Final Report
Energy Investments

Energy costs, taxes and the impact of government interventions on investments

Written by Trinomics
October - 2020

EUROPEAN COMMISSION

Directorate-General for Energy
Directorate A — Energy Policy
Unit A4 — Economic Analysis and Financial Instruments

European Commission
B-1049 Brussels

EUROPEAN COMMISSION

Final Report

Energy Investments

Energy costs, taxes and the impact of government interventions on investments

In association with:

And involving:

Directorate-General for Environment

CONTRACT DETAILS

European Commission, DG ENERGY UNIT A.4

Study on energy costs, taxes and the impact of government interventions on investments in the energy sector

Service request ENER/2018-A4/2018-471

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Luxembourg: Publications Office of the European Union, 2020

PDF/Volume_01	ISBN 978-92-76-23126-4	doi: 10.2833/33834	MJ-03-20-632-EN-N

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Abbreviations

ASHP	Air source heat pump
BEV	Battery electric vehicle
COP	Coefficient of performance
E3ME	Energy-Environment-Economy macro econometric model (Cambridge Econometrics)
EU27	European Union 27 Member states of the European Union (excluding the United Kingdom)
EU28	28 Member States of the European Union
EUR	Euro
EV	Electric Vehicle
FE	Fixed Effects econometric estimation method
FTT	Future Transformation Technologies power sector model (Cambridge Econometrics)
G20	Group of 20, international forum for the governments from 19 countries and the EU
GDP	Gross Domestic Product
GSHP	ground source heat pump
GW	Gigawatt
ICE	Internal Combustion Engine
IEA	International Energy Agency
KTOE	Kilotonnes of oil equivalent
KWH	Kilowatt hour
MWh	Megawatt hour
OLS	Ordinary Least Squares econometric estimation method
PCSE	Panel Corrected Standard Errors econometric estimation method
PHEV	Plug-in hybrid electric vehicle
RE	Random Effects econometric estimation method
TCO	Total cost of ownership
USD	United States Dollar

1 Introduction

1.1 Overview

The overarching objective of this report is to analyse the impact of subsidies on investments in power generation, extraction, transport, and heating. The report gives a comprehensive overview of the evolution of energy investments across the economy and provides an analysis of how fossil fuel and renewable subsidies impacted the take-up of renewables in the EU and Non-EU G20 countries over 2008-2018.

Section 2 presents the key trends in energy investments for the countries in scope with a special focus on fossil fuel extraction and power generation subsidies. Section 3 analyses the role of subsidies in the observed dynamics of investments. Section 3.1 describes the power sector analysis and shows how fossil fuel and renewable subsidies affected the take-up of different technologies using a bottom-up energy sector model, FTT: Power. Section 3.2 to 3.5 present sector case studies using descriptive and econometric analysis. The first case study explores how fossil fuel subsidies impacted extraction investments. The second case study focuses on the electrification of transport and investigates the effect of subsidies on electric vehicle sales. The last case study analysis the buildings heating sector and the impact of buildings energy efficiency subsidies on heat pump sales.

1.2 Methodology

1.2.1 Energy investments

Scope and definitions

Investments within the scope of this study are defined as overnight investments in new capacities or investments in refurbishments[1]. Both public and private sector investments are included. Investments are measured in 2018 Euros. We collected investment data for the categories listed in Table 1-1 below. Definitions for each category are available in the detailed methodology description in Annex B.

Table 1-1 Overview of investment categories in scope

Extraction	Production		Transmission & distribution	Storage	Electrification
Oil	Oil refining	Hydro power - small (<50MW)	Transmission - electricity	Pumped hydro	Heat pumps aerial
Gas	LNG liquefaction or regasification	Bio-power from solid biomass	Transmission - gas	Battery storage	Heat pumps ground
Coal extraction	Coal-fired power plants	Bio-power from biogas	Distribution - electricity	Underground gas storage	Electric passenger vehicles
	Gas and oil-fired power plants	Bio-power from waste	Distribution – gas		
	Nuclear power plants	Biofuel production	Distribution - heat		
	Solar (PV) power - utility scale	Solar thermal heating			

[1] For certain technologies (extraction: oil, gas and coal extraction; production: oil refining, LNG liquefaction and/or regasification, coal fired power plants, gas and oil fired power plants, nuclear power plants and hydro power - large) investment data refers to total investments (new capacities + refurbishments). For all other technologies, investment data refers to new capacities only. Only capitalised refurbishments are defined as investments.

Extraction	Production		Transmission & distribution	Storage	Electrification
	Solar (PV) power - rooftop	Modern bio-heat			
	Concentrated Solar Power (CSP)	Geothermal direct use, heat			
	Wind power - onshore	Geothermal - electricity			
	Wind power - offshore	Ocean energy			
	Hydro power - large (>50MW)				

Approach

Our approach to this task consisted of data collection, validation, visualisation and analysis. Data collection and validation was carried out in a three-staged approach that aimed to deliver monetary estimates (in Euros) of investments in all investment categories for all countries and all years. The first step was to collect data from transversal sources such as the IEA, IRENA, Eurostat and S&P (Platts). This data included data in monetary terms (e.g. EUR or USD) and in capacity terms (e.g. MW) and was used to pre-populate a dataset for each country. In the second step, this dataset was sent to country experts in each country who were tasked to validate pre-populated data and add missing data. In both steps, priority was given to data in monetary terms. Data in capacity terms was only collected if no reliable data in monetary terms could be found. In the third step, capacity data was converted to monetary terms based on representative ratios between capacity additions and investments for a given year, technology and region. Data validation was conducted by comparing data from different transversal sources and checking data with national sources.

Our data visualisation work aimed to convert the collected investment data to easy to interpret graphs on key trends and developments with respect to investments in the energy sector. The results of this are provided in chapter 2 and are accompanied by explanatory notes and (light) analysis.

1.2.2 Impact of subsidies on energy investments

This second half of this report focuses on analysing the link between the collected energy investment data and subsidies data set compiled as a deliverable of Task 3.1.

The power sector analysis uses an ex-post simulation approach performed by the FTT:Power energy sector model. The analysis estimates counterfactual scenarios to simulate how the power generation mix of countries would have evolved if no fossil fuel and renewable subsidies had been introduced. By comparing the observed and the counterfactual power generation mixes, the impact of subsidies could be analysed.

The three sector case studies on fossil fuel extraction investments, electric vehicle, and heat pump take-up, use descriptive and econometric analysis to identify the link between subsidies and investment or sales. The incompleteness of the data limited the use of sophisticated econometric techniques in the case studies. Whenever the sample size allowed, we moved beyond descriptive figures and conducted regression estimates to identify the impacts.

Section 3.1, 3.1.1 and 3.2 give a more detailed description of the methodology used.

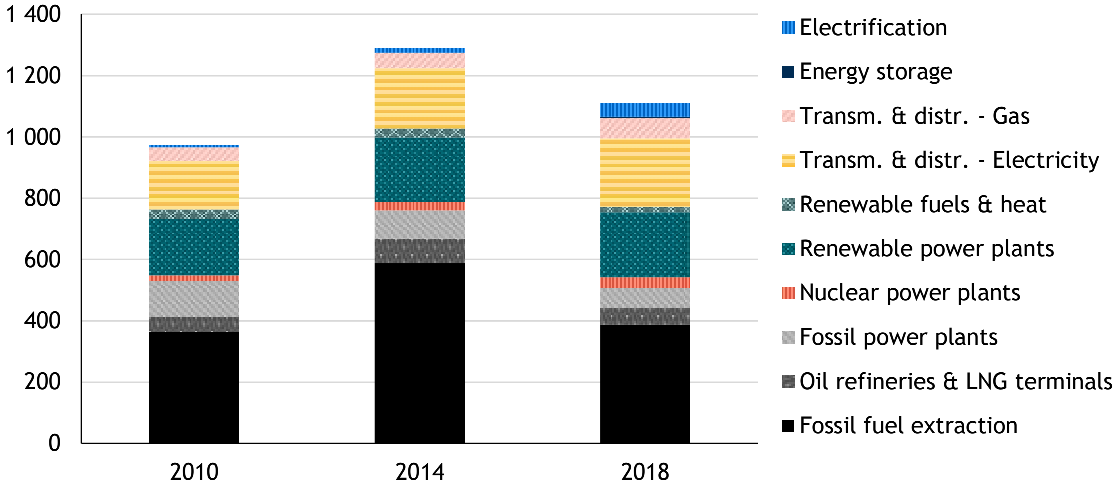
2 Energy investments

In this chapter we provide a high level analysis on the main trends and developments with respect to investments in energy assets. We first discuss the overall developments for all investment categories that we considered. Secondly, we analyse the developments in the main investment categories in more detail (except for transmission & distribution, which is covered in a separate report of this study). Where relevant, we discuss developments for specific regions in more detail, in particular for the EU27 region.

2.1 Overall trends and developments

The total investment volume in energy assets across the EU27 and G20 countries went from approximately EUR 1,000 billion in 2010 up to nearly 1,300 billion in 2014 and back down to 1,100 billion in 2018. These fluctuations are largely driven by changes in fossil fuel extraction, oil refineries and LNG terminals investments, which together accounted for EUR 410 billion in 2010, 670 billion in 2014 and 440 billion in 2018 (see Figure 2-1).

