MSW use for energy in the IEA Bioenergy member countries, and comparison with the amount of domestic MSW produced (data source energy: IEA (2021) World Energy Balances and Renewables Information; data source MSW generation: World Bank[7])

[7] https://datacatalog.worldbank.org/dataset/what-waste-global-database ; accessed in March 2021

BIOGAS/BIOMETHANE

Biogas is generally produced through anaerobic digestion from raw materials such as agricultural waste, manure, municipal waste, sewage sludge, green waste or food waste, or it can be captured from landfill gas. Several countries also use energy crops such as barley, maize, or wheat for biogas production, although there is a declining trend in the use of energy crops. So far, the most common use of biogas is to convert it to power and/or heat. Nevertheless, biogas is increasingly upgraded to natural gas quality (high concentration bio-methane) so it can be injected in the natural gas grid or directly used in natural gas vehicles. It is also possible to produce biomethane (synthetic natural gas / SNG) through gasification and synthesis processes, where solid biomass can be used as input. However, this is still in early stage of deployment.

Figure 8 shows the evolution of biogas/biomethane in the different IEA Bioenergy member countries. Germany is most advanced in biogas use, at a level of almost 4 GJ per capita. Nevertheless, other countries are catching up; particularly Denmark has taken major steps in biogas lately. Due to very favourable subsidies to build and operate biogas plants, Denmark has seen an important growth in generation of biogas based on manure, energy crops, and industrial feedstock. While biogas was previously used directly for CHP generation, the raw gas is now primarily upgraded to biomethane and fed into the national gas grid. A key target in Denmark is to have 100% biomethane in the gas grid by 2040.

The UK, Finland and Italy also reached substantial amounts of biogas (>1GJ per capita), with dedicated targets and support measures.

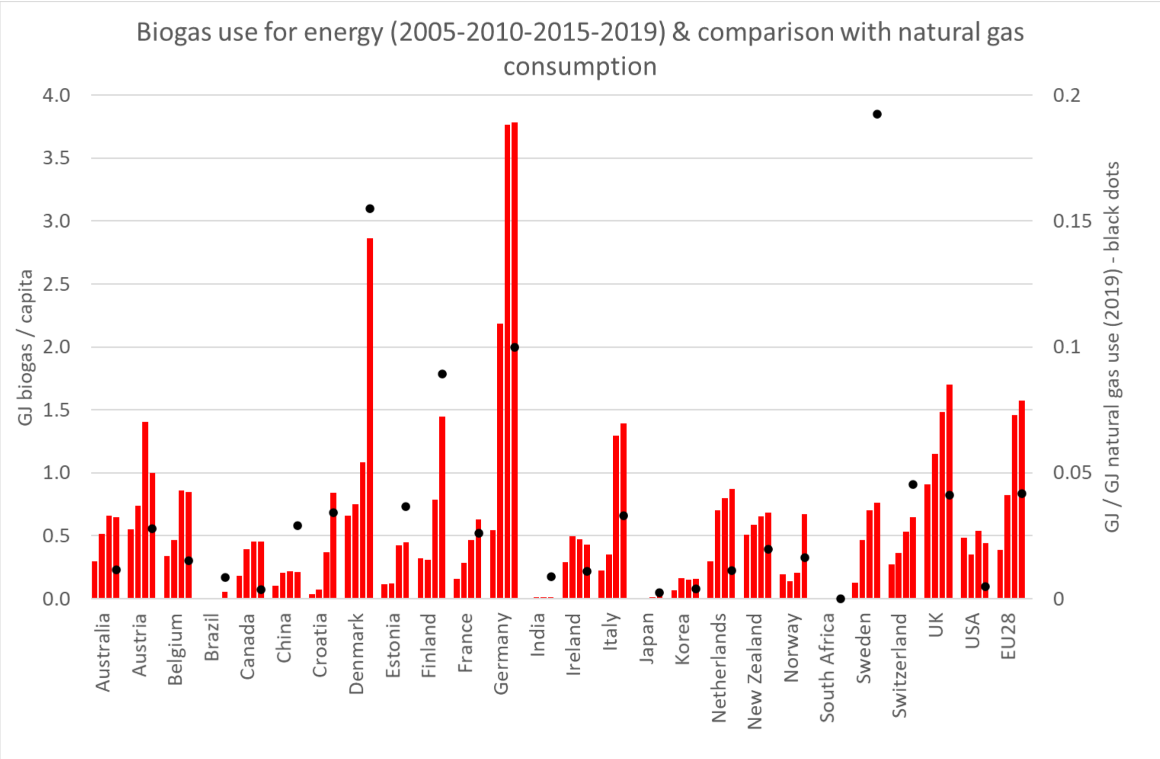

Figure 8: evolution of biogas use for energy in the IEA Bioenergy member countries, and comparison with natural gas consumption (data source: IEA (2021) World Energy Balances and Renewables Information)

Figure 8 also compares biogas/biomethane use with the domestic natural gas use in 2019 (right axis). In Sweden, biogas/biomethane use is already equivalent to 20% of natural gas use, which is also due to the relatively low share of natural gas in the energy mix. In countries and regions with more substantial levels of natural gas, biogas tends to be equivalent to 1-5% of natural gas use, showing that major steps will still be needed to phase out fossil gas.

LIQUID BIOFUELS

Liquid biofuels include biogasoline, biodiesels and other liquid biofuels. Definitions are provided in Annex. It does not include the total volume of gasoline or diesel into which the biofuels are blended.

- *Biogasoline* includes biofuels blended with gasoline fuel, which is predominantly bioethanol.
- *Biodiesels* includes FAME (methyl-ester produced from fatty acids) and an increasing amount of hydrotreated vegetable oil (HVO / renewable diesel) and all other liquid biofuels which are added to, blended with or used straight (unblended) as transport diesel.
- *Other liquid biofuels* include liquid biofuels not reported in either biogasoline or biodiesels. Some countries report unblended biofuels (like E100, B100) in this category. This category also includes liquid biofuels used for heat and/or power production.

Figure 9 shows the evolution of liquid biofuels in the different IEA Bioenergy member countries. Highest levels of liquid biofuels per capita (>3GJ per capita) are reached in Sweden, the USA, Brazil, Finland, and Norway. This is mostly related to transport and will be discussed further in the transport chapter.

The right axis in Figure 9 also compares liquid biofuel use with the domestic use of fossil oil products (in 2019). Mind that fossil oil is also used outside transport, e.g., in industries, so this should not be confused with the share of biofuels in transport (which will be discussed further on). In Brazil and Sweden, the use of liquid biofuels is already equivalent to 22% and 16% of fossil oil supply respectively. In most other countries liquid biofuel use is equivalent to between 2 and 5% of fossil oil use, showing that major steps will still be needed to phase out fossil oil.

