Government subsidies for electricity generation and combined heat and power (CHP) from solid biomass

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Contract details

Natural Resources Defense Council

Financial support for electricity generation and CHP from solid biomass

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Abbreviations

BECCS	Bioenergy with Carbon Capture
CHP	Combined Heat and Power
MS	Member States
RES	Renewable Energy Sources

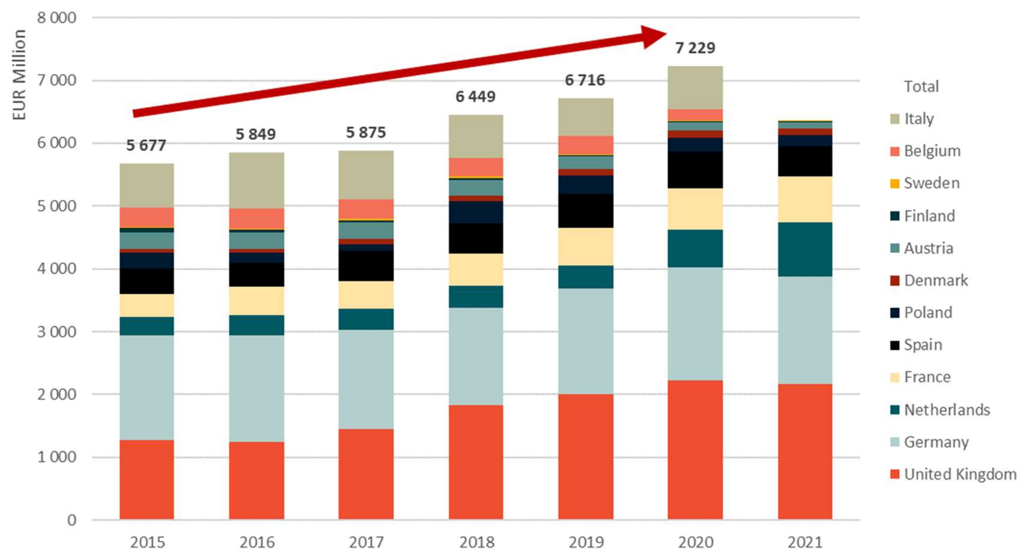
CONTENTS

Executive summary

Subsidies to biomass for electricity production

This report provides a data update and extension of countries to the previous research carried out by Trinomics in 2019 and 2020 on subsidies for biomass electricity. In 2020, the countries analysed spent more than €7.2 billion in subsidies for solid biomass electricity generation and combined heat and power (CHP). The data in this report reveals an overall trend of increasing subsidies for biomass electricity generation and CHP, with subsidies increasing by 27% across the 12 countries from 2015-2020.

Figure 0-1 Increasing subsidies to solid biomass for electricity production, 2015-2021

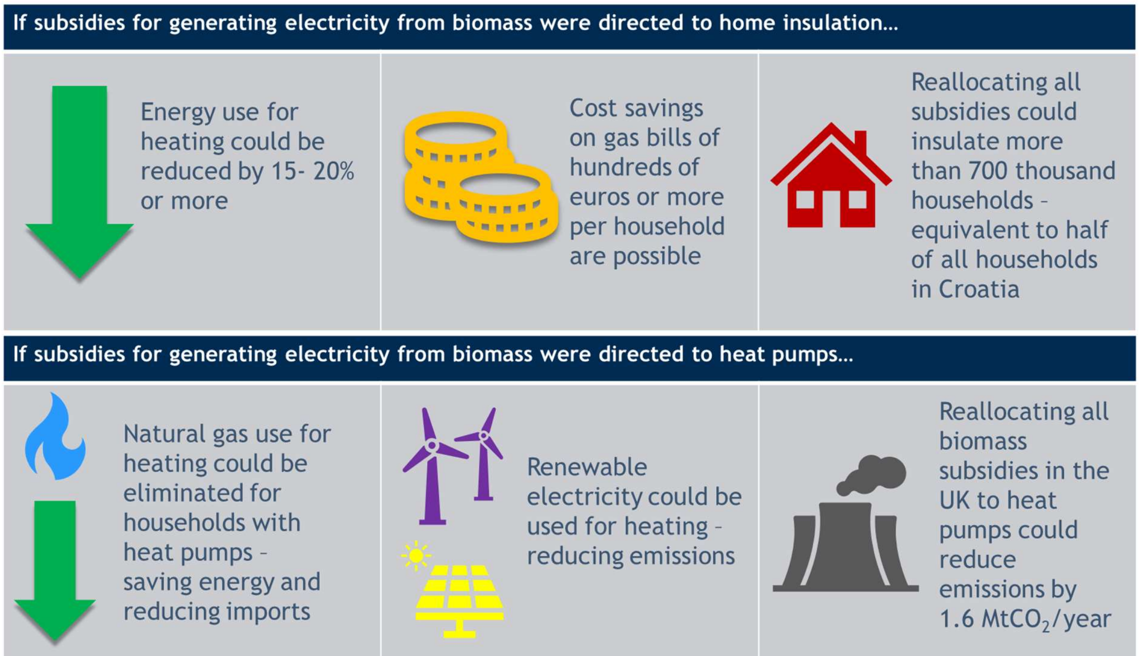


Note: 2021 data is missing for Belgium and Italy, as is information on some subsidies for 2021 in Poland, the Netherlands and Germany.

This work provides a second update for the previously studied countries (Denmark, France, Germany, Netherlands, United Kingdom) and extends the research to other countries that were not previously investigated (Austria, Belgium, Finland, Italy, Poland, Spain and Sweden). As a percentage, the increase was greatest in the Netherlands where subsidies have almost tripled. Meanwhile, Germany and the UK are the top two countries investing (by value) in subsidising electricity from solid biomass.

Alternative use of subsidies

Subsidies for electricity production from biomass are controversial, with concerns over the high costs; the carbon emissions (i.e. treatment as carbon neutral, when evidence strongly suggests this is not the case); and negative impacts on forests and biodiversity. The funds directed to biomass electricity subsidies could alternatively be used in other ways to deliver benefits to consumers and/or contribute to carbon neutrality. This report examines what could be achieved if the subsidies these countries dedicate to biomass electricity were instead used to install energy efficient home insulation or heat pumps. Some of the key benefits are summarised below.


If subsidies for generating electricity from biomass were directed to home insulation…
Energy use for heating could be reduced by 15- 20% or more
Cost savings on gas bills of hundreds of euros or more per household are possible
Reallocating all subsidies could insulate more than 700 thousand households - equivalent to half of all households in Croatia
If subsidies for generating electricity from biomass were directed to heat pumps…
Natural gas use for heating could be eliminated for households with heat pumps - saving energy and reducing imports
Renewable electricity could be used for heating - reducing emissions
Reallocating all biomass subsidies in the UK to heat pumps could reduce emissions by 1.6 MtCO2/year

1 Bioenergy subsidies

1.1 Overview of biomass subsidies – 2015-2021

This 2022 report provides an expansion and update of the reporting on subsidies to solid biomass for electricity generation & CHP carried out by Trinomics on behalf of NRDC in 2019 and 2020. This work provides a second update for the previously studies countries (Denmark, France, Germany, Netherlands, United Kingdom) and extends the research to other countries that were not previously investigated (Austria, Belgium, Finland, Italy, Poland, Spain and Sweden). As in the previous studies, we only include subsidies for electricity generation from solid biomass. We exclude subsidies for electricity from biogas and subsidies that only support solid biomass use for heating, although subsidies that support electricity and heat production via CHP are included. The depicted subsidies only include those that support the demand, production and/or consumption of biomass for electricity; we do not include subsidies for R&D. We also do not include general tax and/or VAT exemptions (e.g. reduced VAT rates for all electricity), although in some countries these can be significant due to biomass's zero carbon rating.

The development of biomass subsidies for these 12 countries during the period 2015-2021 is presented in Table 1-1. For 10 of the 12 countries, it was possible to update the subsidy database to 2021. For the other two, it was only possible up to 2020.

Overall, a trend of increasing subsidies for biomass electricity and CHP can be observed, with subsidies increasing by 27% across the 12 countries from 2015-2020, and by 36% for 10 of those countries from 2015-2021. In 2020, the investigated countries spent more than €7.2 billion in subsidies for solid biomass electricity and CHP.

However, the picture is quite mixed across countries, with six of the 12 countries reducing subsidies over this period, and six increasing subsidies. Generally, the increases are larger than the decreases. Particularly prominent are the increases observed in the Netherlands (almost trebling), France and Denmark (both almost doubling), and the UK (increasing by 70% from 2015-2021). Declines were most prominent in Finland, Sweden, Austria and Belgium. Subsidy levels were relatively stable in Germany and Italy.

Table 1-1 Summary of aggregate bioenergy subsidies 2015-2021, EUR million

Country	Biomass subsidies (in EUR million)							
	2015	2016	2017	2018	2019	2020	2021	Change 2015-2021
2015-2021 data								
United Kingdom	1 269.3 (£921.5)	1 249.8 (£1023.5)	1 445.9 (£1 266.8)	1 825.5 (£1 615.1)	2 005.9 (£1 759.8)	2 218.6 (£1 967.5)	2 159.6 (£1 856.4)	70% (101%)
Germany	1 672.3	1 685.3	1 586.5	1 557.5	1 681.5	1 801.9	1 724.0	3%
Netherlands	288.0	330.0	333.9	343.1	370.2	599.4	856.5	197%
France	375.7	457.5	445.5	523.4	597.5	658.3	725.4	93%
Spain	401.4	377.0	474.6	483.0	537.6	588.0	496.0	24%
Poland	251.1	155.7	104.6	347.1	293.5	226.7	166.4	-34%
Denmark	55.0	63.7	85.1	79.5	105.4	109.3	108.3	97%
Austria	270.4	262.7	263.2	260.4	195.4	136.7	104.9	-61%

Finland	69.0	38.5	36.6	28.2	16.7	16.1	14.7	-79%
Sweden	10.3	17.9	16.7	18.3	20.5	9.2	3.1	-70%
Sub-total	4 662.6	4 638.1	4 792.7	5 466.1	5 824.2	6 364.2	6 358.8	36%
2015-2020 data								
Italy	701.2	894.8	769.5	682.9	607.2	687.3		-2%
Belgium	313.7	315.8	312.8	299.8	284.8	177.8		-43%
Sub-total	1 014.9	1 210.6	1 082.3	982.7	892.0	865.0		-15%
Total	5 677.5	5 848.7	5 875.0	6 448.8	6 716.2	7 229.2		27%

* Note that 2021 values for these countries are missing for some subsidies, actual totals are likely to be higher.