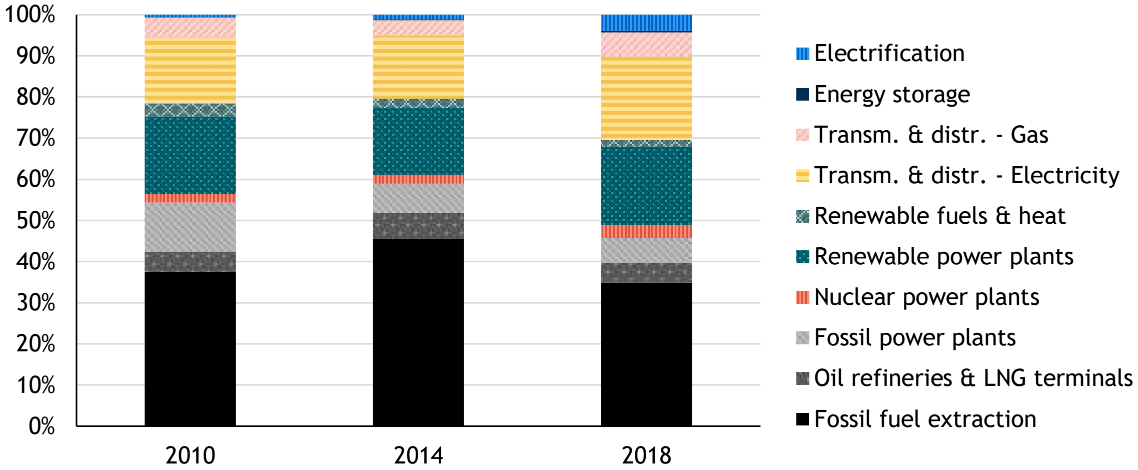
Figure 2-1 Breakdown of investments by category - EU27 and G20 (in billion EUR)



Source: Own elaboration based on data sources specified in annex B.
Notes: Full breakdown only available for 2010, 2014 and 2018 as transmission & distribution investment estimates are only available for those years. Electrification includes heat pumps and electric vehicles. Energy storage includes pumped hydro and battery storage. Renewable fuels and heat includes biofuel production plants, solar thermal heating, modern bio-heat, geothermal direct use and heat distribution networks. Renewable power plants includes wind, solar PV, hydropower, bio-power, concentrated solar power, geothermal electricity generation and ocean energy. Fossil power plants includes coal, gas and oil-fired power plants. Fossil fuel extraction includes oil, gas and coal extraction.

The breakdown of total investments across categories (see Figure 2-2) shows that current fossil investments (extraction, refining, LNG terminals and fossil power plants) were in 2018 at a slightly lower level than in 2010 but still account for close to 50% of the total investment volume. Renewable power plants, fuel and heat production together account for slightly over 20% of total investments, a share which remained roughly constant since 2010. Transmission & distribution investments accounted for 20 to 25% of total investments of which the majority went to electricity infrastructure. Nuclear power plants maintained a share between 2 and 3% of total investments whereas energy storage investments are negligible in the bigger picture. Finally, electrification investments which include investments in heat pumps and electric vehicles developed from a negligible share to 4% of total investments in 2018.

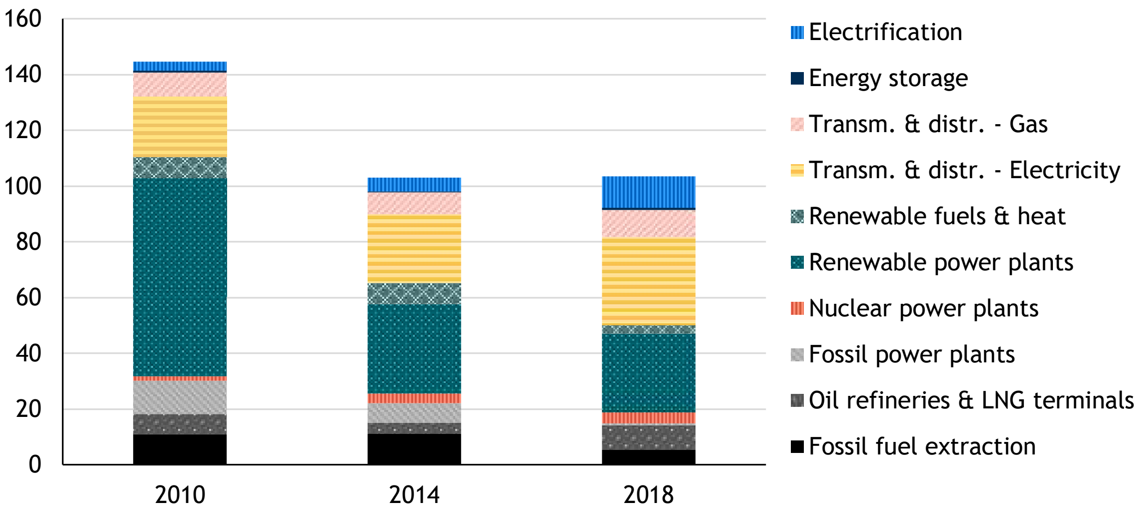
Figure 2-2 Breakdown of investments by category – EU27 and G20 (in %)



Source: Own elaboration based on data sources specified in annex B.

The EU27 accounted for a relatively small share of these investments with annual investment volumes declining from values around EUR 140 billion (2010) to values around EUR 100 billion in 2014 and 2018. The decrease in investments in the EU27 between 2010 and 2014 was primarily driven by a decline in investments in renewable power plants, although it should noted that newly installed renewable capacities were increasing over this period but investment costs declined even more significantly (see Figure 2-3).

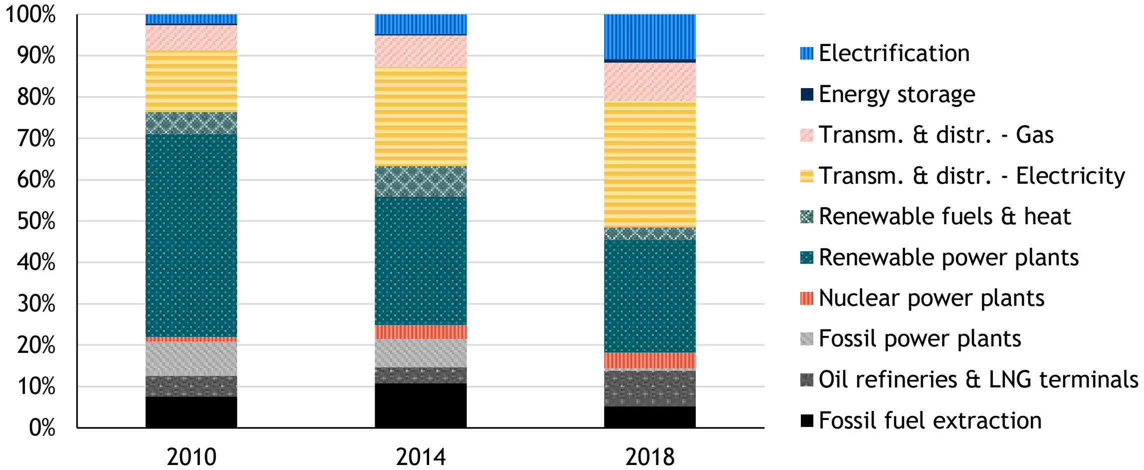
Figure 2-3 Breakdown of investments by category – EU27 (in billion EUR)



Source: Own elaboration based on data sources specified in annex B.

EU27 investments are dominated by renewables and transmission & distribution investments, which together accounted for 70 to 75% of total investments (see Figure 2-4). Investments in fossil fuel extraction, refineries, terminals and power plants account for a much smaller share in the EU, with shares declining from around 20% in 2010 to around 15% in 2018. A remarkable observation is the sharp increase in the share of transmission & distribution and the sharp decrease in the share of renewable power, fuels and heat. While this is partly due to increased spending on the electricity grid, most of it is due to decreased spending in renewables. A more detailed look on these observations is provided in the section on power sector investments.

Figure 2-4 Breakdown of investments by category - EU27 (in %)



Source: Own elaboration based on data sources specified in annex B.

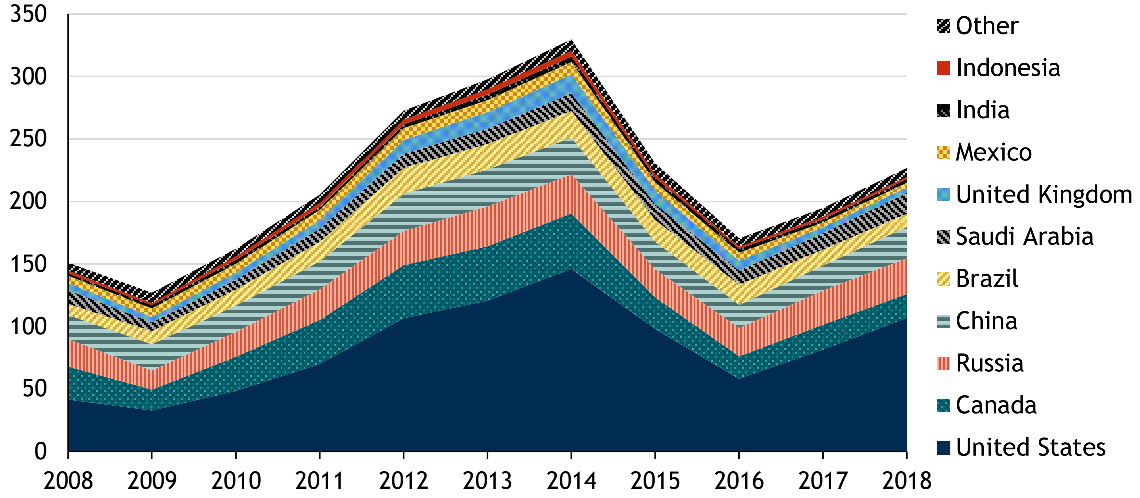
2.2 Detailed assessment: Fossil fuel extraction

Fossil fuel extraction remains the single largest investment category accounting for approximately 40% of total energy investments made in the EU27 and G20. The largest investments are made for oil extraction with typical annual investment volumes around EUR 200 billion. Gas extraction comes second with typical values around EUR 100 billion annually. Coal extraction investments were initially at a similar level as gas extraction with values around EUR 100 billion annually between 2008 and 2014, but decreased significantly to values around EUR 60 billion from 2016 onwards.