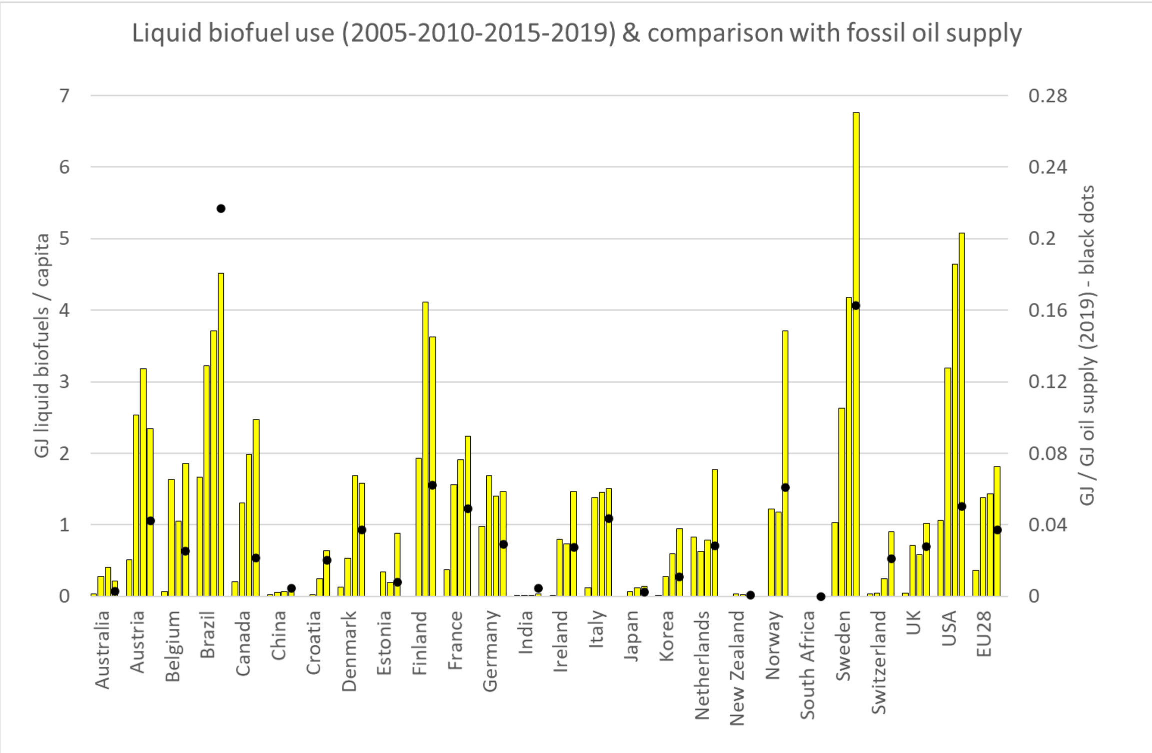

Figure 9: evolution of liquid biofuels in the IEA Bioenergy member countries, and comparison with fossil oil consumption (data source: IEA (2021) World Energy Balances and Renewables Information)

Role of bioenergy and renewable energy in different sectors

The following paragraphs considers final energy consumption in different sectors, and the role of renewable energy and bioenergy for these energy vectors: electricity, heat/fuel consumption and transport energy.

ELECTRICITY

Figure 10 shows the evolution of electricity output in the different IEA Bioenergy member countries. Electricity imports (negative in case of exports) are also indicated in the figure - electricity consumption equals the domestic electricity output supplemented by electricity imports/exports. Electricity consumption varies between the IEA Bioenergy member countries, with major differences from 1.2 MWh per capita in India up to 25 MWh/capita per year in Norway. In most countries, total levels are between 5 and 10 MWh per capita.

The highest levels of electricity consumption per capita tend to be in countries with a high share of (low cost) decarbonised electricity, particularly hydropower and nuclear energy (like in Norway, Canada, Sweden), leading to a higher focus on electric heating in households, offices, and industries.

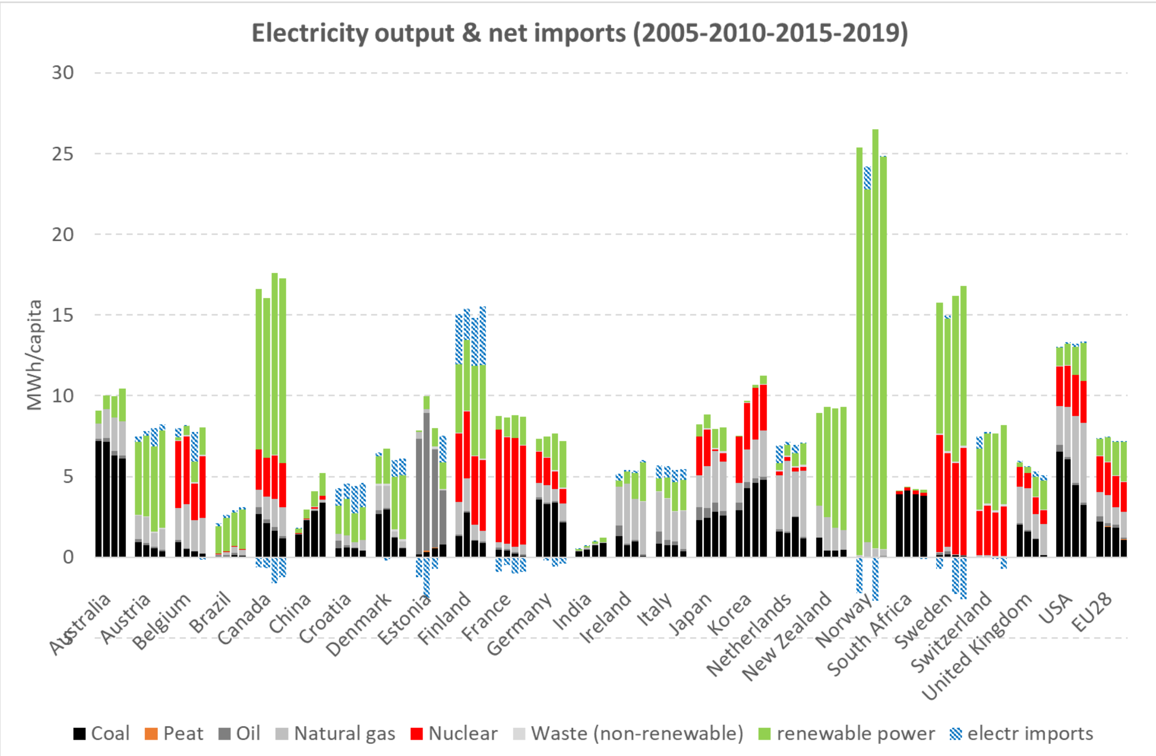

Figure 10: evolution of electricity output (with different sources) and net electricity imports in the IEA Bioenergy member countries (data source: IEA (2021) World Energy Balances and Renewables Information)

- *Coal* power is still dominant in the electricity mix of Australia, China, India, South Korea, and South Africa. In Europe and North America coal power is clearly in decline.
- Power from *oil* products is less significant, except in Estonia where substantial levels of oil shale are used for power production.
- Power from *natural gas* is clearly on the rise in European countries and North America, thereby almost compensating for the decline in coal power in the past 10 years.
- *Nuclear* power remains the dominant power source in France, representing almost 80% of domestic

power production. Levels are also important in Belgium, Sweden and Switzerland (>40% of power), and still highly relevant in Finland, South Korea and the USA (>20% of power).