Figure 1-1 Support to solid biomass for electricity generation and CHP, 2015-2021

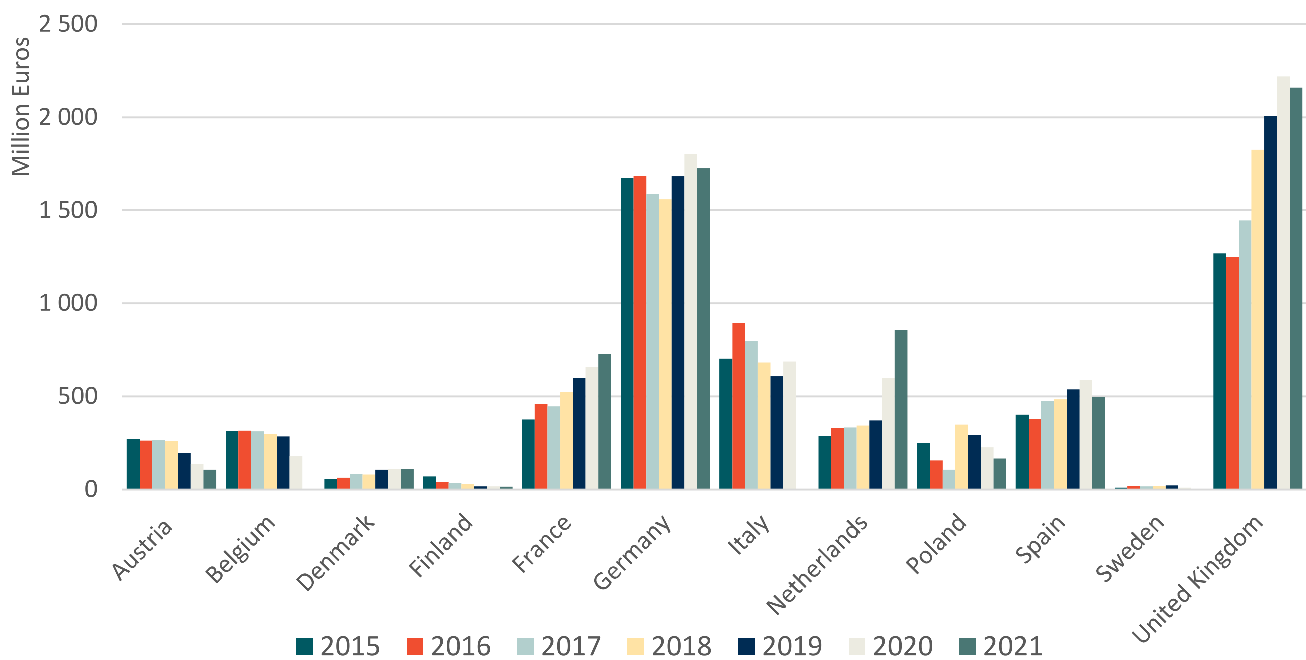


Figure 1-2

Note: There are some limitations to the exercise based on the nature of the data on subsidy reporting. Notably, given the aggregation of subsidy reporting it is likely that some reported subsidies are (1) in fact for heating, rather than electricity or CHP; and (2) may not only refer to solid biomass but also address biogas or other forms of biomass. However, the team has endeavoured to disaggregate and eliminate these out-of-scope items as far as possible.

1.2 Overview of the share of biomass in total renewable energy subsidies – 2015-2018

The share of bioenergy subsidies against the share of subsidies for all renewable energy sources (RES) is presented in Table 1-2 for the period 2015-2020. 2021 is excluded from the analysis since there are no available data for the total RES subsidies of that year.

On average, support to solid biomass represents around 7% of total RES subsidies each year, remaining quite constant in aggregate across the countries. Variations are evident between countries, with the share being relatively high in the Netherlands and Poland. Changes in shares largely mirror the movements in subsidies presented in section 1.1, with marked declines in Austria, Finland and Sweden.

Table 1-2 Overview of the share of biomass in total renewable energy subsidies 2015-2020

Country	Bioenergy subsidies (EUR million)						RES subsidies (EUR million)						Bioenergy as % of total					
	2015	2016	2017	2018	2019	2020	2015	2016	2017	2018	2019	2020	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**
Austria	270	263	263	260	195	137	1 223	1 237	1 322	1 231	1 242	1 163	22%	21%	20%	21%	16%	12%
Belgium	314	316	313	300	285	178	2 244	2 083	2 128	2 283	2 364	2 468	14%	15%	15%	13%	12%	7%
Denmark	55	64	85	79	105	109	1 125	1 057	1 316	1 019	1 076	1 030	5%	6%	6%	8%	10%	11%
Finland	69	39	37	28	17	16	290	263	354	322	586	729	24%	15%	10%	9%	3%	2%
France	376	458	446	523	598	658	5 378	5 523	5 747	5 967	6 890	7 434	7%	8%	8%	9%	9%	9%
Germany	1 672	1 685	1 587	1 558	1 682	1 802	27 817	28 152	29 056	27 850	30 282	33 129	6%	6%	5%	6%	6%	5%
Italy	701	895	770	683	607	687	15 543	16 447	15 429	16 129	14 184	15 102	5%	5%	5%	4%	4%	5%
Netherlands	288	330	334	343	370	599	986	1 261	1 441	1 581	1 669	2 254	29%	26%	23%	22%	22%	27%
Poland	251	156	105	347	294	227	741	595	546	1 096	1 084	1 213	34%	26%	19%	32%	27%	19%
Spain	401	377	475	483	538	588	6 244	6 137	6 524	6 371	6 412	6 025	6%	6%	7%	8%	8%	10%
Sweden	10	18	17	18	21	9	136	252	276	412	229	389	8%	7%	6%	4%	9%	2%
Total	**4 408**	**4 599**	**4 429**	**4 623**	**4 710**	**5 010**	**61 726**	**63 006**	**64 139**	**64 262**	**66 017**	**70 934**	**7%**	**7%**	**7%**	**7%**	**7%**	**7%**
United Kingdom	1 269	1 250	1 446	1 826	2 006	2 219	8 259	8 442	8 948	9 322			15%	15%	16%	20%		

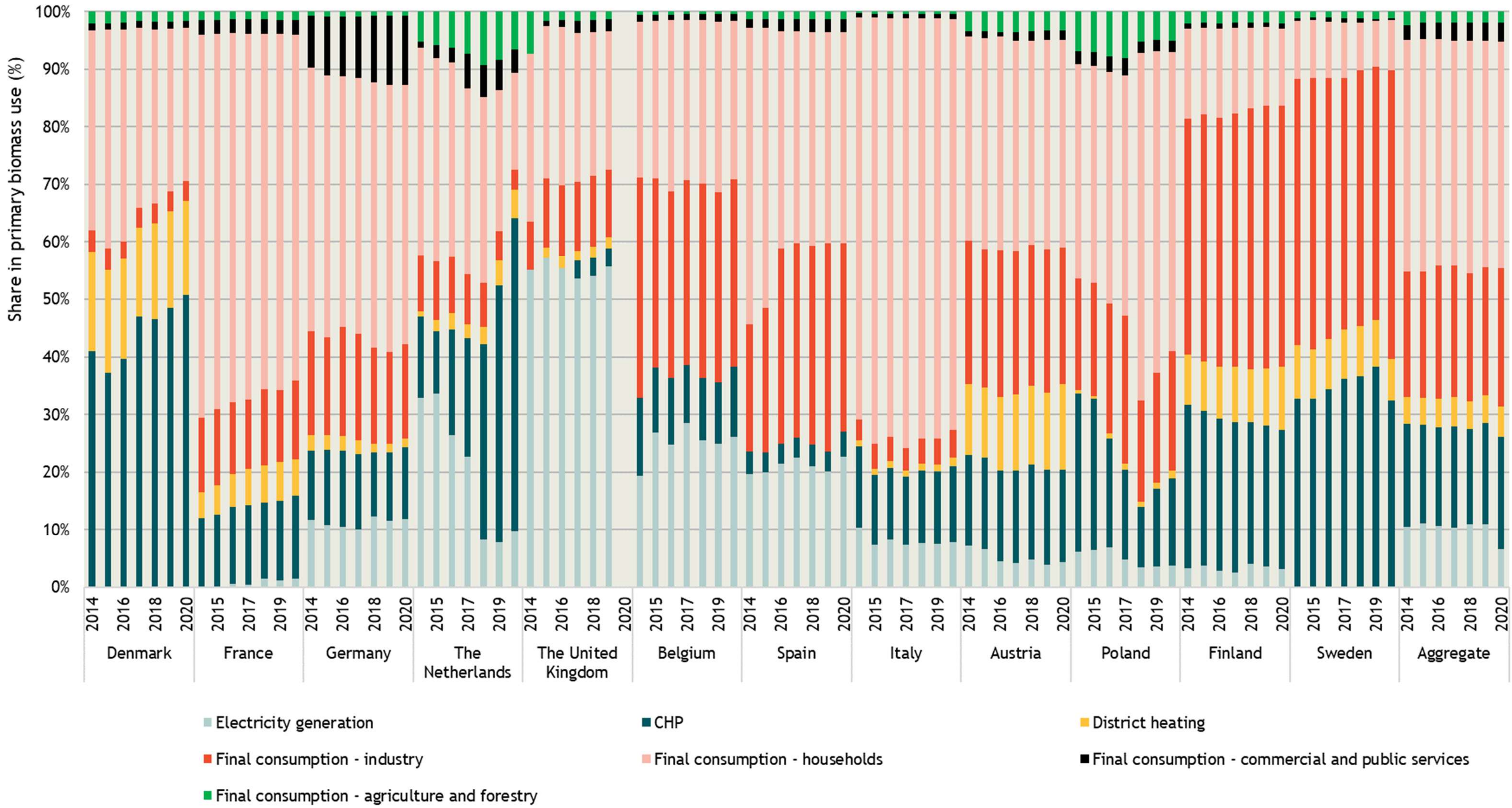
2 Overview of the uses of solid biomass for energy purposes

The energy uses of solid biomass vary among the investigated countries, as depicted in Figure 2-1. Analysis in this section includes solid biomass uses for both electricity and heating purposes.

In all countries, consumption by households plays an important role, particularly in France, Italy, Poland and Germany. Use by industry and for CHP are the second and third largest uses in aggregate. Use in industry is a particularly high share of consumption in Belgium, Spain, Finland and Sweden, the latter two strongly linked to the paper and pulp industry in these countries. Final consumption of solid biomass for CHP is a particularly high share of consumption in Denmark, the Netherlands (for greenhouse horticulture), Finland and Sweden. Use for electricity generation is a particularly high share of consumption in the United Kingdom, Belgium and Spain. Use for electricity generation was previously a high share of consumption in the Netherlands as well, but this has decreased as CHP has increased over the last few years.

The use of solid biomass for district heating is relatively low, although it contributes a notable share of biomass consumption in Denmark, Austria, Finland, Sweden and France. The use of solid biomass for final consumption in agriculture is very low across the countries, totalling more than 5% only in the Netherlands (again linked to greenhouse horticulture) and Poland. Biomass consumption for commercial and public services is also very low across almost all countries. Only in Germany is there substantial consumption by this sector.

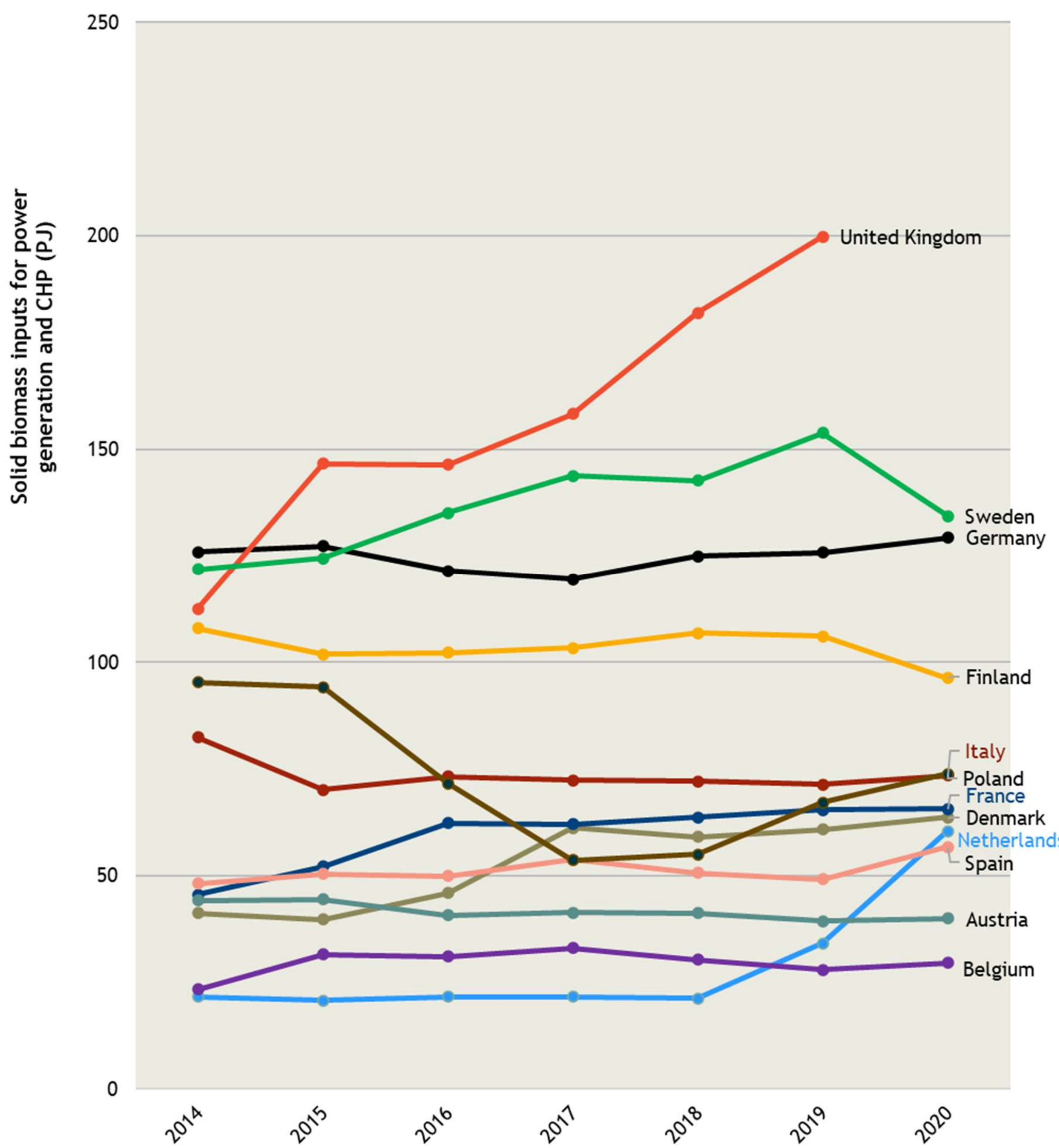
Figure 2-1 Overview of the uses of solid biomass by consumption type in 2014-2020