Investments in oil extraction fluctuate strongly over the years due to changes in oil prices, which dropped sharply in 2008 and 2014.[2] The US is the largest investor in oil extraction accounting for approximately 40% of all oil extraction investments made by EU27 and G20 countries (see Figure 2-5). Other large investors are Canada, Russia, China and Brazil which together account for another 40% of oil extraction investments. There are no EU countries in the top 10 investors for oil extraction. Oil extraction investments for the EU as a whole amounted to 2 to 4 billion per year which is comparable to Indonesia and India which are number 9 and 10 of the top countries.

[2] https://www.macrotrends.net/1369/crude-oil-price-history-chart

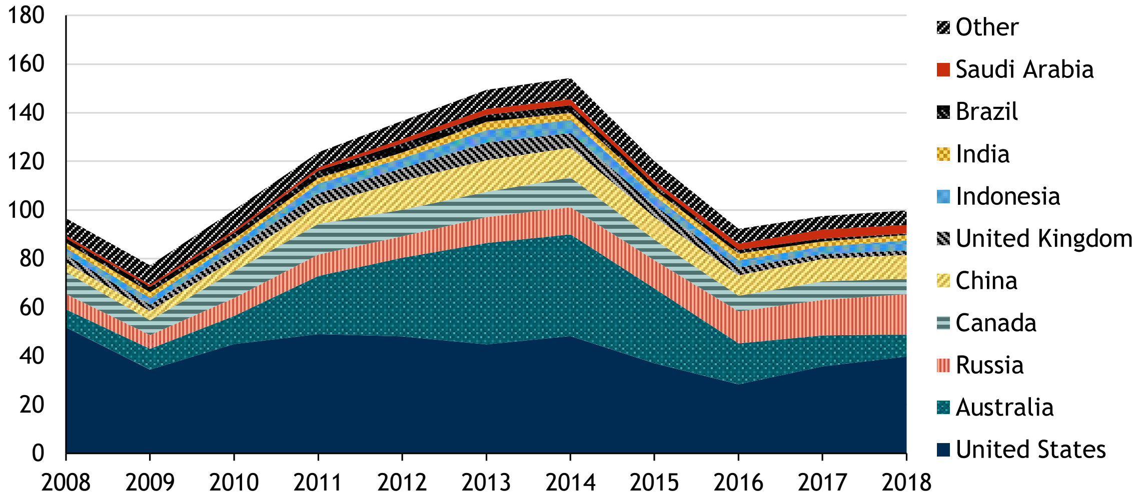
Figure 2-5 Top 10 countries - investments in oil extraction (in billion EUR)



Source: Own elaboration based on data sources specified in annex B.

The top investors for gas extraction over the last decade are similar to the top oil investors, with the United States also at number 1 and Russia, Canada and China among the top 5 investors. The main difference with the top oil investors is Australia, which ranks second for gas extraction but is not part of the top 10 for oil extraction. There are also no EU countries among the top 10 investors, although the Netherlands (#11), Romania (#14) and Poland (#15) are close. The EU as a whole would rank 6th over the 2008-2018 time period but has reduced its gas investments significantly from around 5 billion per year between 2008 and 2015 down to half that level in recent years. This is for a large part due to the reduced investments in the Netherlands, which decreased its annual investments by 2 billion.

Figure 2-6 Top 10 countries - investments in gas extraction (in billion EUR)



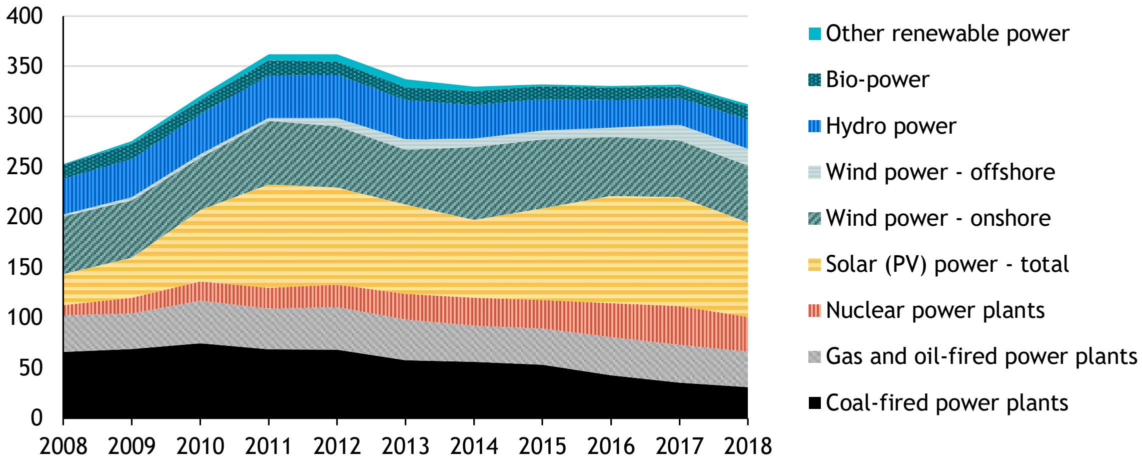
Source: Own elaboration based on data sources specified in annex B.

Investments in coal extraction are dominated by China, which accounts for two thirds of total coal extraction investments. Other countries with significant investments in coal extraction are India, Australia and Russia, which together account for a quarter of coal extraction investments.

2.3 Detailed assessment: Power generation

Investments in power generation (fossil, renewable and nuclear combined) account for approximately 30% of energy investments (EU27 and G20). The overall investment level has remained fairly constant between 2008 and 2018, but the shares of individual technologies have changed significantly (see Figure 2-7). Investments in coal-fired power have decreased most significantly, from a share of 26% (70 billion EUR) in 2008 down to 10% (30 billion EUR) in 2018. Together with a small decline in the share of gas-fired power investments this has resulted in a strongly reduced share of fossil power generation, from 40% (100 billion EUR) in 2008 to 21% (65 billion EUR) in 2018. Most of the fossil generation share went to renewable power generation which increased its share from 56% (140 billion EUR) to 68% (210 billion EUR) but also investments in nuclear power grew, from 4% (10 billion EUR) to 11% (35 billion EUR) of total power sector investments. Renewable power investments remained at a relatively constant level from 2011 onwards even though annual capacity additions grew almost threefold. This can be explained by the sharp cost reductions for solar PV and wind power in particular.

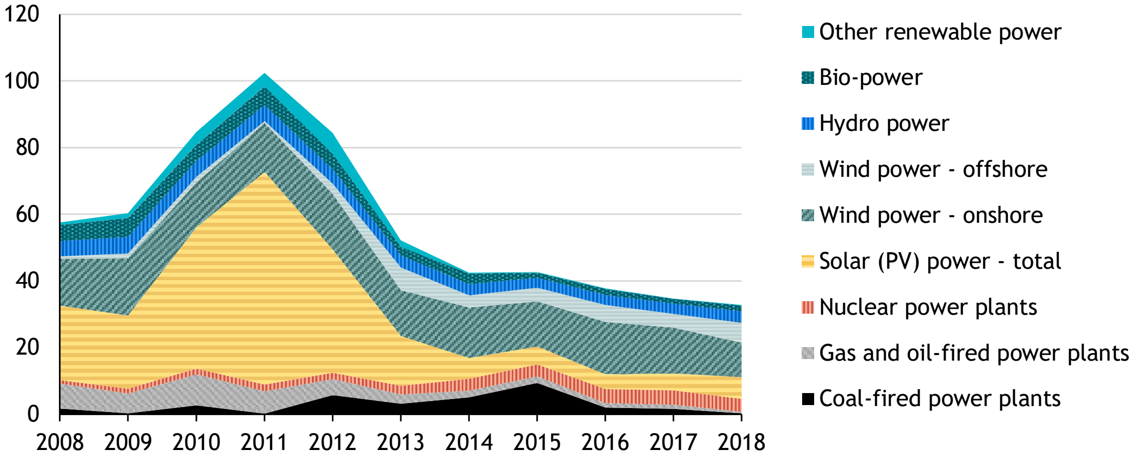
Figure 2-7 Power sector investments – G20 and E27 (in billion EUR)



Source: Own elaboration based on data sources specified in annex B.
Note: Other renewable power includes concentrated solar power, geothermal electricity generation and ocean energy.