Figure 11 focuses on the role of renewable electricity in relation to domestic electricity consumption. Various countries (Norway, Brazil, Austria, New Zealand, Canada, Croatia, Switzerland) have a high basis of hydropower, representing more than 50% of domestic electricity production (almost 100% in Norway). This is highly linked to their topographical conditions, so cannot be simply replicated in other countries. In most countries hydropower has been fairly stable in the past decades, with temporary fluctuations.

So far, Denmark is the only country to reach more than 50% renewable power, without having a strong hydropower basis. Other countries like Germany, Ireland and the UK seem to follow, particularly through wind power.

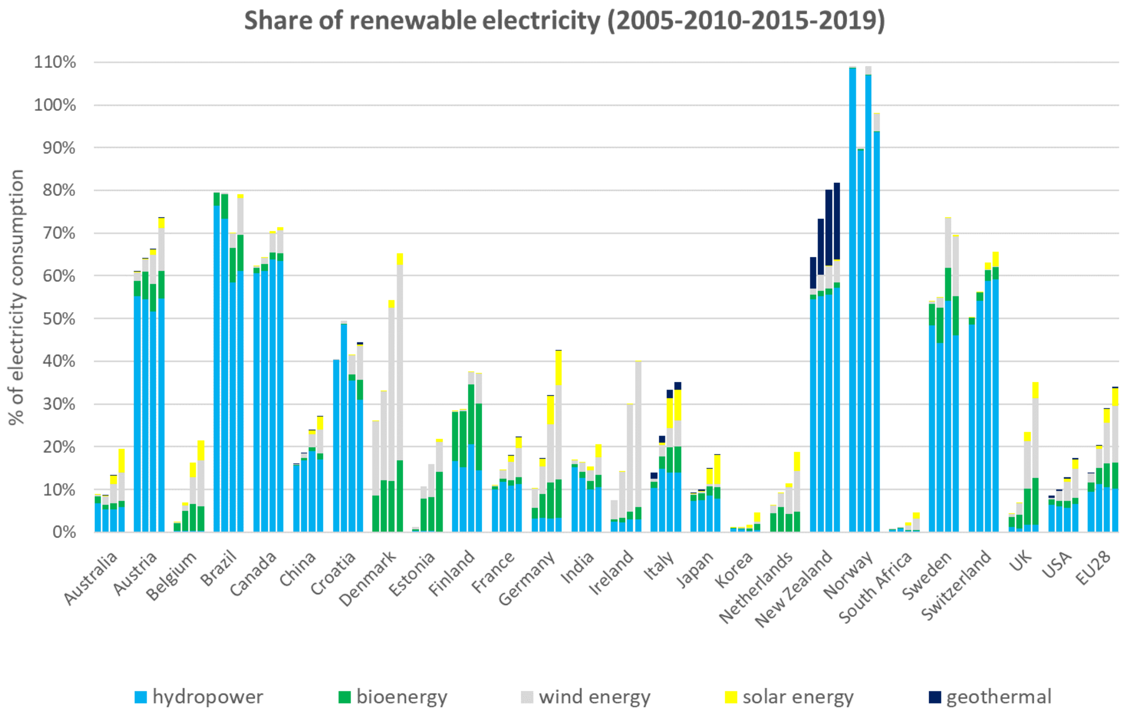

Figure 11: evolution of renewable electricity output in the IEA Bioenergy member countries (data source: IEA (2021) World Energy Balances and Renewables Information)

The main growth for renewable electricity in the past decade has been in wind power, followed by solar power and biomass-based power. Wind power has actually surpassed hydropower in the USA and the EU28. Figure 12 shows the increase of renewable electricity (excluding hydrogen) since 2015.

While almost all countries had a substantial growth in wind and solar power, the growth of bio-power was mainly concentrated in some countries, particularly Estonia, Finland, Denmark, Sweden, Croatia, South Korea and the UK. In several of these countries - particularly in Scandinavia - bio-power is produced through CHP installations where the heat is also used, so this evolution is also part of a strategy to displace fossil fuels in industry and the district heating sector.

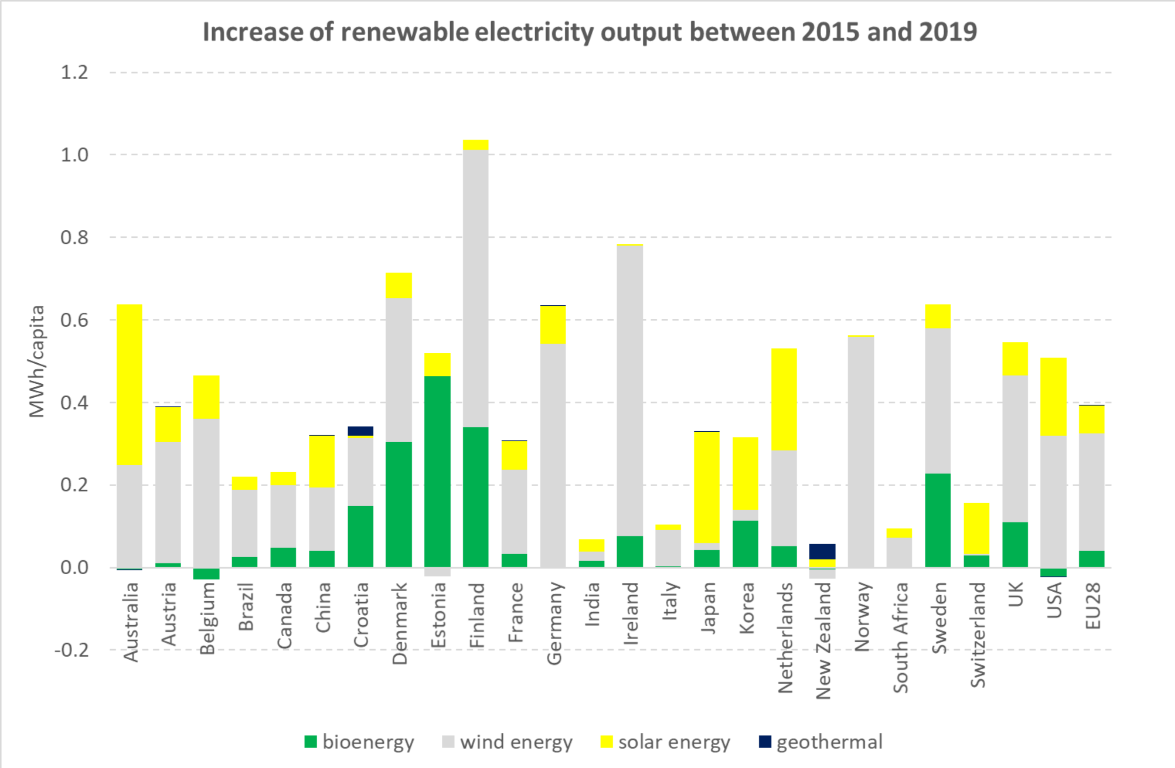

Figure 12: difference of renewable electricity output (excl. hydropower) in the IEA Bioenergy member countries between 2015 and 2019 (Data source: IEA (2021) World Energy Balances and Renewables Information)

Figure 13 indicates the role of biomass-based electricity in the electricity mix in the different countries, subdivided in the different biomass types (solid biomass, renewable MSW, biogas, and liquid biofuels). In Denmark, Finland and Estonia, bioenergy represents more than 15% of electricity consumption (predominantly through CHP), followed by the UK, Sweden, Germany and Brazil. In other countries, typical levels are 5% or 2-3% (with growing tendency in some countries). Countries like Norway, Canada and New Zealand currently have little focus on bio-power because their electricity system is already largely renewable through hydropower (and geothermal energy in the case of New Zealand).