2.1.1 Solid biomass use in electricity generation, district heating, and combined heat and power plants

By looking at the use of solid biomass for electricity generation and CHP for the period 2014-2020 (Figure 2-2), we can observe a few interesting trends. First, for many countries (e.g. Italy, Germany, Finland, Austria, Belgium and Spain) the use of solid biomass is relatively stable or declining over this period. In contrast, a few countries see quite dramatic increases, especially the UK and the Netherlands, both of which heavily subsidise biomass electricity. Solid biomass use has fluctuated in Sweden and Poland; in the former as part of an upwards trend, in the latter as part of a downward trend but increasing again since 2018. France showed increasing consumption between 2014-2016, but this has since stabilised.

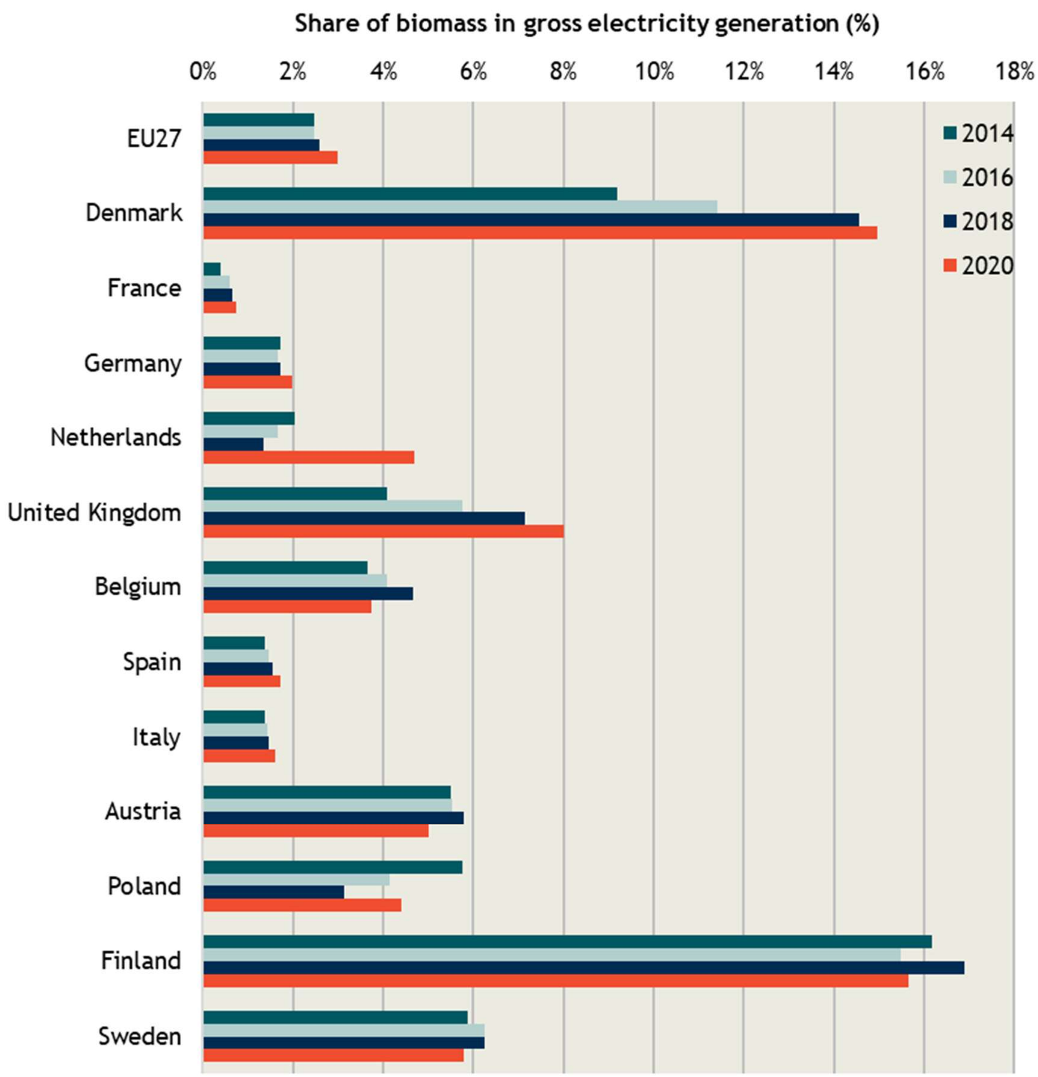
Figure 2-2 Solid biomass inputs for electricity generation and combined heat and power for 2014-2020 (PJ)



2.1.2 Use of solid biomass in electricity generation

Regarding the share of overall electricity generation from solid biomass, Figure 2-3 shows only a small increase to around 3% in the EU27 from 2014-2020. Finland ranks first, with around 16% of its electricity coming from primary solid biomass, followed by Denmark with around 15% - a significant increase since 2014. The United Kingdom generates approximately 8% of its electricity from biomass, almost doubling this share since 2014. The Netherlands also observed a significant increase in the biomass share of electricity production in this period, particularly from 2018-2020. Most other countries experienced only small variations in the share of electricity provided by solid biomass in this period.

Figure 2-3 Electricity generated from solid biomass as a share of total electricity generation 2014-2020 in the 12 in-scope countries



Note: UK 2020 values are for 2019

3 Potential savings from repurposing of biomass subsidies

The purpose of this task is to show the potential impact on household energy bills, energy use and emissions if the biomass subsidies identified in chapter 1 were reallocated to more impactful alternatives. Within this section, we examine two cases: (1) insulation upgrades; and, (2) funding the installation of heat pumps.

3.1 Reallocation of biomass subsidies to home insulation

Approach

The approach is based on estimating the potential savings that could be achieved if the identified biomass subsidies were instead directed to grants subsidising home insulation. The average cost for home insulation is estimated, and the average annual cost savings that could be achieved if these older houses were better insulated is assessed. The number of households and resulting total energy savings are calculated based on this.

Rationale

The EU's building stock is responsible for about 40% of the EU's total energy consumption and 36% of its greenhouse gas emissions.[1] The use of fossil gas boilers in many European homes further compounds the issue. Investing is insulation is one of the key approaches to saving energy and cutting energy bills.

Insulation materials improve the overall energy efficiency and sustainability of buildings by reducing energy losses through the building structure of walls, roofs, floors, etc. In Europe, the vast majority of the buildings date from before 1990 and about half are pre-1960.[2] Every year about 1% of the existing building stock is built new, which means it will take 100 years to replace the entire stock. Insulating existing, older buildings is crucial to achieving energy efficiency improvements. It is estimated that deep renovation of buildings could cut up to 36% of their energy consumption by 2030.

The average energy consumption across the EU and the UK varies. Based on our desk research, the annual energy consumption for an average household in Western Europe is 3,500 kWh for electricity and 12,700 kWh[3] for heating and hot water. The figures can differ considerably per household and per country depending on climate, income, the quality and characteristics of the housing stock (especially size and insulation), and the number and habits of the inhabitants.

Impact of alternative uses for subsidies – insulation

Insulating residential buildings built before 1960 can save 15-20% of their heating energy consumption. Therefore, it is suggested that these building be prioritised for renovation and insulation. Approximately 35-55% of the residential buildings in the investigated countries are pre-1960, ranging from 35% in Austria to 55% in the UK.[4] A 100m^2 semi-detached house built pre-1960 is estimated to consume 25 000 kWh/year[5] for heating, which is higher than the average energy consumption for the

[1] EU urges building insulation push in bid to end reliance on Russian gas
[2] EC (2018). Competitive landscape of the EU's insulation materials industry for energy-efficient buildings
[3] https://www.eea.europa.eu/data-and-maps/daviz/unit-consumption-of-space-heating#tab-chart_1
[4] Europe's Buildings under microscope.
[5] Ibid

same home size built in any year. This increase is due to the age of the buildings and the lack of insulation. Twenty percent of this energy could be saved if these buildings were renovated and well insulated, representing an energy savings of around 5,000 kWh/household/year. It is difficult to translate this into monetary saving, as energy prices are fluctuating significantly, but the table below estimates annual savings at different price levels assuming the use of a gas heater. With the increase in energy prices, insulation becomes an even more cost-efficient investment. Wholesale prices for gas have recently set records of 0.6 EUR/kWh and more, with retail prices expected to catch up[6], so savings depicted in in Table 3-1 are potentially achievable.

Table 3-1 Potential savings per household annually for different price levels

Gas price per KWh (in Euros)	Potential savings in EUR per household annually (based on 25,000kWh/annual consumption)
0.05	250
0.1	500
0.2	1000
0.3	1500
0.4	2000
0.5	2500
0.6	3000

Many different parts of a house can be insulated including the roof, walls (external and internal), façade, and floors, making it difficult to estimate the total insulation cost of a house. However, the cost of roof insulation – which is important as significant amounts of energy are lost through roofs – is likely between €900 and €4,400.[7] Wall cavities —also an important point for insulation — could range between €1,000 to €3,500.[8] Replacing single glass windows with double glass is another way to conserve energy.

For this study, we assumed that an average cost for insulating a semi-detached house is €10,000.[9] Therefore, if the biomass subsides were directed to fully covering insulation, it would be possible to insulate 10,000 residential houses per €100M, saving an average of €15M annually at a gas price of 0.3 EUR/kWh. At these rates, this investment would pay back in full within 8 years at the 0.3 EUR/kWh price level. Assuming €7.2 billion is potentially available, around 700,000 households could be insulated, which is the equivalent of half of all households in Croatia. With cheaper insulation measures (i.e. focusing only on loft/wall insulation, as per the case study examples below) many more households could be insulated.

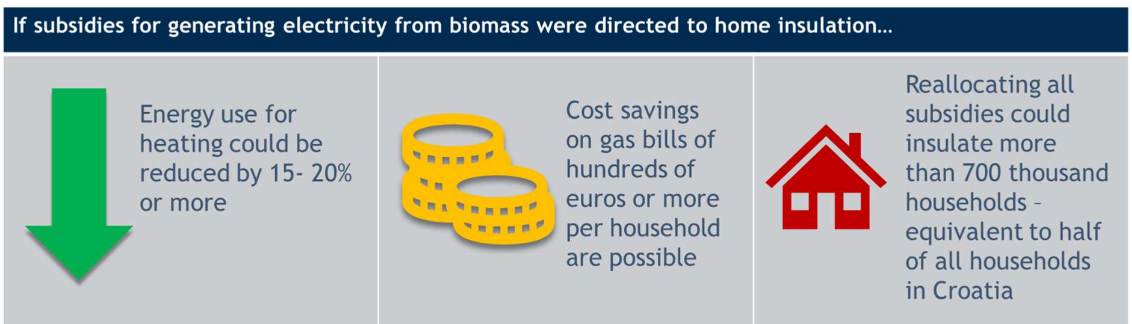
In addition to the financial benefits of redirecting biomass electricity subsidies to insulation, it would also provide environmental benefits given increased insulation would reduce the emissions from gas boilers in the household. A gas boiler emits around 235 CO_2eq (g/kWh);[10] therefore, proper insulation

[6] For example latest retail gas prices (Sept 2022) in the Netherlands show a variable gas price of more than 0.26 EUR/kWh – based on https://www.cbs.nl/en-gb/figures/detail/84672ENG and prices of 2.77 EUR/m3 converted to kWh by dividing by 10.55
[7] https://www.eigenhuis.nl/energie/maatregelen/isoleren-en-ventileren
[8] Ibid
[9] https://www.thegreenage.co.uk/
[10] Casasso, A., Capodaglio, P., Simonetto, F., & Sethi, R. (2019). Environmental and Economic Benefits from the Phase-out of Residential Oil Heating: A Study from the Aosta Valley Region (Italy). *Sustainability*.

could save 1,175 Kg CO_2eq per household, which is equivalent to emissions per passenger for a trip from London to New York.[11] Across 10,000 households, this would equate to around 11,750tCO_2/year.