Power sector investments in the EU clearly show the leading role that the EU played in the initial market development for solar PV and wind power (see Figure 2-8). In particular in the years 2010 to 2012, large investments were made which pushed total EU power sector investments up to EUR 100 billion per year. From 2013 onwards, only onshore wind investments remained at a substantial level while in particular solar PV investment, in monetary terms, declined sharply. Fossil investments were close to zero in most years with only a brief increase in coal-fired power investments in 2014 and 2015, mostly due to investments in Germany. The slight increase in investments in nuclear capacity can be attributed to increased spending in France.

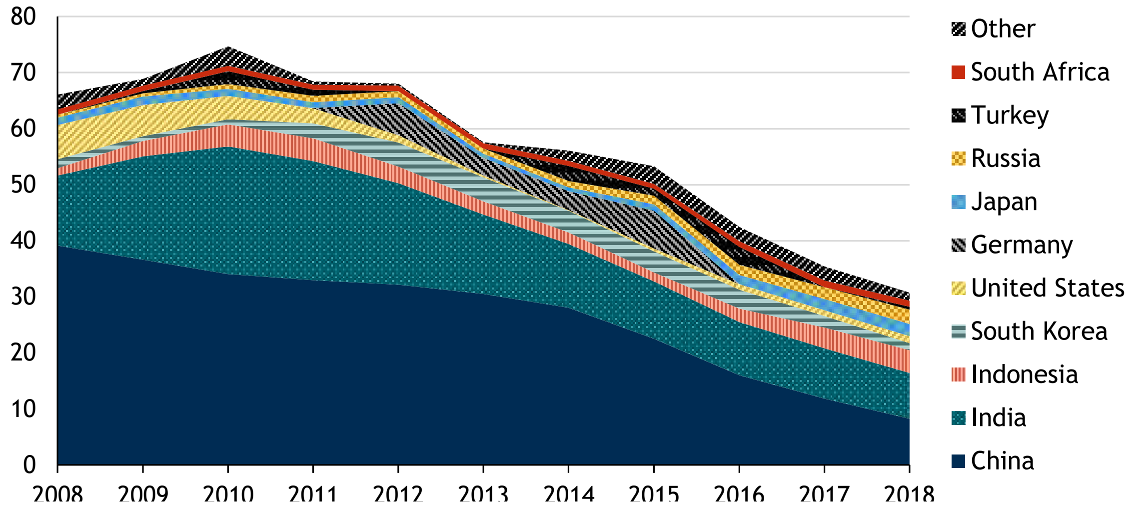
Figure 2-8 Power sector investments - EU27 (in billion EUR)



Source: Own elaboration based on data sources specified in annex B.
Note: Other renewable power includes concentrated solar power, geothermal electricity generation and ocean energy.

Looking at the investments in coal-fired power specifically, it becomes clear that there are really only two countries that invested significantly in this technology over the past decade: China and India. However, both countries have significantly reduced their investments in coal-fired power.

Figure 2-9 Top 10 countries - investments in coal-fired power (in billion EUR)

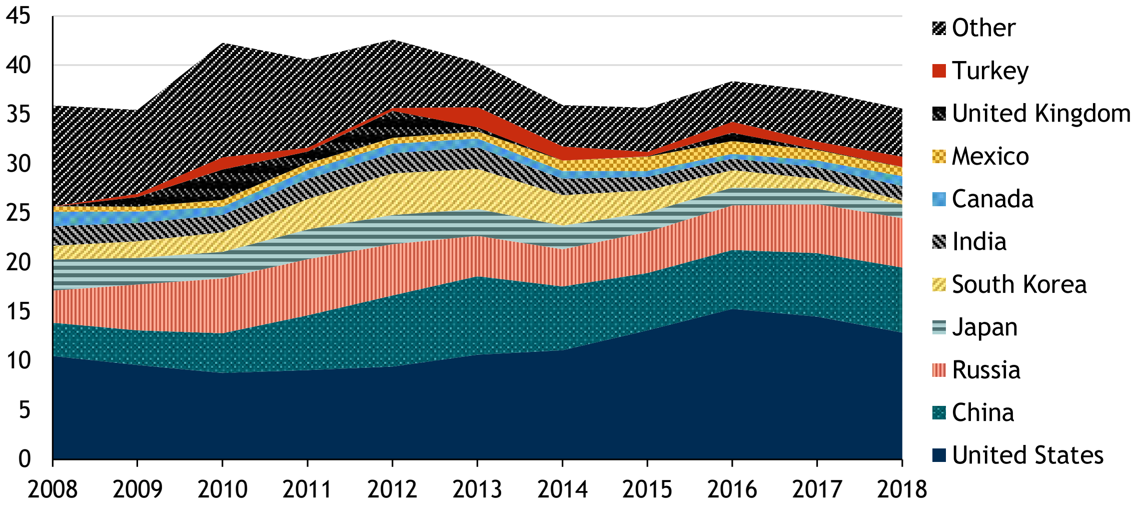


Source: Own elaboration based on data sources specified in annex B.

The main players with respect to investments in gas-fired power are more diverse and include countries such as the United States, Russia, Japan and South Korea in addition to China and India (see Figure 2-10).[3]

[33] The investment figures include also oil-fired power investments but these are small compared to gas-fired power investments.

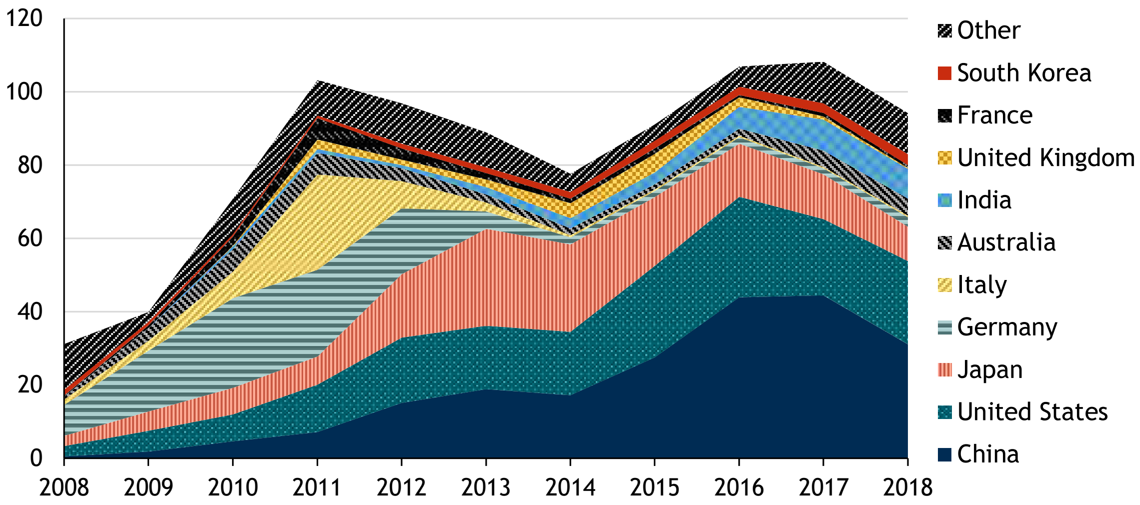
Figure 2-10 Top 10 countries - investments in gas and oil-fired power plants (in billion EUR)



Source: Own elaboration based on data sources specified in annex B.

The investments in solar PV clearly show the leading role of Germany, Japan and the US in the early years and the quick growth of the Chinese market more recently (see Figure 2-11). The US and Japan also have large markets for solar PV in terms of investment volume, while less so in terms of capacity additions. This difference is due to the relatively high installed cost of solar PV in these countries compared to much lower costs in the EU and China. Since 2016, the Indian market has become one of the main markets and has continued to grow.

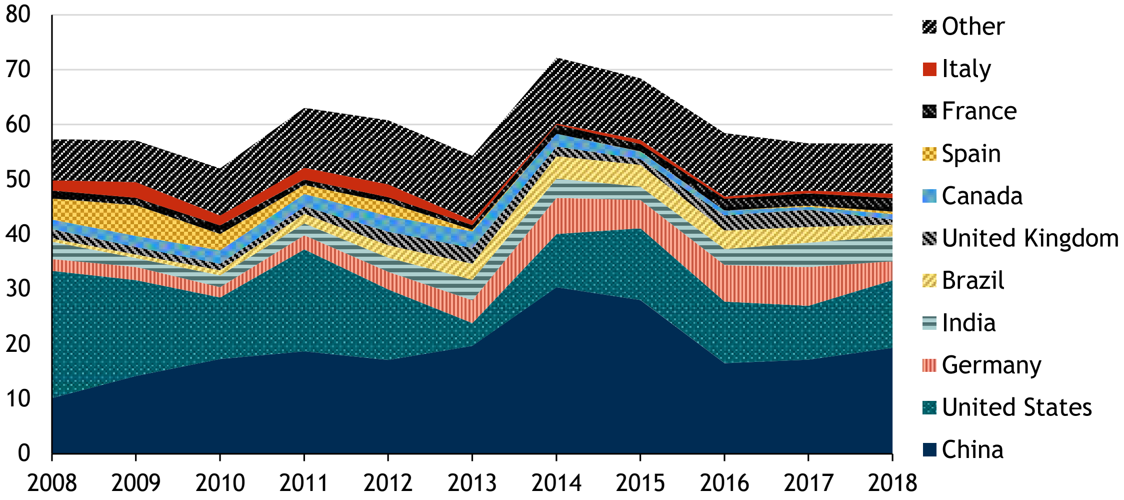
Figure 2-11 Top 10 countries - investments in solar PV (in billion EUR)



Source: Own elaboration based on data sources specified in annex B.
Note: Investments in solar PV shown for Australia include investments in New Zealand.