For most countries solid biomass is the dominant fuel for bioelectricity. However, in Germany, Italy and Croatia bioelectricity is mainly produced from biogas; overall, biogas in the EU28 represents 2% of electricity production, while solid biomass represents 3.3%. In Switzerland renewable MSW is the dominant fuel for bioelectricity; shares of renewable MSW for electricity production are also relevant (>1% of power production) in Belgium, Denmark, Germany, Ireland, the Netherlands, Sweden, and the UK. The use of liquid biofuels for electricity production is less common, with only Italy reaching more than 1% from liquid biofuels.

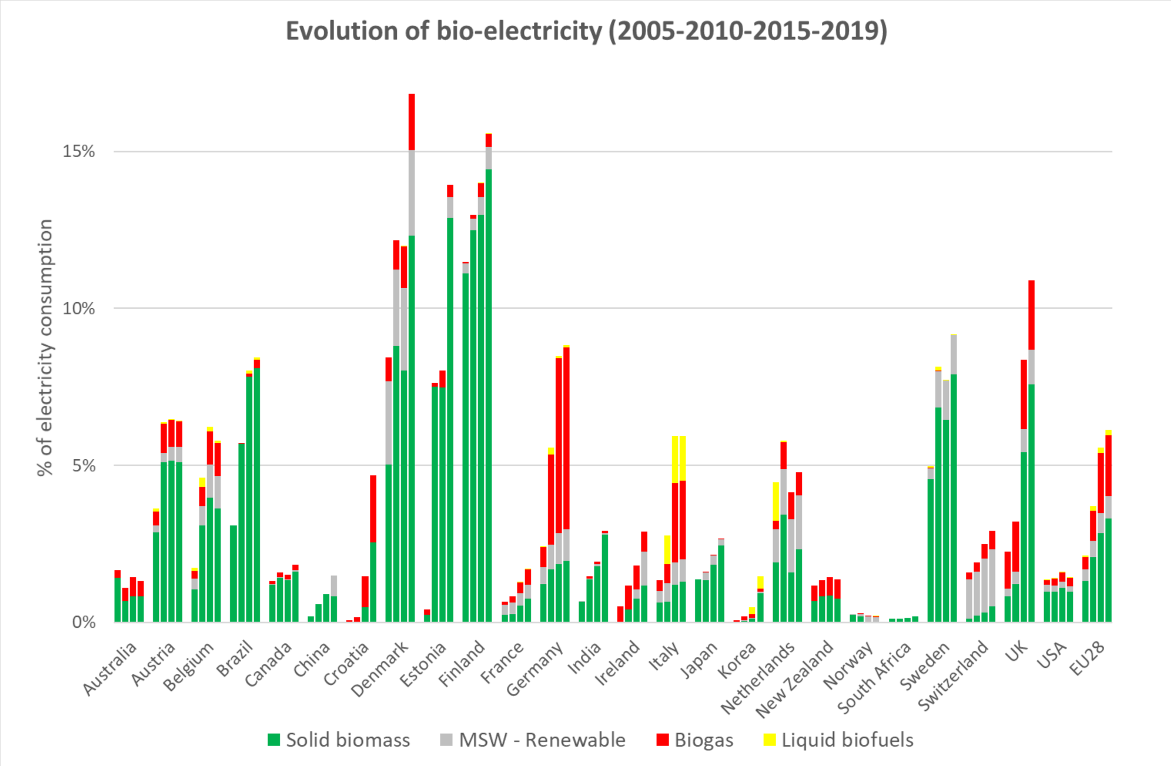

Figure 13: evolution of the share biobased electricity - split by fuel - in the IEA Bioenergy member countries (Data source: IEA (2021) World Energy Balances and Renewables Information)

FUEL/HEAT CONSUMPTION

This chapter considers the final consumption of fuels (fossil and renewable) in industry, the residential sector, commercial and public services and the agriculture/forestry sectors. It also includes heat sold to customers from CHP or heat plants, mainly through district heating; this heat can be produced from different sources – we make distinction between renewable and non-renewable heat provision. Most renewable heat sales are actually biomass based through central CHP or heat installations. The following are NOT included in these figures:

- transport fuels;
- fuel use by energy producing industries for transformation into electricity and/or heat (to be sold to third parties), and for own use;
- electric heating (direct or through heat pumps), as this is not separately reported in IEA statistics (it is part of electricity consumption, see previous paragraph).

Figure 14 shows the evolution of fuel/heat consumption in the different IEA Bioenergy member countries. There is some variation in overall demand levels, which tends to be related to climatic differences (leading to higher fuel/heat demand in colder regions) and the energy intensity of industries (e.g., pulp and paper industries in Finland and high industrialisation in Belgium and the Netherlands). Energy efficiency is high on the agenda in several developed regions, leading to some (modest) reductions in fuel/heat demand in the past decade.

Distinction can be made between (1) fossil fuel consumption, (2) consumption of distributed heat (of which part is renewable based) and (3) renewable fuels (mostly biomass based).

In most of the countries the ***fossil fuel*** component still dominates, still exceeding 75% of fuel/heat provision in Australia, Belgium, Canada, China, France, Germany, Ireland, Italy, Japan, South Korea, South Africa, the UK, and USA. There is a decreasing trend in the use of heating oil, but this is often compensated by an increase in natural gas. In several countries natural gas is the dominating fuel for fuel/heat provision. Coal is the dominating fuel in China and South Africa.