In reality, however, it is likely that only a share of the insulation process would be subsidised by a grant, leading to the insulation of an even greater number of houses. A variety of insulation subsidies are present across Europe, often provided as investment subsidies (grants) or as tax deductible expenses, for example a 30% tax credit in France for insulation equipment[12]; a 70% support provided in Portugal[13]; a 50% subsidy programme on insulation subsidy investments in Slovakia[14]; and a 15-30% subsidy scheme in the Netherlands.[15] Providing partial subsidies would significantly increase the potential impact, allowing for many more houses to be insulated. For example a 50% subsidy would double the impacts.

Figure 3-1: Directing subsidies for electricity from biomass to home insulation



3.2 Reallocation of biomass subsidies to heat pumps

Approach

This approach is based on estimating the potential savings that could be achieved if the identified biomass subsidies were instead directed to grants subsidising heat pumps for space heating. The average cost for the installation and operation of a heat pump is estimated, and the average annual energy savings following the installation of heat pumps is assessed.

Rationale

The costs associated with the installation and operation of renewable, zero-emissions heating from fossil fuel heating vary greatly across the EU, based on several factors. Beyond existing building attributes (e.g., single- and multi-family homes, year of construction, energy efficiency characteristics), there are significant differences in the support schemes member states use to promote switching to renewable heating.[16] The complex taxation on heating fuels further complicates the ability to make an informed choice based on energy bill savings. Even without considering subsidy schemes for heat pump systems, installation costs can vary between member states, although €10,000 is the standard upfront investment.

[11] https://flightfree.org/flight-emissions-calculator
[12] Crédit d'impôt pour la transition énergétique (CITE), ex Crédit d'impôt Développement Durable (CIDD)
[13] Programa de Apoio Edifícios Mais Sustentáveis
[14] Program Zelená obnova
[15] https://www.rvo.nl/subsidies-financiering/isde/woningeigenaren
[16] BEUC study: https://www.b+euc.eu/sites/default/files/publications/beuc-x-2021-111_consumer_cost_of_heat_decarbonisation_-_report.pdf

A study commissioned by the European Environmental Bureau (EEB)[17] estimates the affordability of switching from fossil heating to renewable heating, with a focus on payback time (i.e., the time needed to reimburse the upfront costs through energy bill savings). This report found that only eight EU member states have a payback time of less than eight years, a timeframe that is generally considered too long for households to make the investment in the first place. The most effective way to decrease payback time and ultimately incentivise investment in renewable heating is through subsidies for installation costs. The EEB report estimates that it would cost €70 billion, or around €4.7 billion per year for 15 years, to switch all EU households to renewable heating with a payback time of less than eight years.

Impact of alternative uses for subsidies at household level - heat pumps

We provide indicative figures on the estimated average annual energy savings per household when switching from gas boilers to electric heat pumps. There are significant variations between member states in terms of costs and consumed volumes. However, by taking the average household gas consumption of 12,700 kWh, and an indicative average electricity consumption by heat pumps of 4,000 kWh per household/year, we reach an average energy savings of 8,700 kWh per household/year. In Table 3-2 below, we provide a range of potential savings per household for different price levels. Depending on the relative prices for each fuel, the savings can be substantial. In times of high prices, as currently is the case, savings can be thousands of euros per year. However, as electricity prices are also closely linked to gas prices, heat pump operation costs also increase. The balance between the two must be less than the calculated efficiency (Seasonal Coefficient of Performance) of a heat pump to make it more economical than a gas boiler. With efficiency of heat pumps around 4, electricity unit prices must be less than 4 times as high as natural gas prices to create savings. This is not always the case, necessitating subsidies to make heat pumps financially attractive.

Table 3-2 Potential savings per household annually for different price levels

Gas price (EUR/kWh)	Potential savings on gas bills per household annually (EUR) based on 12,700 kWh consumption	Electricity price (EUR/kWh)	Potential new electricity bill per household annually (EUR) Based on 4,000 kWh consumption
0.05	635	0.05	200
0.1	1270	0.1	400
0.2	2540	0.2	800
0.3	3810	0.3	1200
0.4	5080	0.4	1600
0.5	6350	0.5	2000
0.6	7620	0.6	2400

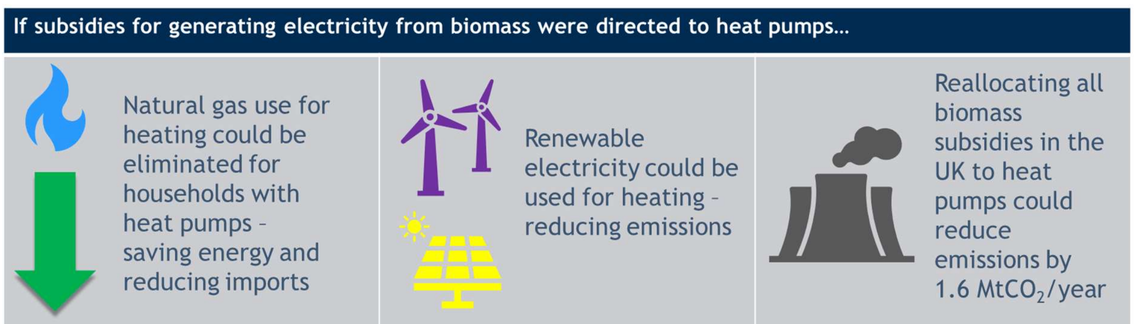
The standard installation costs for a heat pump system is €10,000 EUR. Taken as a whole, if the current subsidies for biomass were directed to heat pumps, it would be possible to cover the installation costs of 10,000 homes per €100 million. Similar to insulation, subsidies for energy efficiency measures such as

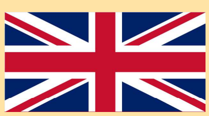
[17] EEB study: https://www.coolproducts.eu/wp-content/uploads/2021/10/Green-heat-FS_v6.0indd.pdf

heat pumps cover only part of the upfront installation costs. Many of the examples provided for insulation also fund heat pumps, and dedicated heat pump grant measures also exist. With a subsidy of €2,500 per heat pump system, the measure could reach 4x as many households (40,000). Assuming €7.2 billion is potentially available, a €2,500 subsidy could pay for installation of heat pumps in more than 2.8 million households, the equivalent of every household in Bulgaria.

In terms of emissions savings, air-to-water heat pumps outperform gas boilers in energy efficiency and CO_2 emissions in all member states. On average, at the EU level air-to-water heat pumps can save up to 57% of CO_2 emissions. However, there are significant variations in the extent of the savings across the EU. The differences depend on the average emissions associated with electricity generation in a country. Member states where this technology has the lowest emissions compared to gas boilers are Sweden (with emissions cut by 92%), France (87%) and Lithuania (82%). Other countries, because of their reliance on coal for electricity production, present a significantly lower gap (e.g., Poland and Estonia, with potential emissions cut of 10%).

Figure 3-2 Directing subsidies for electricity from biomass to heat pumps





Case of subsidy reallocation in the United Kingdom

Home Insulation

Renovating older residential buildings, including installing appropriate heat insulation combined with utilising heat pumps, would result in energy savings and, accordingly, reduce energy bills.

- The cost of insulating (loft + wall cavity) an average residential 3–4-bedroom semi-detached house in the UK costs around £1,500.[18]
- It is assumed that 20% energy saving on gas consumption for heating can be achieved, from an average consumption for heating of 12,000 kWh/year.[19] Energy savings could be even higher in the worst insulated older houses or those with higher heating consumption.
- Energy savings due to insulation at a gas price of £0.15/kWh[20] are estimated at £360/household/year.[21] At these rates, a payback period of around 4 years is expected.
- In the UK most biomass subsidies are currently paid by energy billpayers (homeowners) rather than from government funds. If we focus only on redeployment of the Non-domestic RHI

[18] https://job-prices.co.uk/insulation-cost/ rounded from estimate 650 (loft) + 875 (wall cavity)
[19] https://www.beama.org.uk/static/1a84100d-8fae-4208-9f9fa3e07dee1f1a/UK-homes-Analysis-of-kWH-gas-consumption-for-heating.pdf
[20] Estimated price from 1 Oct 2022 under energy price cap https://usave.co.uk/energy/average-uk-gas-and-electricity-prices-per-unit/
[21] Based on 12 000 kWh annual consumption reduced by 20%

(Renewable Heat Incentive) subsidy, which is government funded, then around £650 million could be available to fund home insulation. Note that alternative energy supports may still be necessary for non-domestic (commercial and industrial) consumers.

- Redirecting £650 million of existing biomass subsidies could insulate around 433,000 homes in the UK, or around 1.5% of the total number of homes.
- This could save 1,040 GWh/year of gas consumption, representing around 0.35% of the UK's total household gas consumption.
- Households would save around £156 million/year, the equivalent of the subsidy cost in just over 4 years.
- In addition, it would cut the UK's total emissions by around 190,000tCO_2.
- Savings would increase if measures were targeted to the worst insulated households with the highest energy consumption.
- As noted above, repurposing other subsidies is more difficult. However, it is not difficult to imagine potentially better uses of the money spent on these subsidies. For example, the £3.8 billion that potential future Contracts for Difference subsidies for BECCS (see chapter 4) would add to homeowners bills is an amount that could pay for insulation for more than 2.5 million households in the UK (around 10% of all homes). This would increase impacts almost 6 times compared to the non-domestic RHI-based example provided above, i.e. saving 6 080 GWh of gas (or 2% of national household consumption), £912 million per year on energy bills (saving households the cost of the measure in around 4 years), and 1.1 MtCO_2 (or around 1.2% of all household emissions).

Heat Pumps

Switching from gas boilers to heat pumps can have important climate and energy security benefits for the UK and is anticipated to be a key part of the net zero transition.

- Installing a heat pump in a residential house in the UK costs an average of £8,650.
- At natural gas prices of £0.15/kWh, households would save £1,800/year on natural gas costs based on 12,000 kWh annual usage.
- However, electricity use for the heat pump is around 3,000 kWh/year, which at an estimated cost of £0.52/kWh[22] results in costs of around £1,600/year.
- Therefore, this would save households £200/year overall, resulting in a very long payback period.
- Installation of solar panels to generate household electricity could reduce electricity costs and increase savings. Furthermore, any reduction in electricity prices relative to gas prices would increase the financial benefit of heat pumps.
- At a national level, redirecting £650 million of existing biomass subsidies (non-domestic RHI) to heat pump installation could pay for the installation of heat pumps in almost 180,000 homes, assuming a £5,000 grant as currently available under the Boiler Upgrade Scheme.[23]
- This could save around 0.7% of all household gas consumption in the UK (or 2,150 GWh/year).
- It would increase electricity consumption by around 550 GWh/year, or 0.5% of existing household electricity consumption.
- It would also cut the UK's total household emissions by about 0.3% (or 282 600tCO_2/year). These savings could increase over time as the electricity system decarbonises.[24]

[22] Estimated price from 1 Oct 2022 under energy price cap https://usave.co.uk/energy/average-uk-gas-and-electricity-prices-per-unit/
[23] https://www.gov.uk/guidance/check-if-you-may-be-eligible-for-the-boiler-upgrade-scheme-from-april-2022
[24] The calculation currently assumes a grid emissions factor of 198gCO_2/kWh (based on DUKES 5.14 2021 provisional value), this value should decrease over time as more renewables are installed.