The key players in onshore wind are similar to solar PV with the largest markets in China and the United States (Figure 2-12). Several EU countries are among the top 10 countries. The EU as a whole would rank second, with an investment volume between half and two thirds of the Chinese market and slightly larger than the US market in most years.

Figure 2-12 Top 10 countries - investments in onshore wind power (in billion EUR)



Source: Own elaboration based on data sources specified in annex B.

Investments in offshore wind gradually increased from around 2 billion EUR in 2008 to over 16 billion EUR in 2018. Investments in offshore wind are driven by investments in the United Kingdom and Germany, which together account for over half of the total investments in offshore wind between 2008 and 2018. Over the same period, China was the third largest investor, with investments and their growth particularly high, higher than in the UK and Germany, in the most recent years. In 2018, China was the number one investor in offshore wind, accounting for almost a third of total investments.

2.4 Country profiles - main G20 countries

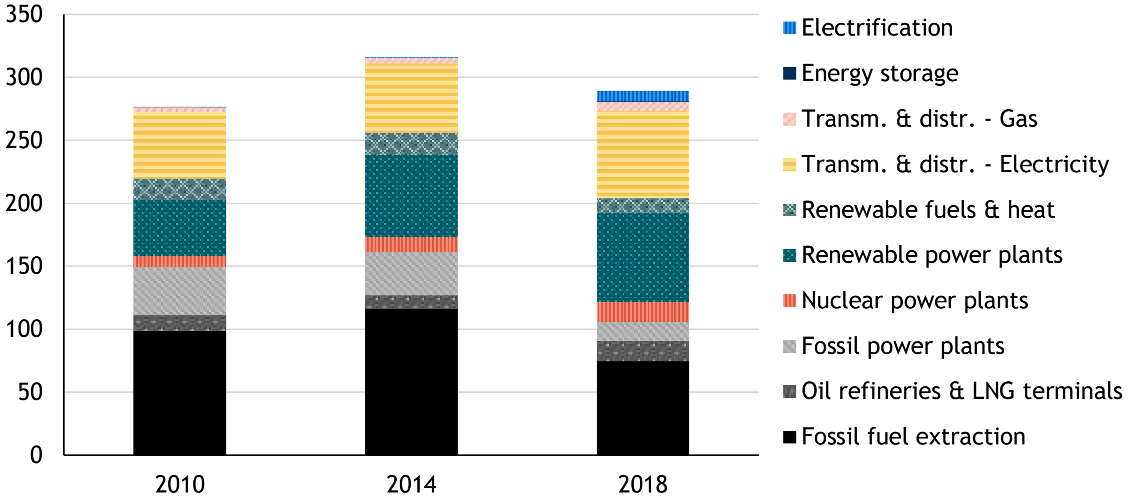
In the sections below we discuss the distribution of investments for the largest G20 countries based on annual energy assets investment volume: China, United States, Russia, India and Canada. These countries all invest more than EUR 50 billion annually[4] and together with the EU27[5] account for approximately 80% of investments for the total group of countries analysed (G20 and EU27).

2.4.1 China

The total investment volume in energy assets in China remained relatively stable with values between EUR 270 and 320 billion. The breakdown of investments across categories (see Figure 2-13) shows that the share of fossil fuel investments decreased significantly from a share over 50% to a share around 35%. Investments in renewable power plants accounted for an increasing share, growing from approximately 15% (EUR 45 billion) in 2010 to 25% (EUR 70 billion) in 2018. Investments in electricity transmission & distribution also gained importance, with a share growing to approximately 25%.

[4] On average for years with data coverage of all categories: 2010, 2014 and 2018.
[5] The same graph for the EU27 is available in section 2.1.

Figure 2-13 Breakdown of investments by category in China (in %)



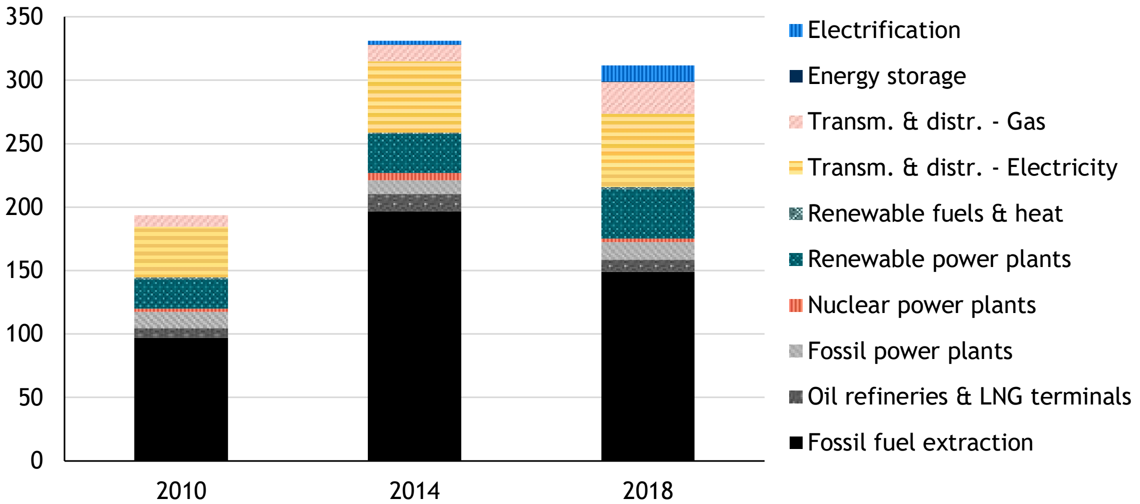
Source: Own elaboration based on data sources specified in annex B.

2.4.2 United States

The total investment volume in energy assets in the United States increased from EUR 190 billion in 2010 to EUR 330 billion in 2014 and decreased to EUR 310 billion in 2018. The increase between 2010 and 2014 was almost entirely driven by investments in fossil fuel extraction, especially shale gas and oil, which doubled over this period (from EUR 100 billion in 2010 to EUR 200 billion in 2014). From 2014 to 2018, investments in fossil fuel extraction decreased to EUR 150 billion, still amounting to a 50% increase compared to 2010.

The breakdown of total investments across categories (see Figure 2-14) shows these developments regarding fossil fuel extraction, too. However, as investments in renewable power plants, electricity transmission & distribution and electrification also increased, the share of fossil fuel extraction peaked around 60% in 2014 (and decreased to 50% in 2018). The share of investments in electricity transmission & distribution decreased from 21% in 2008 to 19% in 2018, but increased in absolute terms from approximately EUR 40 billion in 2010 to approximately EUR 60 billion in 2018. Investments in renewable power plants remained constant in relative terms, but increased in absolute terms from approximately EUR 20 billion in 2010 to EUR 40 billion in 2018.

Figure 2-14 Breakdown of investments by category in the United States (in %)

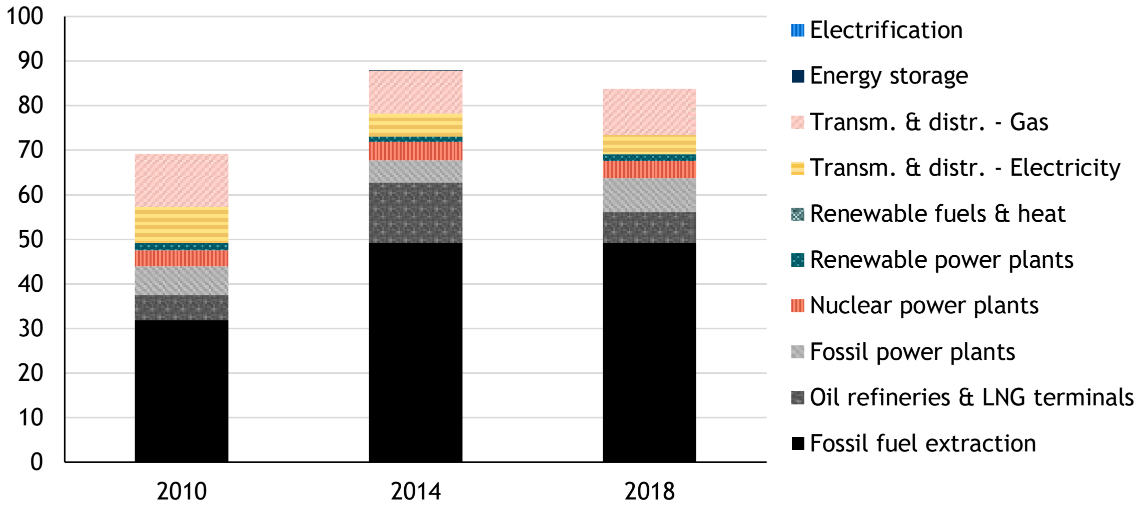


Source: Own elaboration based on data sources specified in annex B.

2.4.3 Russia

Energy investments in Russia increased from EUR 70 billion in 2010 to 90 billion in 2014 and 85 billion in 2018. These developments can be attributed to increased spending on fossil fuel extraction (gas), from just over EUR 30 billion in 2010 to nearly EUR 50 billion in 2014 and 2018.