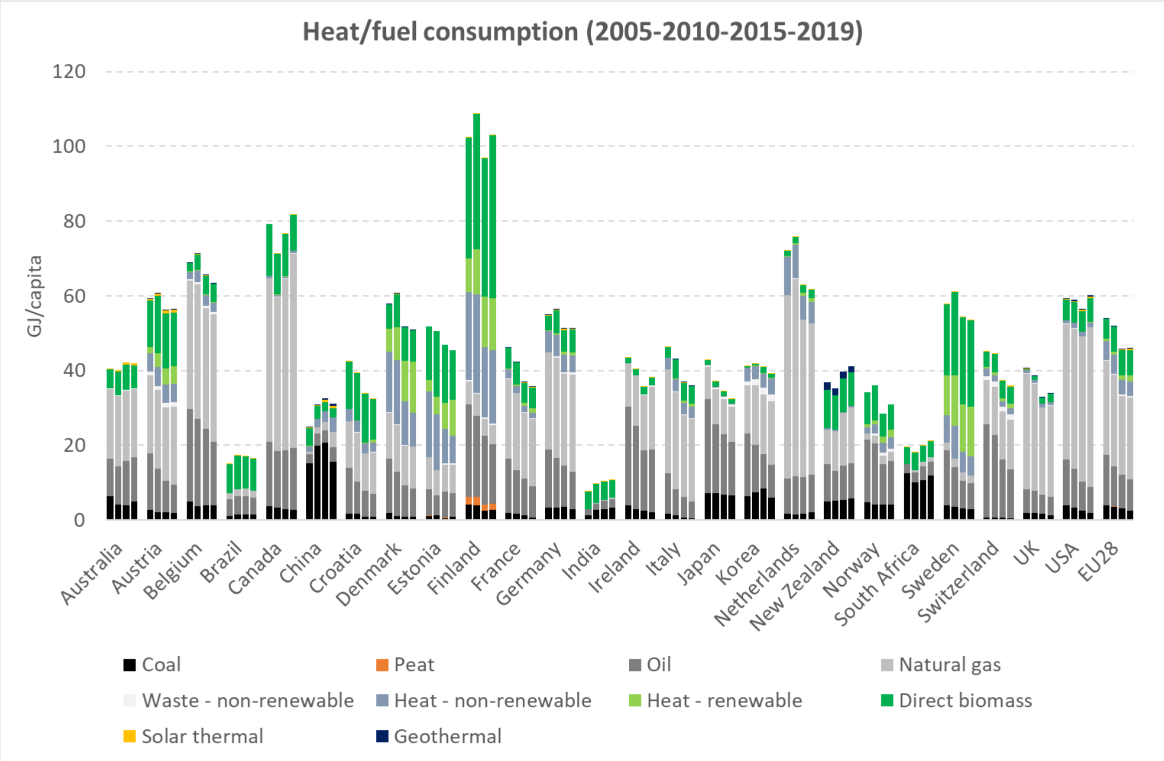

Figure 14: evolution of fuel/heat consumption in the IEA Bioenergy member countries (data source: IEA (2021) World Energy Balances and Renewables Information)

District heating and centralised heat sales are widely deployed in Scandinavian countries Sweden, Denmark, Finland and Estonia, exceeding 30% of fuel/heat consumption. Relevant levels (>10%) are also reached in Austria, China, Croatia, Germany, Italy, South Korea, Netherlands, and Norway. Several of these countries also put high focus in moving from fossil to biobased heat in these centralised CHP and heat installations.

The third component is ***renewable fuel*** (direct use of biomass for heating), or heat provided by solar thermal or geothermal installations. This component is dominated by biomass. In some developing countries (China, India) biomass use for heat goes down, which is mostly due to a reduction of traditional biomass use, often replaced by fossil fuels. Other countries have a relatively stable use of biomass for heating or a (slightly) increasing trend.

Figure 15 shows the combination of renewable fuels and the renewable share of distributed heat in relation to their share in overall heat/fuel demand. The most important progress has been made in countries with important shares of district heating (Denmark, Estonia, Sweden, Finland), particularly through the replacement of fossil fuels by biomass for centralised heat production. Several of these countries have implemented a CO_2 tax on fossil fuels which was an important driver for industries (and heat producers) to move from fossil fuels to bioenergy.

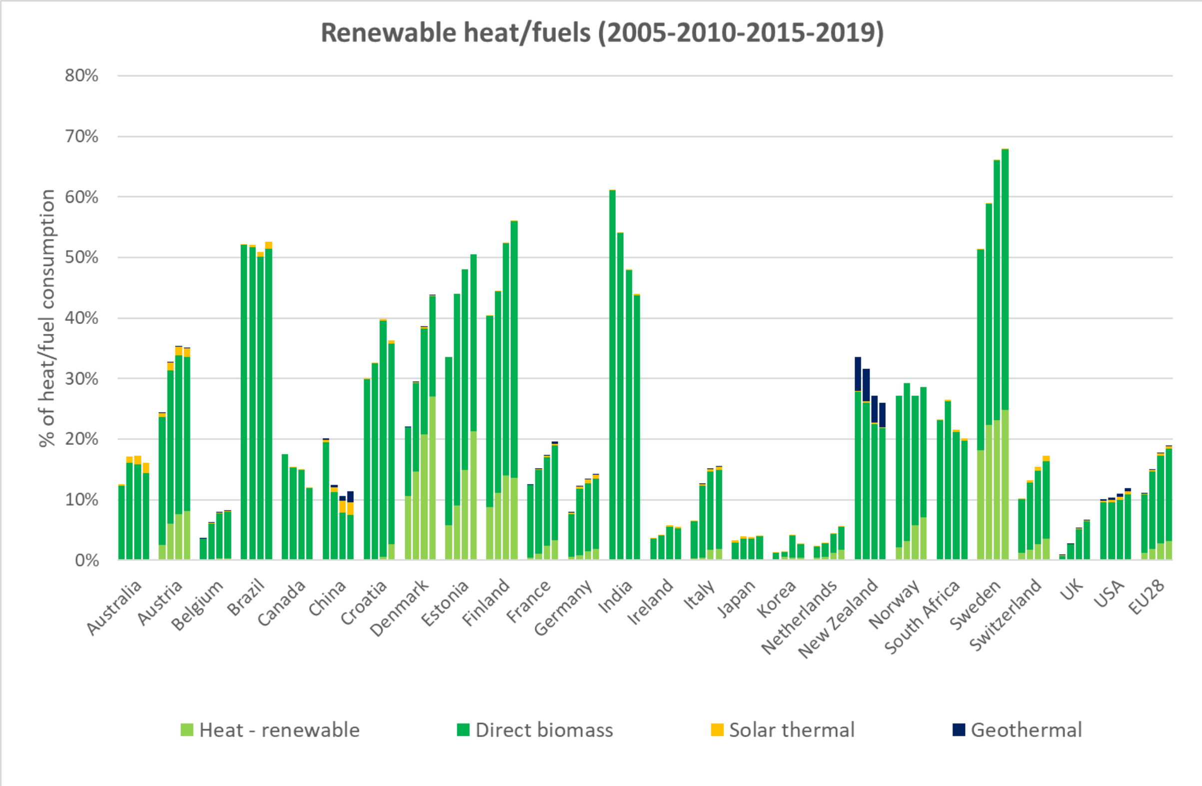

Figure 15: evolution of the share of renewable heat/fuels in the IEA Bioenergy member countries (Data source: IEA (2021) World Energy Balances and Renewables Information)

TRANSPORT ENERGY CONSUMPTION

In this chapter we consider the consumption of fossil oil based fuels (diesel, gasoline, LPG and other oil-based fuels like aviation fuels), natural gas, biofuels (biodiesel, biogasoline, other liquid biofuels and biomethane) and electricity in the transport sector. Only domestic fuel use is considered (including domestic flights); international travel is not included in these figures.