Case of subsidy reallocation in the Netherlands

Home Insulation

Renovating older residential buildings, including installing appropriate heat insulation combined with utilising heat pumps, would result in energy savings and, accordingly, reduce energy bills.

- The cost of insulating the floor of an unheated attic in an average residential semi-detached house in the Netherlands costs around EUR 900.[25] It is estimated that up to 14% energy savings on gas consumption for heating can be achieved.
- Based on an assumed energy consumption for heating of 12,000 kWh/year.[26] Energy savings due to insulation at average projected gas price of 0.079 EUR/kWh[27] are estimated at EUR 132 per household per year[28], resulting in a pay-back period of approximately 7 years. At current prices, of around 0.26 EUR/kWh, the savings are much higher (435 EUR/year) and payback much shorter (2 years).
- In the Netherlands the majority of biomass subsidies are paid for by consumers in their final bills (e.g. the MEP/SDE/SDE+/SDE++). Therefore, almost none of the EUR 856.5 million[29] of annual total existing biomass subsidies in 2021, would be available to directly redistribute to other purposes.
- However, it is not difficult to imagine potentially better uses of the money spent on the subsidies for solid biomass. For example, if the equivalent of EUR 856 million in subsidies for the MEP/SDE/SDE/SDE++ were instead spent (via the ISDE) on insulation, many households could be insulated. Assuming a 30% subsidy, as per ISDE, then around 3.2 million households could be insulated (of around 8.1 million in total households). It should be noted that the EUR 856 million is an annual amount. Repeating this spending annually too would mean that within less than three years the whole housing stock of the Netherlands could be addressed.
- However, it is unclear how many households would actually need this type of insulation. Older buildings would more likely require much more difficult and expensive insulation measures, whilst newer buildings might not require additional insulation and would benefit from alternative heating systems such as heat pumps (see below).
- The key point to note is that the sums being spent on biomass subsidies could fund a massive energy efficiency retrofit programme in the Netherlands.
- Following through on impacts, to provide an idea of potential savings, if 3.2 million households were insulated this could save up to 5,329 GWh/year of gas consumption, representing around 6.3% of the Netherlands total household gas consumption.[30]
- Households would save around EUR 421 million per year (at 0.079 EUR/kWh, more if the price was higher), therefore saving households the total cost within around 2 years.

[25] Based on estimates from https://www.eigenhuis.nl/energie/maatregelen/isoleren-en-ventileren

[26] Building Performance Institute Europe (BPIE) https://www.bpie.eu/wp-content/uploads/2022/03/Strategy-paper_Solidarity-and-resilience_An-action-plan-to-save-energy-now-1.pdf

[27] Based on the average of the projected gas prices costs for the coming decade https://open.overheid.nl/repository/ronl-5412742791dd477bf0cc1dd12b83e0fbe38b253c/1/pdf/Effectenonderzoek%20energiemaatregelen%20in%20Belastingplan%202023.pdf

28[28] Based on 12 000 kWh annual consumption reduced by 14%

[29] Based on this study's subsidy overview.

[30] National statistics: https://www.cbs.nl/nl-nl/nieuws/2022/35/gasverbruik-25-procent-lager-in-eerste-halfjaar-2022

- In addition, it would cut the Netherlands' total emissions by around 1 $MtCO_2$, or 6.2% of household emissions, and 0.5% of total national emissions.[31]

Heat Pumps

Switching from gas boilers to heat pumps can have important climate and energy security benefits for the Netherlands and is anticipated to be a key part of the net zero transition.

- Installing a heat pump in a residential house in the Netherlands costs an average of EUR 7,800.[32] Typically the house should be well insulated (e.g. minimum energy label class B) before installing a heat pump.[33]
- At natural gas prices of EUR 0.079/kWh, households would save EUR 840/year on natural gas costs based on 12,000 kWh annual usage.
- However, electricity use for the heat pump is around 3,000 kWh/year, which at an estimated cost of EUR 0.15/kWh[34] results in costs of around EUR 460/year.
- Therefore, this would save households EUR 380/year overall, resulting in a payback period of around 20 years without subsidy.
- In energy terms, a total of up to 9,000 kWh could be saved. However, the actual energy balance would depend on the fuels used to generate the electricity.
- Installation of solar panels to generate household electricity could reduce electricity costs and increase savings. Furthermore, any reduction in electricity prices relative to gas prices would increase the financial benefit of heat pumps.
- At a national level, spending the equivalent of the EUR 856 million of existing biomass subsidies on heat pump installation could install heat pumps at almost 440,000 homes, assuming a 25% subsidy for heat pump costs (which is representative of existing subsidy schemes).[35]
- This could save around 6.2% of all household gas consumption in the Netherlands.
- It would increase electricity consumption by around 1,350 GWh/year, or 6.7% of existing household electricity consumption.
- It would also cut the Netherlands' total household emissions by about 0.5 $MtCO_2$, or 3.3% of household emissions. These savings could increase over time as the electricity system decarbonises.[36]

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[31] Estimated yearly emission from latest RIVM national inventory report 2021: https://www.rivm.nl/bibliotheek/rapporten/2021-0007.pdf

[32] European Environmental Bureau, European Heat Subsidies Report, https://www.coolproducts.eu/wp-content/uploads/2021/10/coolproducts-heating-subsidies-report-web-october21.pdf

[33] https://www.eigenhuis.nl/energie/maatregelen/duurzaam-verwarmen/warmtepomp/is-mijn-woning-geschikt#/

[34] Based on the average of the projected electricity prices costs for the coming decade https://open.overheid.nl/repository/ronl-5412742791dd477bf0cc1dd12b83e0fbe38b253c/1/pdf/Effectenonderzoek%20energiemaatregelen%20in%20Belastingplan%202023.pdf

[35] https://www.verwarminginfo.nl/warmtepomp/subsidie

[36] The calculation currently assumes a grid emissions factor of 325gCO_2/kWh, this value should decrease over time as more renewables are installed.

4 Cost of Bio-energy with Carbon Capture and Storage (BECCS)

Introduction

One of the potential innovations intended to combat emissions during energy production is Bioenergy with Carbon Capture and Storage (BECCS) power plants. These power plants would use biomass (e.g., wood pellets) to produce power. Besides the power generated, a flue gas containing CO_2 would be emitted. Proponents of BECCS argue that it can capture carbon capture this gas and extract up to 95% of the CO_2. This could theoretically lead to negative emissions if we hold to the (highly questionable) assumption that biomass is carbon neutral. This is among the main reasons that large-scale BECCS application is being considered by some, particularly as this carbon 'removal' could also be monetised, securing additional revenue for biomass plant operators. Drax power in the UK is amongst Europe's largest biomass power plants in Europe and is closely considering BECCS, already applyiung for two units to be approved as Nationally Significant Infrastructure Projects (NSIPs).

However, in addition to concerns regarding the reality of BECCS climate neutrality/removal, there are significant concerns about the potential cost of this technology. Major concerns include: the amount of subsidies that may be required to demonstrate the technology at scale and make it commercially attractive for operators; the impact of additional subsidy costs on household energy bills; and the cheaper renewable or low-carbon alternatives that could be better investments. This section explores each of these concerns further, combining information from existing studies to provide further insight.

4.1 Cost of BECCS

Based on a review of the available literature, we have gathered a set of estimations to break down the actual costs of BECCS. While the priority for data collection is in the UK context, and in particular Drax, figure ranges refer to general costs when the latter are not available. Before diving into the specific breakdown of BECCS costs, we note that the figures available in the literature vary significantly. This is especially the case for capital expenditure and fuel costs, which are the biggest factors in total BECCS cost. However, the literature also shows a wide variation in costs associated with other components, such as transportation, storage and operations costs.

Scientific and policy papers have been included in the analysis when they address issues of cost estimations. The most relevant available study is an analysis conducted by Ricardo for the UK Department for Business, Energy and Industrial Strategy (BEIS) that explores the potential for BECCS in the UK.[37] Other sources include academic articles which, besides cost estimations, focus on life-cycle assessments of BECCS plants (both for the UK and European contexts). Cost estimates from BECCS literature are difficult to compare, as they use widely varying assumptions regarding technical performance, technology maturity, system boundaries, financing, commodity pricing, coproduct sales, and carbon taxation.

[37] Ricardo (2018) *Analysing the potential of bioenergy with carbon capture in the UK to 2050.* https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/911268/potential-of-bioenergy-with-carbon-capture.pdf

Capital costs

Capital costs (i.e., fixed, one-time investments into the construction of plants and equipment) is one of the biggest factors in the overall cost of BECCS. Ricardo (2018) estimates that Capex for different NOAK (nth-of-a-kind) plant types range between **£36/MWh** (for plants with chemical looping) to **£64/MWh** (for pre-combustion IGCC). However, the report acknowledges that, due to a lack of data (i.e., very few real world examples at that time and now), cost figures are not robust.[38] In line with these findings, another study[39] addresses levelised costs of energy for various biomass energy technologies with CCS capital costs divided into direct and indirect: the range of direct capital costs spans from $23.2/MWh (£16.24) to $36.07/MWh (£25.24), and for indirect capital costs, the values range between $11.23/MWh (£7.86) and $16.78/MWh (£11.74).[40] Similar values are provided by Lazard,[41] which, in a review of LCOE for several energy sources, associates capital costs to biomass with CCS of $53/MWh (£42.4).[42]

Fuel costs

Different ranges for value estimations are shown for the costs of fuels. In the study by Ricardo (2018), for biomass fuel costs (UK energy crops or imported wood pellets) a central price of £25/MWh is taken, with a range of £15/MWh to £40/MWh used for sensitivity analysis. In a study reviewing the existing literature on the costs of biomass energy with CCS, value ranges include £0 – 26.7/MWh for forestry and mill residues, £5.8 – 23.2/MWh for wood chip and stem wood, and £22.3 – 47.8/MWh.[43] Yi et al (2020) disaggregate biomass cost into wood production harvest and transport (£10.97/MWh), wood processing in pellets plant (£8.47/MWh) and wood pellets transported to port by rail (£2.19/MWh).

Operations and Maintenance (O&M) costs

Concerning operations and maintenance costs, the literature provides coherent yet still diverse value estimations. Ricardo (2018) differentiates between fixed and variable Opex:[44] for the former, cost estimations range between £15/MWh (for chemical looping) and £28/MWh (for pre-combustion IGCC); variable Opex ranges between £1/MWh and £2/MWh. Yang et al. (2021) also distinguish between fixed and variable operations and maintenance costs. Fixed O&M costs are estimated at between £9.4 and £12.3/MWh, while variable O&M costs are estimated between £13.77/MWh and 17.205/MWh. Although both estimates exclude fuel costs, they differ quite significantly.

Transport and storage

Data available from the literature varies widely, depending on the parameters included in the calculation of the costs. This is exemplified by a paper on the current development and costs of BECCS, which reviewed the recent literature on the topic.[45] The article reports highly fluctuating figures, particularly for transport. Overview of costs for CO_2 transport in most studies are assumed to be fixed. The values available from the literature vary in a range of 5 to 17 EUR/tCO_2 (4.32 to 14.92 £/tCO_2) In studies that calculate transport costs based on volumes and distance, the range was much wider, from 5 to 380 EUR/tCO_2 (4.39 to 333.5 £/tCO_2) varyingly accounting for topography, existing land use,

[38] No cost data was found in the published literature for molten carbonate fuel cell technology and Allam cycle technology. These estimates are based on information gathered through stakeholder consultations.
[39] Yang, B., Wei, Y. M., Liu, L. C., Hou, Y. B., Zhang, K., Yang, L., & Feng, Y. (2021). Life cycle cost assessment of biomass co-firing power plants with CO2 capture and storage considering multiple incentives. *Energy Economics*, *96*, 105173.
[40] Based on $/£ exchange rate from 2021 (date of publication of the study)
[41] https://www.lazard.com/media/450337/lazard-levelized-cost-of-energy-version-110.pdf
[42] Based on $/£ exchange rate from 2017 (date of publication of the study)
[43] Values were converted based on €/£ exchange rate from 2020, date of publication of the study
[44] In this case, Opex excludes fuel costs.
[45] Tanzer, S. E., Blok, K., & Ramirez, A. (2021). Decarbonising industry via BECCS: promising sectors, challenges, and techno-economic limits of negative emissions. *Current Sustainable/Renewable Energy Reports*, 1-10.

compression boosting, seasonality of biomass, shared pipelines or multi-modal transport.[46] Capture costs typically include the cost of equipment, labor, chemicals, and energy to capture and compress CO_2 so that it is transport-ready. Capture costs ranged from 3 to 30€/tCO_2 (2.63 to 26.33 £/tCO_2) for near-pure fermentation CO_2 and 42 to 110€/t CO_2 (36.8 to 96.5 £/tCO_2) for complex configurations that use amine-based solvents to capture CO_2 from multiple dilute streams, such as in paper mills. In the Ricardo study, the cost of CO_2 transport and storage for all plants was assumed to be £19/tCO_2.