Figure 2-15 Breakdown of investments by category in Russia (in %)

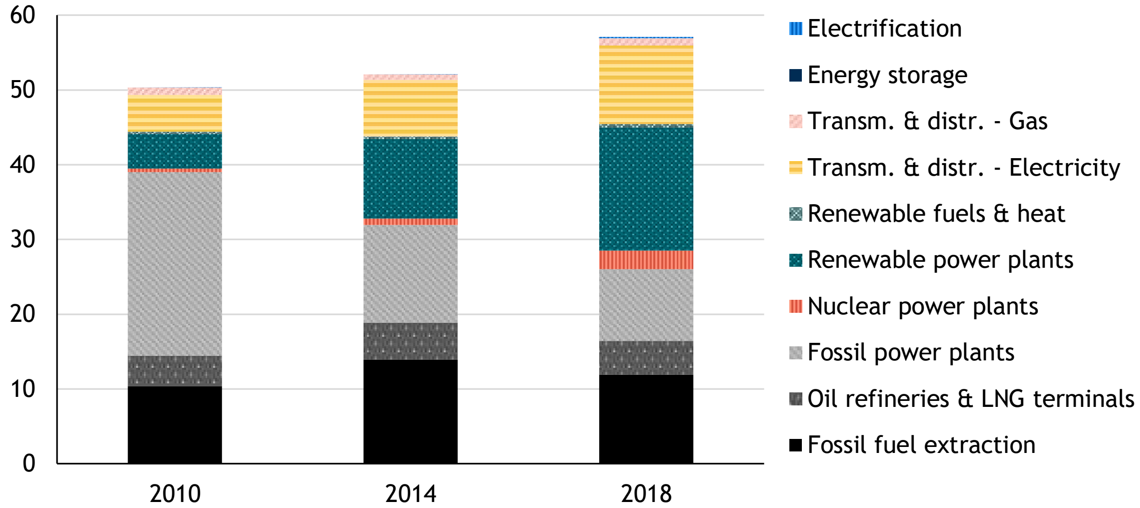


Source: Own elaboration based on data sources specified in annex B.

2.4.4 India

The investment volume in India has been relatively stable with values between EUR 50 billion and 60 billion for 2010, 2014 and 2018. The main takeaway from the distribution of investments in India is that the overall investment portfolio is clearly becoming more sustainable. While the country still invests in fossil power plants, renewable power plants are taking an increasing share of total investments, increasing from 7% of total investments in 2010 to 25% in 2018.

Figure 2-16 Breakdown of investments by category in India (in %)

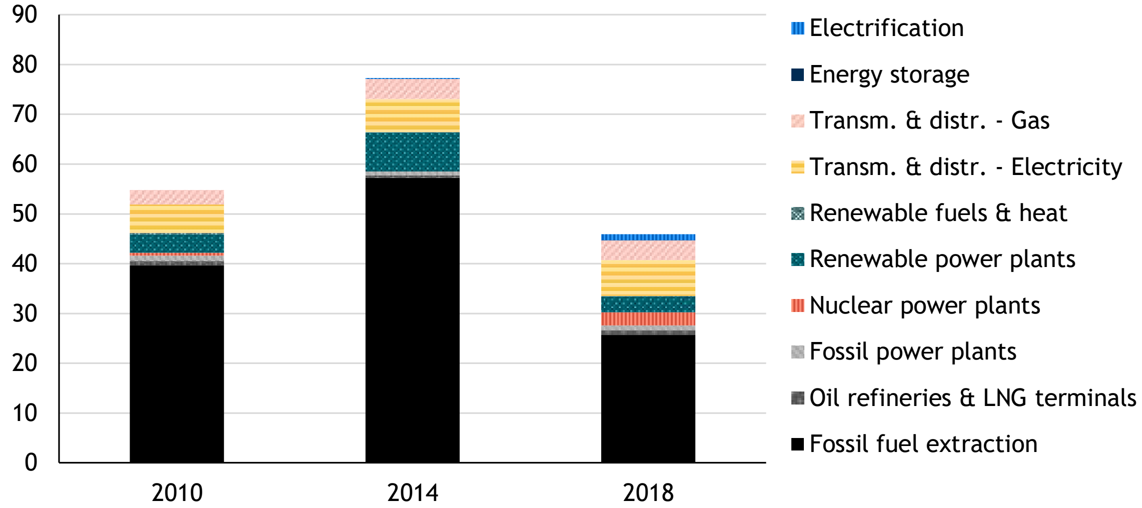


Source: Own elaboration based on data sources specified in annex B.

2.4.5 Canada

The investments in Canada increased from EUR 55 billion in 2010 to nearly 80 billion in 2014 and decreased to EUR 45 billion in 2018. Canada's investments are dominated by fossil fuel extraction, which accounts for 55-75% of total investments. The decreased share of extraction in 2018 can entirely be attributed to a sharp decline in spending on fossil extraction, which was less than EUR 30 billion in 2018, down from close to 60 billion in 2014 and 40 billion in 2010.

Figure 2-17 Breakdown of investments by category in Canada (in %)



Source: Own elaboration based on data sources specified in annex B.

3 Impact of energy subsidies on investments

The objective of this chapter is to analyse the impact of subsidies on renewable investments and the take-up of low-carbon technologies. It gives a comprehensive analysis on how fossil fuel and renewable subsidies impacted the take-up of renewables in the EU and G20 countries over 2008-2018.

The first part of the chapter analyses the impact of fossil fuel and renewable subsidies in the *power sector*, assessing how fossil fuel subsidies hindered the take-up of renewables in the power generation mix and how renewable subsidies helped in broader renewable penetration. This analysis uses a simulation approach performed by the FTT:Power model to develop counterfactual scenarios where subsidies were removed.

The second part of the chapter presents three *sector case studies* using data visualisation and, if the data quality allows, econometric analysis. The selection of case studies and the analytical methods were determined by the completeness and quality of the investment and subsidies data collected in Task 3.1 and Task 8.1 (referred to as investment and subsidies data set in the following sections). The case studies assess:

- how fossil fuel subsidies affected the investment in extraction
- how electric vehicle (EV) subsidies impacted EV sales
- how buildings energy efficiency subsidies affected the take-up of heat pumps

3.1 Power sector analysis

In the power sector, for the EU27 and G20, subsidies have been provided that aim to support the investment and ongoing operation of power generation capacity. These subsides cover both fossil fuel and renewable technologies. In this analysis we assess the expected contribution of power sector subsidies to the uptake of power generation technologies.

To carry out this analysis, we used the power sector model FTT:Power to run counterfactual scenarios where subsidies for power generation technologies were removed, in order to assess how this would impact the development of power generation capacity.

We ran two scenarios:

1. Removing only fossil fuel subsides for power generation;
2. Removing all subsidies (fossil fuel + renewable subsidies).

Overall, we find that subsidies for fossil fuel power generation had a small negative impact on the uptake of renewable generation capacity in the EU27. This finding reflects the relative low levels of fossil fuel subsidies across many Member States such that the removal of this support would not substantially impact investors’ decisions to invest in renewable power generation capacity.

When renewable subsidies are also removed, we find that the renewable subsidies had a much larger impact on the cost competitiveness of renewable generation capacity. This reflects the high levels of renewable support across many countries in the EU27 and G20 through measures such as feed-in tariffs. The modelling suggests that subsidies had a strong impact on the uptake of Solar and Wind capacity and, without support, renewable investment would slow considerably.

3.1.1 *Approach*

This analysis uses Cambridge Econometrics' FTT:Power model to assess the impact of subsidies in the power sector. FTT (Future Technology Transformations) is a technology diffusion model, initially developed by J.-F. Mercure (Mercure, FTT:Power A global model of the power sector with induced technological change and natural resource depletion, 2012) to analyse the take-up of different generation technologies as energy demand evolves and different technologies develop.

FTT:Power has been widely used in projects analysing the impact of subsidies, government regulation and other power sector policies in the energy sector. FTT:Power has also been used in the previous report on energy costs and prices, which Cambridge Econometrics and Trinomics conducted for the European Commission (European Commission , 2018). While building on this analysis, the current report covers the EU27 and G20 countries, a wider range of subsidies and the full timeframe of 2008-2018.