As is shown in Figure 16, overall levels of transport energy consumption are fairly stable around 30 GJ/capita (0.6-0.8 toe/capita) for most countries. Exceptions at the lower end are emerging economies (China, India, Brazil, South Africa) where transport energy consumption is expected to further increase with economic development. At the high end we see Canada and the United States with very high transport energy consumption levels, particularly in terms of gasoline (will be discussed further on).

The overall picture shows that fossil fuels still represent over 95% of transport energy for most countries, with dominating roles for diesel or gasoline, depending on the fleet composition. This reflects the challenge to displace fossil fuels in these sectors.

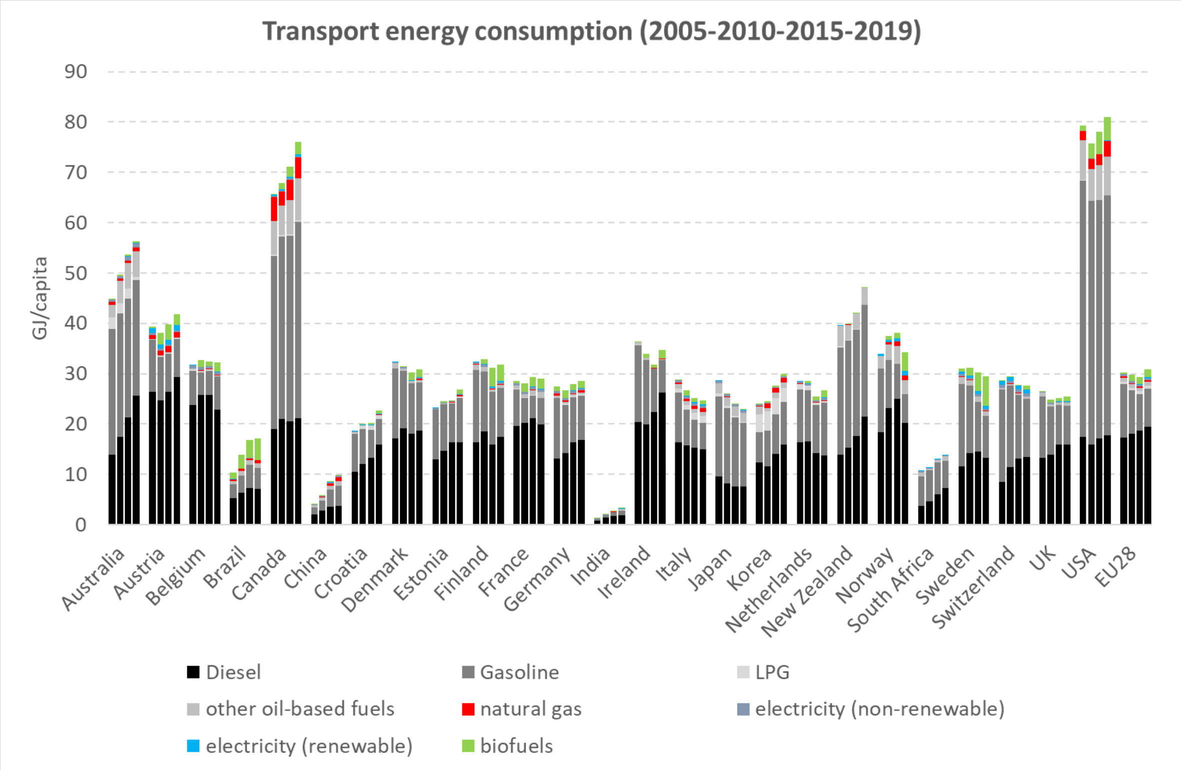

Figure 16: evolution of transport energy consumption (with different fuels) in the IEA Bioenergy member countries (data source: IEA (2021) World Energy Balances and Renewables Information)

- *Fossil diesel* fuel is mostly linked to heavy transport (trucks, buses). Nevertheless, in several European countries (e.g., Belgium, France, Germany) diesel fuel is also used in a substantial share of the light duty vehicle fleet (cars and vans). Typical levels of diesel use are between 15 and 25 GJ/capita (except in developing economies). A general trend in most countries is that fossil diesel consumption is still rising (particularly in Australia, Austria, Croatia, Finland, Ireland, Korea, New Zealand, and South Africa), or at least stable. Exceptions are Belgium and France, where there is a move back to gasoline for cars, and in Norway and Sweden where biodiesel has taken big steps in the past years, thereby replacing fossil diesel.

- *Gasoline* fuel is mostly linked to light duty transport (cars, vans, motorcycles). Even when setting aside emerging economies, there is much wider variation between the countries (as compared to diesel), from 5 GJ/capita in France, Italy, and Croatia, up to 39 GJ/capita in Canada and even 48 GJ/capita in the USA. Part can be explained by the fleet composition (more diesel cars in several European countries), part by typical driving distances in the USA and Canada, but also different fuel economy regulations, lower fuel prices and preference for bigger vehicle sizes. Gasoline use went down slightly in several countries since 2015, which is likely due to more stringent fuel economy regulations. In Norway, the decrease in gasoline may be partly related to increased sales of electric cars.

- *LPG* still has some relevant use in Croatia (3%), Italy (5%), South Korea (9%), and represents on average 1.8% of transport energy at EU28 level. Nevertheless, there seems to be a declining tendency, particularly in Australia, Japan, and the Netherlands where LPG used to reach relevant levels.

- The category '*other oil-based fuels*' mostly consists of aviation fuels used for domestic flights. This is mostly relevant for larger (or stretched) countries, like Australia, Brazil, Canada, China, Japan, New Zealand, Norway, South Africa, and the USA where domestic aviation typically reaches 5 to 10% of domestic transport energy consumption. Mind that flights between European member countries are not counted in the EU28 figures.

- *Natural Gas* has some relevant use in Austria (3%), Brazil (3%), Canada (5%), China (7%), India (3%), Italy (3%), Norway (2%), South Korea (3%) and the USA (3.5%), and an average at EU28 level of 1.1%. There seems to be a slightly increasing tendency in natural gas use in several countries, but in most countries its share remains below 1%.

Figure 17 considers the evolution of renewable options in transport since 2005, indicating the different categories of biofuels as well as renewable electricity.