Potential revenues from carbon storage

The current UK Emission Trading Scheme (UK-ETS) does not integrate carbon capture and storage as part of emission removals. However, calls have been advanced for both the UK and the EU ETS to reward negative emissions. This system is seen as a major potential driver of further uptake of BECCS and Direct Air Carbon Capture and Storage (DACCS).[47] In this context, a consultation by the UK Emission Trading Authority[48] was launched in early 2022 to gather expert input on the possible future development of the UK ETS – of which the input by stakeholders is yet to be made public. Part of this consultation aimed to understand whether and how the scheme can be used as a potential approach to support the growth and deployment of removals and their impacts on the functioning of the UK ETS. Among the potential technologies and nature-based solutions that could yield negative emission allowances, the consultation mentions BECCS and DACCS. This is therefore an option being considered for the future development of UK ETS, which, has until now, had no concrete application.

In a separate consultation (closing early October 2022), the UK government asked stakeholders for expert input on the development of business models for BECCS.[49] Several options are explored to further incentivise BECCS development. The option indicated to be the most promising involves a combination of a CfD for electricity generation (CfDe) and a CfD for carbon (CfDc) – intended as a dual payment mechanism under one CfD contract framework. The benefit is that it fulfils the 'polluter pays' principle, with emitters paying the costs of removals and could reduce the proportion of support payments. A CfDc could transfer part of the costs of power BECCS to emitters through integration of a BECCS project within an appropriate carbon market option, as discussed above. However, until such a market for negative emissions exists, the Government does not rule out funding the CfDc from public money or from a levy on bills. The CfDc would provide flexibility to integrate negative emissions allowances into the existing ETS or an ad hoc market until the carbon price meets the strike price to remain investable. The publication of the responses to the said consultation could provide more insight into this specific opportunity for carbon revenues.

4.2 LCOE of BECCS

The Levelised Cost of Energy (LCOE) is an approach used to assess and compare different methods of energy production. The LCOE of a certain energy-generating asset is the average total cost of building and operating the asset per unit of total electricity generated over the assumed lifetime of the asset. Alternatively, it can be thought of as the average minimum price at which the electricity generated by the asset is required to be sold to offset the total costs of production and operation over its lifetime.

[46] Tanzer, S. E., Blok, K., & Ramirez, A. (2021). Decarbonising industry via BECCS: promising sectors, challenges, and techno-economic limits of negative emissions. *Current Sustainable/Renewable Energy Reports*, 1-10.
[47] https://www.argusmedia.com/en/news/2208390-eu-ets-pilot-phase-for-beccs-daccs-in-2025-study
[48] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1067125/developing-the-uk-ets-english.pdf
[49] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1097632/power-beccs-business-model-consultation.pdf

The ability to apply this approach to any energy technology allows for a comparison of the cost of a technology. As a result, LCOE is a widely used metric in the energy sector.

Adding CCS to a biomass plant can affect the LCOE calculation in various ways, including:

- The CCS process requires additional equipment – which has associated capital and O&M costs.
- The CO_2 captured by CCS needs to be transported and stored – this also has associated variable and O&M costs.
- Adding CCS to a plant affects how it operates, typically decreasing its overall efficiency through impacts on combustion efficiency and/or from energy consumption to power the CCS equipment.
- The captured CO_2 can represent a potential revenue stream to offset against the costs if a price can be agreed for the captured CO_2.

The balance of these impacts on the LCOE can be instructive when comparing against other technologies and when thinking about the level of subsidies that may be needed to incentivise BECCS. The LCOE calculation also allows for testing the sensitivity of calculations to changing assumptions (e.g. to changing costs of wood pellets).

Calculating a BECCS LCOE

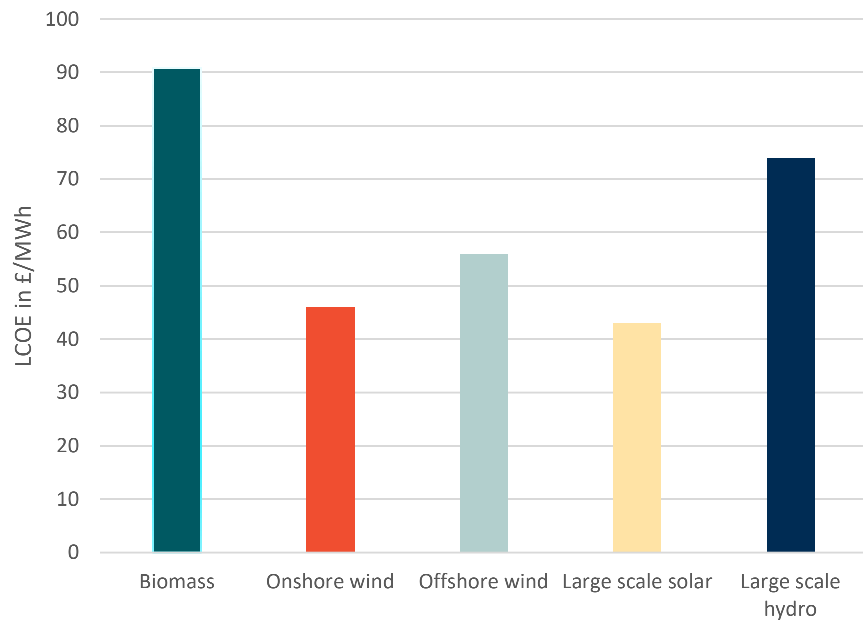
To calculate the LCOE of any energy-producing technology, three key variables must be considered: capital expenditures, operations and maintenance (O&M) expenditures, and fuel expenditures. The literature review from the earlier part of this section provides information on each of these three variables. Information from different sources from the UK, China and the U.S was compiled and analysed. Table 4-1 provides an overview of the variables and the range of values that were found for each. Next, the average for each of these variables was calculated and these were used in our estimation of the LCOE.

Table 4-1: Breakdown of main LCOE components for power from biomass

Variables	Range £/MWh	Average £/MWh
Capital expenditures	26-41	33
Operations and Maintenance expenditures	10-22	16
Fuel expenditures	35-45	42
Average LCOE	78-98	**91**

Comparing this average LCOE for biomass to the LCOE of other renewables (see Figure 4-1) shows that biomass is already the most expensive of the main renewable energy technologies. The main explanation for the large difference in LCOE relates to the fuel costs for biomass. The fuel costs are on average £42/MWh, making up nearly half of the LCOE of biomass. Other renewables such as wind, solar and hydro do not require any fuel and thus have a significantly lower LCOE. The LCOEs of other renewables are based on estimates of projects commissioning in 2025 performed by the UK's Department for Business, Energy & Industrial Strategy.[50]

Figure 4-1: LCOE of Biomass vs other renewables



To calculate the LCOE for BECCS, a literature review was conducted. Similar to the LCOE calculation for biomass, an average LCOE was calculated based on the values found in the literature review. Table 4-2 provides an overview of the range of values found in the literature for BECCS and the average costs of BECCS and biomass.

Table 4-2: Comparison of average values BECCS and Biomass

Variables	Range £/MWh	BECCS £/MWh	Biomass £/MWh
Capital expenditures	46-58	52	33
Operations and maintenance expenditures	21-31	24	16
Fuel expenditures	62-70	66	42
CO_2 transport & storage	25-27	26	-
Range LCOE/Average LCOE	**149-205**	**168**	**91**

When considering BECCS, LCOE increases significantly. This is to be expected given the additional equipment required and impacts of the process on the efficiency of power generation. In more detail:

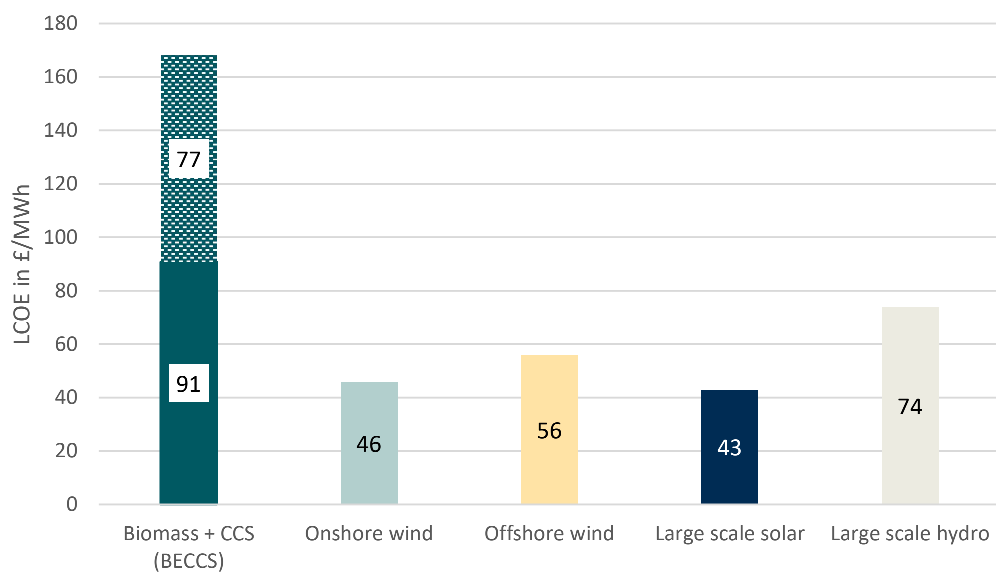
- The capital expenditures for carbon capture and storage (CCS) increases the capital expenditures to 52£/MWh on average (+19£/MWh compared to biomass without CCS).

[50] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/911817/electricity-generation-cost-report-2020.pdf

- Operations and maintenance expenditures also increase as a CCS mechanism has costs associated with its operations and maintenance, resulting in average maintenance and operations expenditures of 24£/MWh (+8£/MWh compared to biomass without CCS).
- Moreover, the fuel expenditures are also higher because CCS reduces the efficiency of the power generation process. This means that more fuel is needed for delivering a similar amount of energy compared to biomass without CCS. As a result, the average fuel expenditures increase to 66£/MWh (+24£/MWh compared to biomass without CCS).
- Finally, the carbon that is captured must be transported through pipelines to storage facilities (e.g., deep saline aquifers, depleted oil and gas fields), which costs of 26£/MWh on average (+26£/MWh as biomass without CCS doed not have this cost).

The total difference between biomass and BECCS is thus significant, with BECCS adding +77£/MWh on top of the 91£/MWh for biomass resulting in an average LCOE of 168£/MWh, this is similar to the 179£/MWh Contracts for Difference strike price for BECCS proposed in the UK. Figure 4-2 provides a graphical overview of the differences between BECCS and other renewables. The patterned area shows the costs added through BECCS (77£/MWh) when compared to biomass without CCS.