FTT:Power

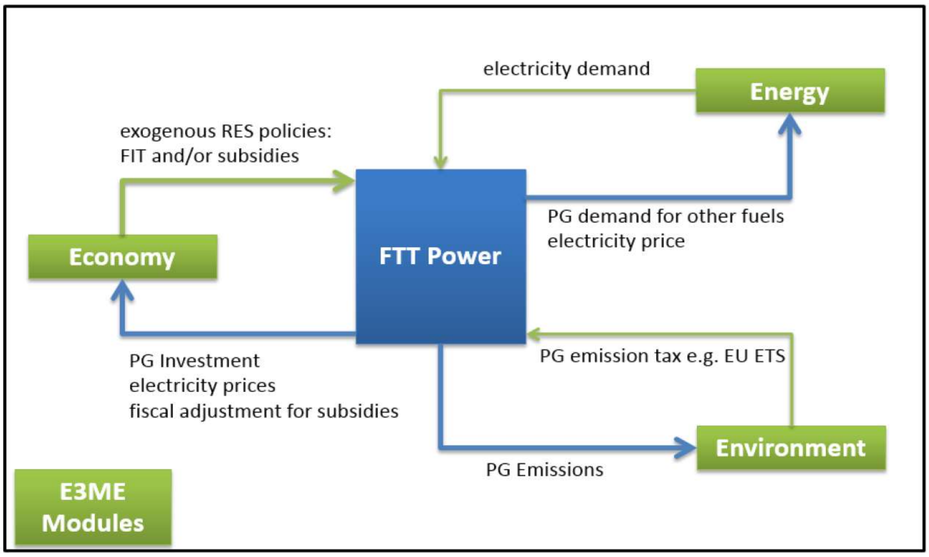
FTT:Power is the electricity sector submodel of Cambridge Econometrics' E3ME (Energy-Economy-Environment macro-econometric model of https://www.e3me.com/). For a given level of energy demand calculated based on the needs of the economy, FTT:Power calculates in a bottom-up modelling framework how that energy demand is met based on the available technologies and their costs.

The model uses an advanced framework for the dynamic selection and diffusion of innovations. It includes a decision-making core that represents investors wanting to build new generation capacity, who have the choice of several technologically feasible options with different costs. The resulting diffusion of competing technologies based on investor choices is constrained by the available renewable and non-renewable resources. The decision-making takes place by pairwise levelised cost (LCOE) comparisons, conceptually equivalent to a binary logit model, parameterised by measured technology cost distributions. Costs include reductions originating from learning curves, as well as increasing marginal costs of natural resources using cost-supply curves. The diffusion of technology follows a set of coupled non-linear differential equations, sometimes called 'Lotka-Volterra' or 'replicator dynamics', which represent the better ability of larger or well-established industries to capture the market, and the life expectancy of technologies.

The different technology diffusion rates result in path-dependent technology investment trajectories and power generation mixes. The power generation mix impacts electricity prices which feeds back to electricity demand in the E3ME model. Figure 3-1 summarises these connections.

Subsidies directed to the power sector and to different generation technologies change the relative costs of the technologies, investment into them and their take-up. Due to the path dependency of technology investment, power sector subsidies can affect the power generation mix even once the subsidies have been removed.

Figure 3-1 FTT:Power model: basic structure



Scenarios

To model the impact of power sector subsidies on installed generation, the FTT:Power model is used as an ex-post simulation tool, run over a historical period. Three scenarios have been constructed to capture the full impact of the subsidies, for each country and technology:

- *Observed power sector development (Baseline):* This scenario is a calibrated endogenous model run capturing the observed historical power sector development. It serves as a reference point to quantify the role of subsidies in the observed capacity changes. The power generation mix in the model has been calibrated to match published power generation and capacity data ((Eurostat, 2020), (Eurostat, 2020) and (International Energy Agency, 2018));
- *Removing only fossil fuel subsidies for power generation (Fossil fuel subsidies removed):* This is a counterfactual scenario, in which the model is run without the set of fossil fuel subsidies in place during the historical period (as collected in Task 3.1). This model simulation captures an alternative power sector development pathway which would have happened if fossil fuel subsidies had not been introduced;
- *Removing all subsidies (fossil fuel + renewable subsidies) (All subsidies removed):* This is a counterfactual scenario, in which the model is run without the full set of fossil fuel and renewable subsidies in place during the historical period (as collected in Task 3.1). This model simulation captures an alternative power sector development pathway that would have happened without the introduction of any fossil fuel and renewable subsidies.

By comparing the power generation mix and the installed capacities in the counterfactual scenarios and observed baseline, it is possible to identify the impact of subsidies over the observed timeframe. Effects are calculated for each generation technology in the model and for all EU27 and non-EU G20 countries where the data coverage is sufficient. This analysis covers all direct subsidies that are applied to the power generation sector. Subsidies affecting energy efficiency and energy demand from the wider economy are not included

- *The impact of fossil fuel subsidies* can be estimated by comparing the installed capacities and the power generation mix in the Fossil fuels removed scenario (the counterfactual scenario without fossil fuel subsidies) and Baseline (the observed outcomes);
- *The net effect of renewable and fossil fuel subsidies* can be estimated by comparing the installed capacities and the power generation mix in the All subsidies removed scenario (the

counterfactual scenario without fossil fuel and renewable subsidies) and the Baseline (observed outcomes).

The model results therefore help us to identify the impact of fossil fuel subsidies on the take-up of renewable technologies in the power sector and the role that renewable subsidies have played in encouraging renewable take up.

Calibration

The baseline results from the FTT:Power scenarios are calibrated to match historical electricity capacity data from Eurostat and the IRENA, and historical electricity generation data from the IEA.[6] In essence, this process involves calculating a 'calibration factor', namely the ratio between the values from the historical data and the results from the FTT:Power baseline scenario. The FTT:Power results for each scenario are then scaled up (or down) by this calibration factor to produce the calibrated results.

3.1.2 Processing the power sector subsidies - scenario inputs

Data processing

The power sector subsidies used as scenario inputs for the modelling form a selected subset of the subsidies dataset compiled in Task 3.1. Box 3-1 describes how power sector subsidies were selected and processed to be used as modelling input for the analysis.

Box 3-1 Processing the power sector subsidies

Selecting and processing the power sector subsidies

The following subset of the *subsidy database* have been used:

- Power sector subsidies were used from the energy conversion, electricity sector, which covers the subsidies applied directly to power generation technologies. This excludes investments in transmission infrastructure or back-up power generation, which do not relate to specific technologies.
- Both fossil fuel and renewables subsidies were used. Nuclear generation is excluded because it is neither a fossil fuel nor renewable technology. RES-Hydro subsidies were omitted from the analysis because they predominately reflect small hydro plants whereas the modelling in FTT:Power covers large hydro only. Subsidies with no specified source (all energy, electricity) and subsidies for hydrogen from fossil fuels were also omitted because of the imperfect match to FTT:Power technologies.
- Fossil fuel subsidies aimed at industry restructuring were not used because these policies aim to support the removal of existing fossil fuel infrastructure rather than promote fossil fuel take-up. The main scenarios consider how the direct subsidies change relative costs between technologies; therefore, these subsidies are omitted.
- Subsidies with no values for the timeframe even after the extrapolation were omitted.
- Subsidy values were deflated to a common 2018 price base and converted to millions of euros
-
- Table 3-1 shows the selected power sector subsidies for Belgium

[6] Eurostat was a preferred source for the G20 regions that it covers (the EU27 Member States, the UK and Turkey). For other regions, IRENA capacity data was used. Between these two data sources, however, there were significant gaps in capacity data, particularly in fossil fuel technologies in non-EU countries (since IRENA data only covers renewables). In these cases, we calculated a calibration factor by comparing IEA electricity generation data against FTT:Power generation results, and then applied this calibration factor to the FTT:Power capacity results to produce the calibrated capacity results.

Table 3-1 Excerpt from the selected power sector subsidies included in the modelling: Belgium (BE)

ID	Name of policy (English)	Fuel	Unit	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
BE	Strategic reserve	FF-All fossil fuels	2018 € M	293	232	233	188	130	21	22	26	17	18	47
BE	Green certificates - biomass	RES-Biomass (solid)	2018 € M	60	84	102	142	164	173	189	210	232	259	288
BE	Green certificates - solar	RES-Solar	2018 € M	282	305	365	364	417	405	340	383	410	411	371
BE	Green certificates - wind offshore	RES-Wind offshore	2018 € M	0	8	20	76	93	162	232	273	250	295	350
BE	Green certificates - wind onshore	RES-Wind onshore	2018 € M	0	0	0	0	0	0	9	46	46	15	29

Source: Own elaboration based on the subsidies data set

- Power sources listed in the subsidies data set were matched to the categories used in the FTT:Power model. In cases where the subsidies refer to multiple fossil fuel or renewable technologies the subsidies were distributed equally across the constituent technologies. The matching is shown in Table 3-2.
- For modelling purposes, the subsidies were separated into:
  - feed-in-tariffs/feed-in premiums and
  - other types of subsidies: grants, tax exemptions etc.
- The final modelling input is the value of the subsidies expressed as values per megawatt hour of existing generation.