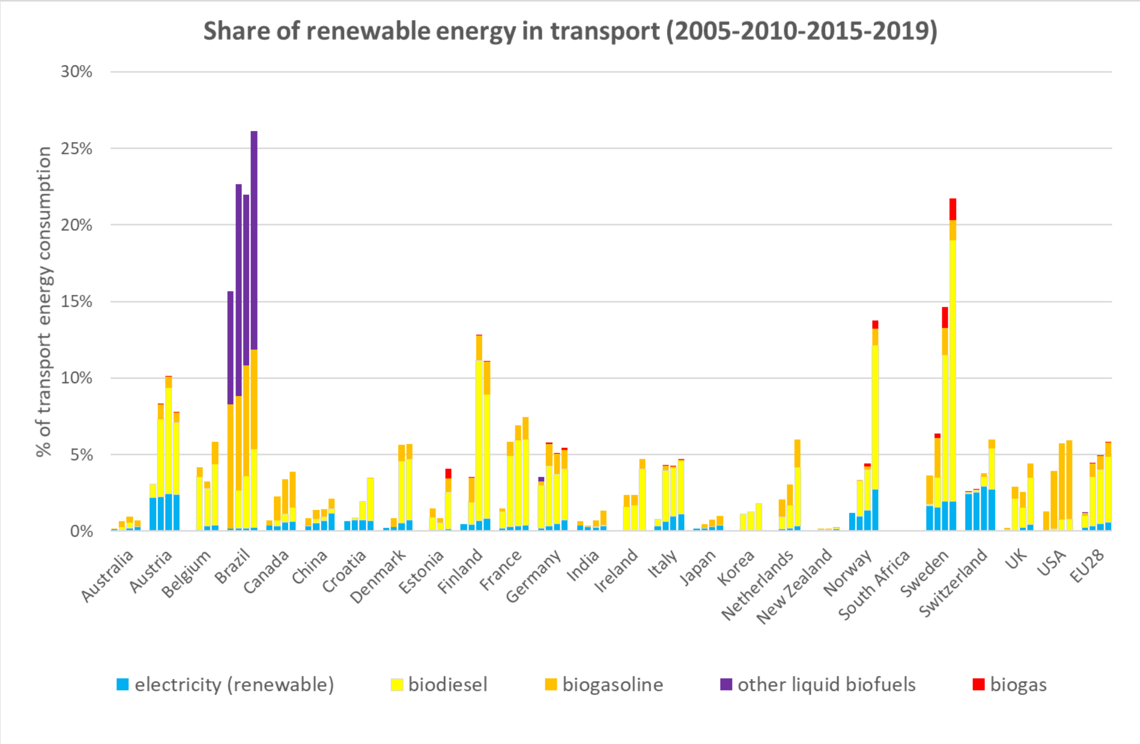

Figure 17: evolution of the share of renewable energy in transport in the IEA Bioenergy member countries (data source: IEA (2021) World Energy Balances and Renewables Information)

Brazil and Sweden have achieved a renewable energy share in transport of 25% and 21%, respectively, with Norway and Finland also reaching more than 10%. Most other countries have renewable shares of 4 to 6% or lower.

The distribution of biodiesel vs biogasoline (typically bioethanol) tends to follow the distribution of diesel vs gasoline, with dominance of biodiesel in countries with a high diesel share and dominance of bioethanol in countries with a high gasoline share (Brazil, USA, Canada). Nevertheless, in these countries biodiesel is now also increasingly used as an alternative for diesel in the heavy-duty sector.

Brazil (which reports blended ethanol as 'biogasoline' and pure ethanol as 'other liquid biofuel') already has a long history with bioethanol since the 1970s, thereby stimulating the production of ethanol and the use of pure ethanol in adapted or fuel-flexible cars, and also putting a minimum blend level of ethanol (of 20% or more) in regular gasoline. It now also imposes minimum levels of biodiesel in diesel fuel.

Sweden, Norway, and Finland saw high increases of biofuels in the past decade, mostly driven by increasing blend obligations for fuel distributors. The focus in these countries is currently on biodiesel fuel. The availability of hydrotreated vegetable oil (HVO), next to biodiesel (FAME) facilitated an increase of blend obligations and a move beyond the FAME blend wall of 7% by volume (as prescribed in the EN590 diesel fuel standard).

In many countries the current blend wall of ethanol in regular gasoline (usually 10% by volume, in some countries still only 5%) limits its further expansion. This is also the case for biodiesel in countries where there is limited availability of HVO, and expansion of biobased diesel is limited by the maximum blending of FAME prescribed in the diesel fuel standard.

While many countries took substantial steps in biofuel introduction between 2005 and 2010 (mostly through obligations or tax exemptions), levels tended to stall between 2010 and 2015, particularly related to regulatory uncertainty (e.g., ongoing uncertainty in the EU between 2010 and 2015 on how to deal with potential indirect land use effects). In recent years, levels have increased again, which in the EU may be due to the publication of the updated Renewable Energy Directive, providing longer term (2030) prospects for (advanced) biofuels. Meanwhile, the increased focus on advanced (residue based) biofuels in the EU did not necessarily lead to an increase of the actual volume of biofuels as advanced biofuels could be double counted towards the renewable energy in transport target, and multipliers for renewable electricity in transport (including from existing uses in rail) were increased. So, the 10% target for 2020 in the EU will probably be reached with physical average biofuel levels of 5-6% and 1% renewable electricity.

Biomethane in transport is so far only relevant in a few countries, e.g., Sweden, Norway, Estonia, and some small shares in Germany and Italy.

Renewable electricity is considered as an important option in transport towards the future and particularly in the light duty segment and urban traffic. As of today, electricity use only represents between 0.1 and 4% of transport energy (currently mostly in rail), with the renewable share depending on the national electricity mix. Highest shares of renewable electricity (up to 3% of overall transport energy use) are reached in Switzerland, Austria, Norway, and Sweden; all these countries combine almost fully decarbonized power with a well-developed public transport system.

Sales of electric and plug-in hybrid cars are substantially increasing in recent years and several regions put high targets on EV sales (e.g., with the EU targeting a 100% share of EVs in car sales by 2035 and the US aiming to make half of all new cars sold in 2030 electric). Norway – which provides very high incentives for electric vehicles and free charging - is most advanced in electric car sales, with 54 % of new passenger cars in 2020 being fully electric. Electric road vehicles already represented 1.7% of total transport energy use in 2019 in Norway, and this will further increase in the coming years.

Even with promising prospects for electric vehicles, with different EV introduction speeds in different regions and considering typical vehicle lifetimes of over 10 years, the replacement of the car fleet will take time so fuels will still be needed for the car sector in the next few decades; moreover, the heavy-duty sector will still remain dependent on (predominantly diesel) fuels for quite some time. So renewable fuels will remain an important option to displace fossil fuels in transport.

Annex

DEFINITIONS

IEA statistical data is collated from national bodies on a joint annual questionnaire (with Eurostat and the United Nations), so that the data is the same as reported in e.g., Eurostat. However, data is presented as summarized data, and the way it is displayed or categorized differs from the way in which Eurostat and others display their data. The details of how IEA data is collated and displayed are explained in the IEA Energy Statistics Manual which is available from the IEA website. Also available on the IEA website are the balance definitions, part of which are displayed below. For more definitions, please check the Documentation of the World Energy Balances 2020[8].

Total Energy Supply

is made up of: Indigenous production (+); imports (+); exports (-) and stock changes (+/-).