Figure 4-2: BECCS compared to biomass and other renewables



Fuel price sensitivity

As noted above, the fuel (biomass) price is a major driver in the cost of power from biomass and BECCS plants require more fuel to produce the same amount of power as biomass plants without CCS due to lower efficiency, with estimates mentioning efficiency losses of approximately 10%.[51] A biomass report published by Argus[52] on April 6, 2022 gives an insight into the prices of wood pellets in Northwest Europe, the Baltics and the Northeast U.S., all amongst the most common sourcing grounds for UK

[51] https://www.sciencedirect.com/science/article/pii/S0306261918307062?casa_token=IbcrBs9UPsIAAAAA:ktlyzMrNn6n-L-6pWZGVDyUP9dyraKoErL4aTNGqr0qxp-ecjyCqWR6TsiB_u50tleL2zYfx_A

[52] https://www.argusmedia.com/-/media/Files/sample-reports/argus-biomass-markets.ashx?la=en%26hash=872E2C03A0A78FE3F236BBF00E7729E3114326E0

biomass. This showed average prices of wood pellets that would translate into fuel costs of around 50£/MWh. An article by Bioenergy Insight[53] points out that the price per ton of wood pellets in the UK surged in 2022, rising by approximately 25-40% (cost average £360-385). Increased fuel costs reinforce the weak financial case for BECCS and bioenergy, a concern that is already highlighted by the biomass industry and financial community in Government analysis[54].

Implications for energy bills and policy

Biomass generation has one advantage compared to other renewable technologies in that it is not weather dependent, and therefore more reliable from an energy system perspective. However, amongst its major disadvantages is its susceptibility to higher (biomass) fuel prices. Additionally, the actual carbon neutrality of biomass energy is questionable, particularly in the timeframe necessary to deal with the climate crisis. Adding CCS to biomass brings the attractive prospect of negative emissions (assuming the carbon absorbed in the burnt biomass is captured, and more biomass is grown in its place, also absorbing CO2). However, the analysis presented in the previous section makes clear that adding CCS to a biomass plant (e.g. BECCS) would make it by far the most expensive renewable power generation technology. It would require public support to be economically viable in a normal power market, begging the question of subsidies and costs to households.

The UK example – BECCS at Drax Power

Taking the UK's Drax power plant as an example, which has applied to convert at least two units to BECCS, it is possible to make some broad assumptions about the potential cost of BECCS and how this compares to other technologies.

At Drax Power, it is estimated that two units of 461.5 MW capacity[55] could each be converted to BECCS. At a load factor of 61% (assumed on the basis of the average of actual quarterly load factors for biomass between 2020 and 2022)[56], these would each generate around 2,749,000 MWh annually. The Government plans for BECCS to operate from 2027 onwards.

The Government has estimated that a new BECCS plant will require a guaranteed price of £179/MWh, guaranteed as the 'strike price' under the contracts for difference (CfD) subsidy mechanism. Under the CfD mechanism, energy generators are paid the difference between a reference price (i.e., the market price) and their guaranteed price. If the market price is below their guaranteed price, they receive a payment. If the market pays them more than their guaranteed price, then they pay the excess back. The government is currently considering whether to separate this payment into two - a payment for electricity generated and a payment for carbon stored.

For the purposes of this analysis, it is assumed that BECCS would receive a single payment up to £179/MWh covering both electricity generated and carbon captured. The CfD payments are currently funded through an extra charge on energy bills – with 40% of the cost added to household bills.

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[53] https://www.bioenergy-news.com/news/wood-pellet-prices-rise-as-uk-ends-russian-imports/

[54] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1026637/investable-commercial-framework-power-beccs.pdf

[55] The listed capacity is the post-BECCS conversion capacity, the original capacity of the units is around 640MW, but Drax estimates that adding BECCS would reduce capacity by around 28%

[56] See https://reports.electricinsights.co.uk/

To calculate the total subsidy that may be paid to support BECCS, assumptions must be made on the wholesale prices over the CfD period, which we assume as 15 years (a standard contract length). We have assumed three price scenarios:

- Low: £50/MWh
- Medium: £100/MWh
- High: £150/MWh

The results are presented in Table 4-4 and show that CfD subsidy payments would likely run into multiple hundreds of millions of pounds per year, and could total multiple billions over the full term. Annually these two units alone could impose additional costs per household[57] of between £2-9 per year on energy bills.

Table 4-3 Summary of costs of subsidising BECCS for two units at Drax power

	Wholesale price	Difference with strike price of 179£/MWh	CFD payments per year	Total CfD payments over 15 years	Cost per household per year
	£/MWh	£/MWh	£	£	£
LOW	50	129	636 246 421	3 817 478 527	9.09
MEDIUM	100	79	389 639 281	2 337 835 687	5.57
HIGH	150	29	143 032 141	858 192 847	2.04

Technologies like offshore wind also receive these contract payments funded by billpayers. But they can now be built far more cheaply than BECCS. For example, strike prices of around £40/MWh have been agreed to for offshore wind.[58] At these prices, even in a low-price scenario offshore wind will refund billpayers. Or, if market prices were high, BECCS would add £2/year to everyone's bills, and offshore wind of the same capacity would cut bills by £10/year.

If the £3.8 billion that could be added to bills (under the scenario of low wholesale prices) were instead invested in energy efficiency, then around 2.5 million homes could be insulated, resulting in a saving of up to £1.8 billion per year on consumer energy bills (based on £360 annual savings per household, see chapter 3, box 1 for more detail on calculations).

The opportunity cost of BECCS is also relevant in the context of energy efficiency, the benefits of which were analysed in section 3.1 and 3.2. The financial savings to households from spending the equivalent of the CfD subsidy for BECCS on home energy efficiency would represent a much better financial return.

In summary, from a cost/financial perspective there is very little to recommend BECCS in comparison to other renewables. The only basis for a BECCS investment is valuing the CO2 abatement/removal highly enough that this would be attractive, yet it is likely to be amongst the most expensive carbon emissions abatement options relative to other alternatives.

[57] Assuming 28 million households in the UK
[58] https://www.lowcarboncontracts.uk/dashboards/allocation-round-dashboard

Annex A - Detailed subsidy list and sources

Table A-1 Detailed subsidy list and sources

	Subsidy ID			Amount of the subsidy								
Country	Instrument name	Instrument type	Use	2015	2016	2017	2018	2019	2020	2021	Data source	Calculation approach
Austria	Feed-in tariffs solid biomass	Feed-in tariff	Electricity	270 404 573	262 703 063	263 210 654	260 357 197	195 363 478	136 684 000	104 912 000	https://www.e-control.at/de/statistik/oeko-energie/oekostrommengen	N/A
Belgium	Green certificates - biomass	RES quotas with tradable certificates	Electricity	216 315 307	178 576 636	165 429 286	165 979 748	145 128 812	61 366 653	x	https://www.energiesparen.be/groene-energie-en-wkk/cijfers-en-studies	Flanders
Belgium	Green certificates - biomass (solid)	RES quotas with tradable certificates	Electricity	97 410 000	137 204 000	147 400 000	133 800 000	139 700 000	116 400 000	x	https://energie.wallonie.be/fr/rapports-annuels-sur-l-evolution-du-marche-des-certificats-verts-et-des-garanties-d-origine.html?IDC=9822&IDD=153520	Wallonia
Denmark	Promotion of Renewable Energy Act, nr. 356 04/04/2019 - solid biomass	Feed-in Premium	Electricity	54 999 490	63 717 587	85 096 304	79 494 022	105 379 300	109 315 271	108 323 249	https://www.retsinformation.dk/Forms/R0710.aspx?id=208204	
Finland	Energy aid (investment aid) for solid biomass (electricity production)	Grants	Electricity	27 880 000	0	0	0	0	0	0	http://www.res-legal.eu/search-by-country/finland/single/s/res-e/t/promotion/aid/subsidy-energy-aid/lastp/127/ http://www.finlex.fi/en/laki/	
Finland	Production support for biomass from forestry sector	Grants	Electricity	7 838 433	6 131 180	4 675 600	6 598 800	16 478 786	15 675 149	14 636 778	https://finlex.fi/fi/laki/alkup/2015/20150034	
Finland	Feed-in tariff for renewable energy (sliding feed-in premium for wood chips)	Feed-in tariff	Electricity	33 188 187	32 280 151	31 767 132	21 503 939	156 323	345 639	0	http://www.finlex.fi/en/laki/ https://energiavirasto.fi/en/energy-authority	
Finland	Feed-in tariff for renewable energy (wood power plant)	Feed-in tariff	Electricity	132 891	131 514	140 884	97 618	96 812	115 403	58 000	http://www.finlex.fi/en/laki/ https://energiavirasto.fi/en/energy-authority	
France	Compensation supplement	Grants	Electricity	0	0	200 000	0	23 300 000	18 100 000	12 800 000	http://www.cre.fr/operateurs/service-public-de-l-electricite-cspe/montant#section1	
France	Feed-in tariffs - other RES (non solar, non wind)	Feed-in tariffs	Electricity	375 724 350	457 524 116	445 323 473	523 400 000	574 200 000	640 200 000	712 600 000	https://www.cre.fr/Documents/Deliberations/Decision/evaluation-cspe-2021	

Germany	EEG feed-in tariff and premium for biomass	Feed-in tariffs	Electricity	1 654 124 486	1 658 808 510	1 558 616 170	1 532 415 628	1 658 356 440	1 777 863 798	1 724 031 018	https://www.gesetze-im-internet.de/eeg_2014/BJNR106610014.html#BJNR106610014BJNG000601125	
Germany	CHP feed-in tariff from biomass and waste*	Feed-in tariffs	CHP	18 159 625	26 446 040	27 903 176	25 123 578	23 164 962	24 008 824	x	https://www.netztransparenz.de/KWKG/Jahresabrechnungen	
Italy	Simplified purchase/resale arrangement of power - Biomass (solid)	Producer price guarantees (price regulation)	Electricity	7 000 000	5 000 000	7 000 000	8 000 000	7 000 000	4 000 000	x		
Italy	Former Green Certificates scheme - Biomass	RES quotas with tradable certificates	Electricity		474 000 000	541 000 000	480 000 000	437 000 000	518 000 000	x	https://www.gse.it/documenti_site/Documenti GSE/Rapporti delle attività/RA 2020.pdf	
Italy	New Green Certificates scheme - Biomass	RES quotas with tradable certificates	Electricity	508 218 505	231 000 000	16 000 000	12 000 000		1 000 000	x	GSE, Rapporto delle attività https://www.gse.it/documenti_site/Documenti GSE/Rapporti delle attività/RA 2020.pdf	
Italy	Renewable energies incentives 2012 - Biomass	Feed-in premiums	Electricity	14 000 000	27 000 000	51 000 000	52 000 000	54 000 000	47 000 000	x	GSE, Rapporto delle attività https://www.gse.it/documenti_site/Documenti GSE/Rapporti delle attività/RA 2020.pdf	
Italy	Renewable energies tariff 2016 - biomass	Feed-in premiums	Electricity		0	3 000 000	11 000 000	12 000 000	13 000 000	x	GSE, Rapporto delle attività https://www.gse.it/documenti_site/Documenti GSE/Rapporti delle attività/RA 2020.pdf	
Italy	D.M. 18 december 2008 - "Tariffa onnicomprensiva"- Solid biomass	Feed-in tariff	Electricity	95 000 000	90 000 000	89 000 000	89 000 000	91 000 000	104 000 000	x	GSE, Rapporto delle attività https://www.gse.it/documenti_site/Documenti GSE/Rapporti delle attività/RA 2020.pdf	
Italy	CIP6 - Biomass and biogas*	Feed-in tariff	Electricity	76 980 000	67 820 000	62 520 000	30 880 000	6 220 000	260 000	x	GSE, Rapporto delle attività https://www.gse.it/documenti_site/Documenti GSE/Rapporti delle attività/RA 2020.pdf	Estimated values used for data aggregation. Based on Eurostat 20% of this subsidy was assumed to go for Solid biomass.
Netherlands	Investment subsidy sustainable energy (ISDE)	Grants	Electricity	0	14 433 848	17 554 663	23 772 831	22 979 050	4 766 413	x	rijksbegroting miljoenennota 2022; https://klimaatmonitor.databank.nl/jive	
Netherlands	Feed in Premium for Renewable energy (MEP/SDE/SDE+/SDE++) - Biomass for electricity	Feed-in premiums	Electricity & Heat	287 197 000	315 217 000	316 273 000	318 636 000	346 744 631	593 967 899	855 792 497	https://www.rvo.nl/subsidies-regelingen/stimulering-duurzame-energieproductie/feiten-en-cijfers/resultaten-2016; Jaarbericht SDE & MEP 2009; Jaarbericht SDE & MEP 2010; Jaarbericht SDE & MEP 2011.	