Production

Production refers to the production of primary energy, i.e., hard coal, lignite, peat, crude oil, NGL, natural gas, combustible renewables and waste, nuclear, hydro, geothermal, solar and the heat from heat pumps that is extracted from the ambient environment. Production is calculated after removal of impurities (e.g., sulphur from natural gas). Calculation of production of hydro, geothermal, etc. and nuclear electricity is explained in in section *Units and conversions*.

Imports and Exports

Imports and exports comprise amounts having crossed the national territorial boundaries of the country, whether or not customs clearance has taken place.

Stock Changes

Stock changes reflect the difference between opening stock levels at the first day of the year and closing levels on the last day of the year of stocks on national territory held by producers, importers, energy transformation industries and large consumers. A stock build up is shown as a negative number, and a stock drawdown as a positive number.

Total Final Consumption

Is the sum of the consumption in the end-use sectors and for non-energy use. Energy used for transformation processes and for own use of the energy producing industries is excluded. Final consumption reflects for the most part deliveries to consumers.

Non-energy use

Covers those fuels that are used as raw materials in the different sectors and are not consumed as a fuel or transformed into another fuel. Non-energy use is shown separately in final consumption under the heading non-energy use.

[8] Available at: https://iea.blob.core.windows.net/assets/4f314df4-8c60-4e48-9f36-bfea3d2b7fd5/WorldBAL_2020_Documentation.pdf

Note that for biofuels, only the amounts specifically used for energy purposes (a small part of the total) are included in the energy statistics. Therefore, the non-energy use of biomass is not taken into consideration and the quantities are null by definition

Electricity output

Shows the total number of GWh generated by power plants (electricity plants and CHP plants).

Heat output

Heat production includes all heat produced by main activity producer CHP and heat plants, as well as heat sold by autoproducer CHP and heat plants to third parties. The use of fuels for heat which is not sold is included under the sectors in which the fuel use occurs.

Primary solid biofuels

Primary solid biofuels is defined as any plant matter used directly as fuel or converted into other forms before combustion. This covers a multitude of woody and herbaceous materials generated by industrial processes or provided directly by forestry and agriculture (firewood, wood chips, bark, sawdust, shavings, chips, sulphite lyes also known as black liquor, animal materials/wastes and agricultural residues that are used for energy production such as bagasse or straw).

Biogases

Biogases are gases arising from the anaerobic fermentation of biomass and the gasification of solid biomass (including biomass in wastes). The biogases from anaerobic fermentation are composed principally of methane and carbon dioxide and comprise landfill gas, sewage sludge gas and other biogases from anaerobic fermentation.

Biogases can also be produced from thermal processes (by gasification or pyrolysis) of biomass and are mixtures containing hydrogen and carbon monoxide (usually known as syngas) along with other components. These gases may be further processed to modify their composition and to produce substitute natural gas.

Liquid biofuels

Liquid biofuels include biogasoline, biodiesel and other liquid biofuels. It does not include the total volume of gasoline or diesel into which the biofuels are blended.

Biogasoline includes bioethanol (ethanol produced from biomass and/or the biodegradable fraction of waste), biomethanol (methanol produced from biomass and/or the biodegradable fraction of waste), bio-ETBE (ethyl-tertio-butyl-ether produced on the basis of bioethanol; the percentage by volume of bio-ETBE that is calculated as biofuel is 47%) and bio-MTBE (methyl-tertio-butyl-ether produced on the basis of biomethanol: the percentage by volume of bio-MTBE that is calculated as biofuel is 36%).

Biodiesels includes biodiesel (a methyl-ester produced from vegetable or animal oil, of diesel quality), bio-DME (dimethylether produced from biomass), Fischer Tropsh (Fischer Tropsh produced from biomass), cold pressed bio-oil (oil produced from oil seed through mechanical processing only) and all other liquid biofuels which are added to, blended with or used straight (unblended) as transport diesel.

Other liquid biofuels include liquid biofuels not reported in either biogasoline or biodiesels.

Industrial waste

Industrial waste of non-renewable origin consists of solid and liquid products (e.g., tyres) combusted directly, usually in specialised plants, to produce heat and/or power. Renewable industrial waste is not included here, but with solid biofuels, biogas or liquid biofuels.

Municipal waste

Municipal waste consists of products that are combusted directly to produce heat and/or power and comprises wastes produced by households, industry, hospitals, and the tertiary sector that are collected by local authorities for incineration at specific installations. Municipal waste is split into renewable and non-renewable.

Hydro / solar PV / wind energy / tide, wave, ocean

For hydro, solar, wind and tide/wave/ocean energy, the energy content of the electricity produced is considered in TES*. Other sources for electricity also have waste heat which is counted in the TES (e.g., 'Nuclear' shows the primary heat equivalent of the electricity produced by a nuclear power plant with an average thermal efficiency of 33%). So, care should be taken when using TES to compare the role of the different energy sources as this overestimates the role of resources producing electricity with a high share of unused waste heat.

*When it comes to electricity from non-combustible sources, the IEA, in line with IRES, adopts a coherent principle across sources – the "physical content method" – by measuring the primary energy equivalent at the first point downstream in the production process for which multiple energy uses are practical. This means that hydro, wind and solar become "energy products" in the statistical sense at the point of generation of electricity, and that their "primary energy equivalent" is computed as the electricity generated in the plant, while the kinetic energy of the wind or the water does not enter the "energy balance" although being "energy" in a scientific sense.

The IEA had at a point used the "partial substitution method", based on the assumption that hydro, wind, solar electricity had displaced thermal generation. This involved using an average thermal conversion efficiency (e.g., 36%) to back-compute their corresponding "primary energy equivalent". This made their shares in the primary energy supply greater (around three times as much). However, the principle was abandoned as it relied on arbitrary conversion factors and was creating some transformation losses inside the energy balance that did not really exist.
https://www.iea.org/newsroom/news/2017/september/commentary-understanding-and-using-the-energy-balance.html

UNITS AND CONVERSIONS

The standard conversion factors of the International Energy Agency were used.

- kilo (k): 10^3
- mega (M): 10^6
- giga (G): 10^9
- tera (T): 10^{12}
- peta (P): 10^{15}
- exa (E): 10^{18}

Most figures in the country reports are expressed in PJ (petajoule) or in toe (tonne of oil equivalent).

1 PJ = 23884.6 toe = 0.2778 TWh (terawatt hour)

SYMBOLS AND ABBREVIATIONS

- CHP: Combined Heat and Power
- CO_2: carbon dioxide
- DME: dimethylether
- ETBE: ethyl-tertio-butyl-ether
- ETS: Emission Trading System
- EU: European Union
- GHG: Greenhouse gases
- IEA: International Energy Agency
- IRES: International Recommendations for Energy Statistics
- MSW: municipal solid waste
- MTBE: methyl-tertio-butyl-ether
- RES: Renewable Energy Sources
- TES: total energy supply
- UK: United Kingdom of Great Britain and Northern Ireland
- US/USA: United States of America

IEA Bioenergy
Technology Collaboration Programme