Netherlands	Energy Investment rebate (EIA) - Energy saving technologies	Tax allowance	Electricity	789 408	351 479	88 874	705 308	470 476	679 659	725 300	rijksfinancien fiscale regelingen	
Poland	Green certificates	RES quotas with tradable certificates	Electricity	251 125 271	136 893 983	72 113 518	162 811 630	146 645 802	127 412 253	166 378 975		
Poland	Aid for high-efficiency cogeneration systems and for the promotion of energy from renewable sources	Grants	Electricity	0	18 767 340	32 501 350	92 849 272	56 137 167	71 434 691	x		
Poland	Investment aid for the promotion of energy from renewable sources	Grants	Electricity & Heat	0	0	0	624 244	0	29 356	x		
Poland	Auctions for the support of electricity from renewable energy	Producer price guarantees (price regulation)	Electricity	0	0	0	90 840 500	90 731 435	27 785 355	x		
Spain	Specific retributive regime - biomass (crops)	Feed-in tariffs	Electricity	275 556 824	277 831 606	309 737 148	307 592 007	313 839 558	334 501 910	290 213 099	https://www.boe.es/eli/es/rd/2014/06/06/413/con	
Spain	Specific retributive regime - waste treatment	Feed-in tariffs	Electricity	125 822 830	99 214 966	164 846 373	175 433 602	223 741 126	251 263 726	205 740 478	https://www.boe.es/eli/es/rd/2014/06/06/413/con	
Spain	First Call for aid for investment in electricity generation facilities with biomass, wind and photovoltaic solar energy in the Autonomous Community of Andalusia co-financed with European Union Funds*	Direct transfers	Electricity	0	0	0	0	0	1 972 966	0	https://www.infosubvenciones.es/bdnstrans/GE/en/convocatoria/726036/document/454107	According to Eurostat the contribution of Solid Biomass to renewable energy sources percentage is taken (3.9%)
Spain	First call for aid for investment in electricity generation facilities with renewable energy sources in the Autonomous Community of Castilla y León co-financed with European Union Funds*	Direct transfers	Electricity	0	0	0	0	0	273 000	0		According to Eurostat the contribution of Solid Biomass to renewable energy sources percentage is taken (3.9%)
Sweden	The Electricity Certificate System - biomass	RES quotas with tradable certificates	Electricity	10 340 146	17 863 139	16 724 797	18 326 433	20 538 100	9 228 037	3 055 602	https://www.energimyndigheten.se/fornybart/elcertifikatsystemet/marknadsstatistik/	
United Kingdom	ROCs - Fuelled	RES quotas with tradable certificates	Electricity	878 038 095	790 250 036	699 480 450	821 602 760	903 112 475	893 033 292	938 797 341	https://www.ofgem.gov.uk/environmental-programmes/ro/contacts-publications-and-data/public-reports-and-data-ro	
United Kingdom	Contracts for difference	Sliding Feed-in premiums	Electricity	0	12 535 272	283 045 510	447 753 106	465 790 806	607 599 040	459 481 722	https://www.legislation.gov.uk/ukdsi/2014/9780111116784/contents	
United Kingdom	Climate change levy (CCL) Exemption of electricity generated from certain renewable resources	Tax exemption	Electricity	113 734 766	64 706 349	14 470 259	734 851	0	0	0	https://www.gov.uk/government/statistics/main-tax-expenditures-and-structural-reliefs	

United Kingdom	Non-domestic renewable heat incentive	Sliding Feed-in premiums	CHP	277 508 092	382 326 682	448 886 150	555 424 900	636 964 715	717 920 296	761 284 318	source: https://www.ofgem.gov.uk/data-portal/total-periodic-support-payments-cumulative-m	

x = no data available yet for this period

Country notes on the subsidies

Data for the countries that have been previously investigated in the 2020 report on CHP and solid biomass subsidies mainly the Netherlands, France, Germany, Denmark and United Kingdom are updated till 2021. Further research has been conducted, and some changes in historical data can be observed specifically:

Netherlands

Historical data for the Netherlands has been updated in this report with the result that aggregate subsidies have increased substantially compared to those reported in 2020. The primary reasons are:

- Feed in Premium for Renewable energy (MEP/SDE/SDE+/SDE++) - Biomass for electricity: is the main subsidy instrument, values for this have been significantly revised based on new information supplied via direct contact with the responsible ministry in the country. The values may include some subsidies towards CHP and/or heat plants. This change has increased the estimated subsidies by 150-250m EUR/year 2015-2019.
- Investment subsidy sustainable energy (ISDE): relatively small revisions to this subsidy amount have been made, based on specific actual values, rather than budgeted estimates. These changes amount to around a 5-10m EUR/year increase between 2015-2019.
- Energy Investment rebate (EIA) - Energy saving technologies: updated values were added, minor variations (<500k EUR) for the years 2015-2019 were observed due to updates to the calculation approach.

France

Historical data for France have been updated in this report with the result that aggregate subsidies are lower than reported in 2020. The primary reasons are:

- Heat Fund: This subsidy was incorrectly included in 2020, as the scope of the work is focused on electricity and CHP only, whilst this subsidy supports heat generation. It is not included in the estimates in this report. This amounted to approximately 100m EUR/year 2015-2019;
- Reduced (10%) VAT rate applicable to deliveries of firewood and related wood products: this subsidy has been also scoped out as it applies to firewood for household heating not for use in electricity production or CHP. This subsidy amounted to approximately 100m EUR annually between 2015-2019;
- Compensation supplement: the values for this subsidy have been updated, the 2020 values were based on budgeted spends for this element. The updated values are based on actual spending.

Germany

Historical data for Germany have been updated in this report with the result that aggregate subsidies are lower than reported in 2020. The primary reasons are:

- Reduced VAT tariff for wood pellets and firewood: this subsidy has been scoped out as it applies to firewood for household heating not for use in electricity production or CHP. This subsidy amounted to approximately 60m EUR annually between 2015-2019;
- Promotion of single measures for the use of renewable energy: this subsidy has been scoped out as it is used to fund biomass for heating and cooling purposes not for use in electricity production or CHP. This subsidy amounted to approximately 150-200m EUR annually between 2015-2019;

- EEG feed-in tariff and premium (for biomass): the 2019 values have been updated based on new reporting. This increased the value by approximately 100m EUR.
- CHP feed-in tariff from biomass and waste (KWK Umlage): the 2018 and 2019 values have been updated based on new reporting. This increased the values by approximately 2m EUR in 2018 and 4m EUR in 2019.

Denmark

Recent data for Denmark were researched showing no change in historical data. Denmark has only one subsidy that supports the usage of biomass and it is designated for electricity generation.

United Kingdom

Historical data for the United Kingdom have been updated in this report with the result that aggregate subsidies are lower than reported in 2020. The primary reasons are:

- Domestic Renewable Heat Incentive (RHI): this subsidy has been scoped out as it applies to household heating not for use in electricity production or CHP. This subsidy amounted to approximately 60m EUR annually between 2015-2019;
- ROCs – fuelled subsidy: small differences in historical subsidies are observed;
- Contracts for difference: a 2020 estimated value was provided in the 2020 study, this has been updated with the actual value for this study.
- Climate change levy (CCL) Exemption of electricity generated from certain renewable resources: downward revisions to historical numbers were made to correct for exchange rate differences in the 2020 report.

Furthermore, the research within this study has been extended to 7 other countries that were not previously investigated (Austria, Belgium, Finland, Italy, Poland, Spain, and Sweden). Detailed data about the biomass subsidies that support electricity generation in these countries is found in Annex A.

Sweden

In addition to the one relevant subsidy for electricity from solid biomass that was identified and quantified a further small subsidy was also identified. This subsidy provided investment support to renewable energy production for agricultural businesses, designed to move these away from diesel generators to biomass (or solar or other renewables). A 2020 evaluation[59] noted around 7 million EUR spent on this subsidy, of which an estimated 70% is thought to have been allocated to biomass projects, however it is unclear over which period this amount is spread.

[59] See https://greppa.nu/vara-tjanster/nyheter/arkiv---nyheter/2021-02-01-investeringsstod-nytta-for-miljo-och-klimat and https://www2.jordbruksverket.se/download/18.598bc9e717466bc7acf55f55/1599544766202/utv19_10.pdf

Annex B – Subsidies for boilers (Italy)

Italian subsidies to boilers powered with biomass

Conto termico (Thermal Account):

The Thermal Account incentivises interventions for the increase of energy efficiency and the production of thermal energy from renewable sources for small plants. Two categories of projects are eligible to benefit from the scheme:

A) energy efficiency improvements in existing buildings

B) small-scale projects concerning systems producing thermal energy from renewable and high efficiency system.

The subsidy consists of direct transfers to support the use of renewable energy sources and energy efficiency in across all energy products. Amongst others, the subsidy involves also the use of biomass for district heating and residential boilers.

Source: GSE, https://www.gse.it/servizi-per-te/news/conto-termico-i-numeri-del-contatore-al-1-gennaio-2022

Table 0-1 Total subsidy amounts for "Thermal account", in EUR millions

2015	2016	2017	2018	2019	2020	2021
38.1	35.7	89.9	174	264.1	302.7	326.5

Tax deduction on building retrofit measures:

This measure consists of a tax deduction, to the extent of 65% of the costs (since June 2013, it was 55% before) up to a deduction limit, changing according to the kind of the interventions. These reductions concern IRPEF (income tax of physical persons) and IRES (corporate income tax) and are granted for interventions that increase the energy efficiency of existing buildings, in particular when the expenditure is incurred for: Reduction of total energy requirements (energy efficiency); Thermal improvement of the building (energy efficiency); Installation of solar panels; Replacement of winter heating systems. As part of the numerous activities incentivied by the subsidy, there is the cost deduction for the installation of heating systems powered by biomass

Table 0-2 Subsidy amounts for "Tax deductions on building retrofit measures", in EUR million

2015	2016	2017	2018	2019	2020
1 429.8	1 129.8	1 375.3	1 634.2	1 828.9	2 008.1

Source: Ministry of the Ecological Transition, "Catalogo dei Sussidi Ambientali Dannosi e Favorevoli" http://www.minambiente.it/sites/default/files/archivio/allegati/sviluppo_sostenibile/catalogo_sussidi_ambientali.pdf

Annex C - Further information on BECCS and LCOE

The calculation of the BECCS LCOE in section 4.2 was carried out by extracting values on the capital expenditures, O&M expenditures, fuel expenditures and CO2 transport & storage from the literature. The LCOE formula is as follows:

$$LCOE = \frac{NPV\ of\ total\ costs\ over\ lifetime\ of\ plant}{NPV\ of\ electrical\ energy\ produced\ over\ lifetime\ of\ plant}$$

Or:

$$LCOE = \frac{\sum \frac{C_t + M_t + F_t}{(1+r)^t}}{\frac{E_t}{(1+r)^t}}$$

With:

C_t: *capital expenditures over time*

M_t: *maintenance & operations expenditures over time*

F_t: *fuel expenditures over time*

E_t: *Electricity generated over time*

r: *discount rate*

In short the discounted sum of the capital expenditures, operations and maintenance expenditures and fuel costs incurred over the lifetime of the plant are divided by the discounted amount of electrical energy produced over the lifetime of the plant.

Within each of the papers analysed in the literature review we converted the variable values to £/MWh. As a result the estimated lifetime of the plant, discount rate and the electricity generated over time are already integrated into each of the variable values. Essentially, this means that that adding up each of the variables expressed in £/MWh results in the LCOE.

Fuel costs

To check how sensitive the LCOE is to fuel prices, estimations of wood pellet prices are made based on findings from the literature.

Area	Wood pellet price	Converted to £/MWh
North-west Europe* (cif)	$303.22/t	64.21$/MWh -> 56.64£/MWh
Baltics (fob)	€240.91/t	51.02€/MWh -> 42.54£/MWh**
North-east U.S (fob)	$264.70/t	56.06$/MWh -> 49.34£/MWh

* North-west Europe includes the UK and Denmark

** Calculated using the exchange rate on 6th April 2022 (date of price)

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