Table 3-2 Energy technologies in the subsidies data set and the FTT-E3ME framework

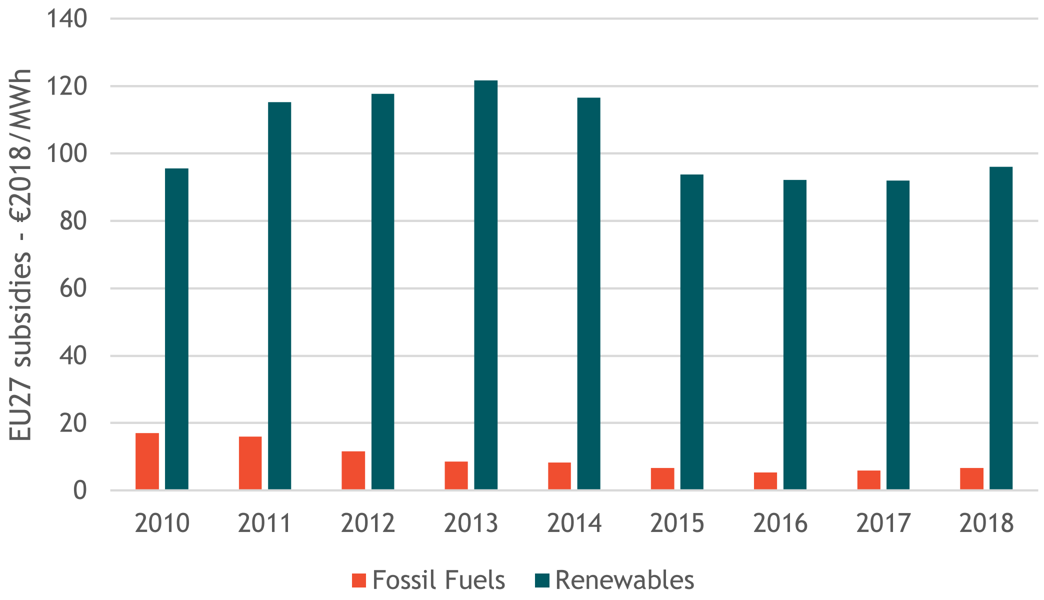
Subsidies Database	FTT-E3ME
FF-All fossil fuels	Coal, oil and natural gas
FF-Coal / Lignite	Coal
FF-Crude oil & NGL, FF-Petroleum products, FF-PP-Gasoil, FF-PP-Heavy fuel oil (HFO)	Oil
FF-Natural gas	Natural gas
RES-All	Biomass, biogas, solar, wind, BIGCC and geothermal
RES-Biogas	Biogas
RES-Biomass & biogas, RES-Liquid Biofuels-Biodiesel	Biomass and biogas
RES-Biomass (solid)	Solid Biomass
RES-Geothermal	Geothermal
RES-Solar	Solar PV
RES-Wind, RES-Wind onshore, RES-Wind offshore	Wind

Scenario inputs

This section summarises the modelling inputs for the power sector analysis, which were derived from the selected set of subsidies. The absolute value of subsidies does not illustrate well the strength of support to specific technologies across countries, because it masks the share of those technologies in the generation mix. Therefore, subsidies are presented here as euro values per megawatt hour of generation over the 2010-2018 period.[7]

Figure 3-2 and Figure 3-3 show weighted averages for renewable and fossil fuel subsidies in the EU27 and Non-EU G20 countries. Figure 3-2 shows that for the EU27 countries, support for renewables is substantially higher than the level of fossil fuel subsidies, with a slight decrease in both values over time. Figure 3-3 presents the same information for the Non-EU G20 countries, showing a generally lower level of power sector subsidies than for the EU27. While renewable support is higher than fossil fuel subsidies for this group as well, the difference between the two figures is not as large as in the EU27 case, which reflects the legacy of high levels of renewable support in early years. The level of fossil fuel subsidies slightly decreased over the observed period, but support for renewables in the power approximately doubled over the time frame, which is a substantial expansion.

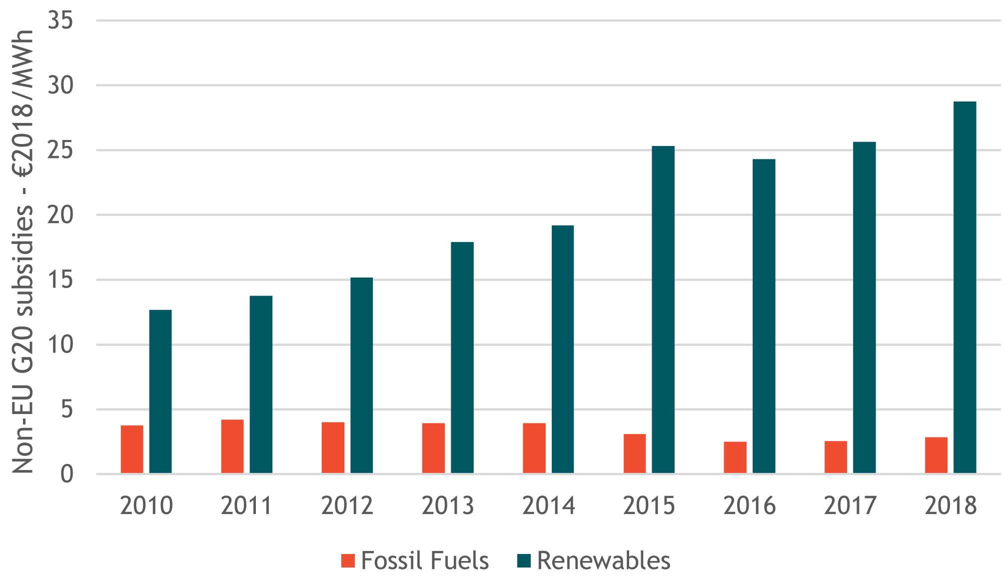
Figure 3-2 Average fossil fuel and renewable subsidies in the EU27, weighted



Source: Own calculation based on the subsidies data set

[7] Note that 2010 was the earliest available timeframe for which the FTT-E3ME model framework was possible to be initialised.

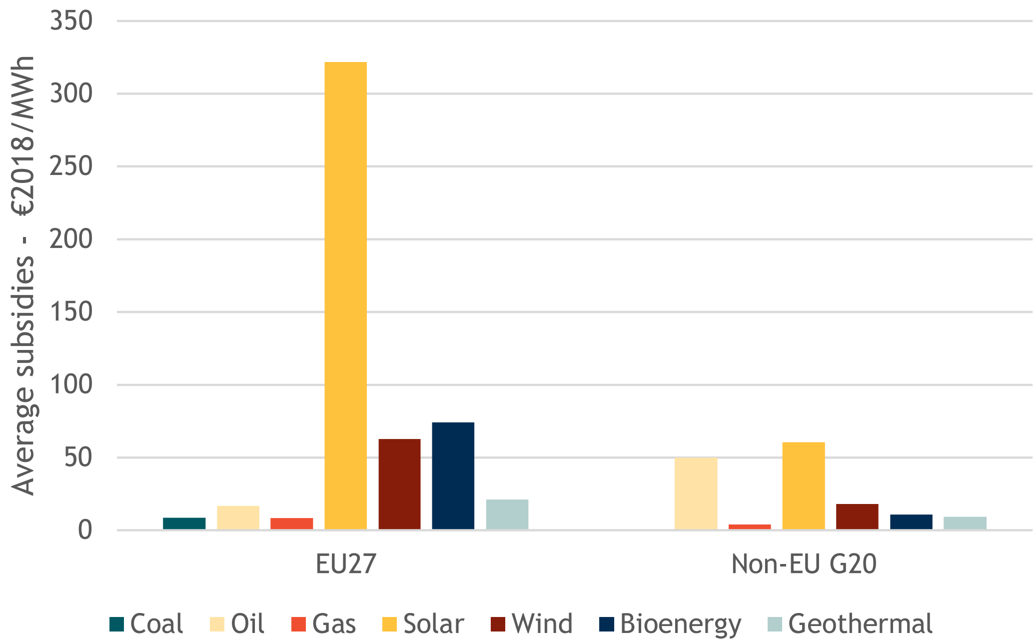
Figure 3-3 Average fossil fuel and renewable subsidies in the non-EU G20, weighted



Source: Own calculation based on the subsidies data set

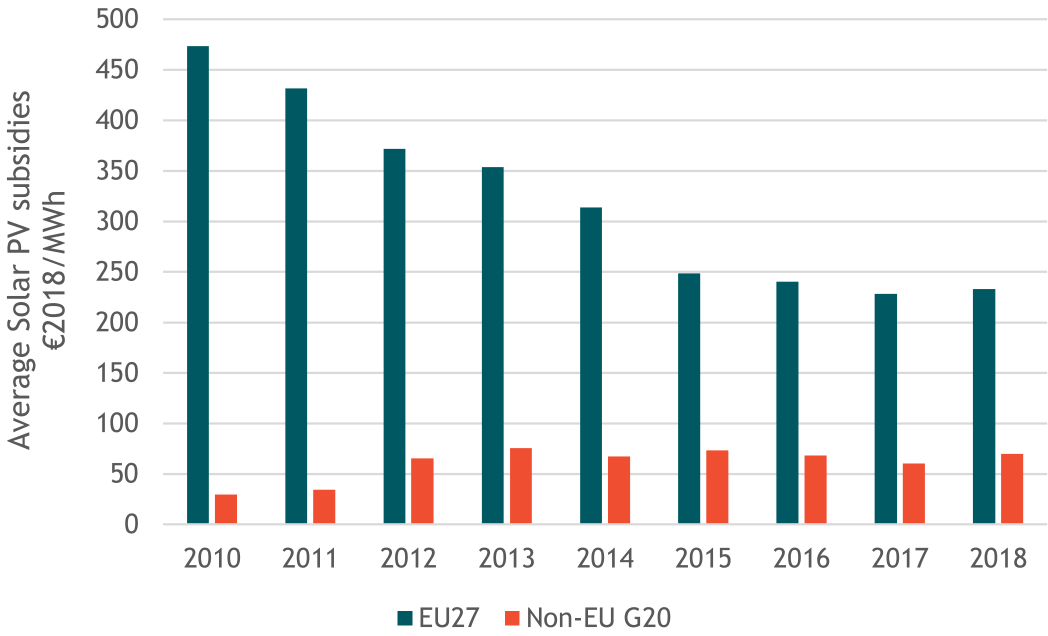
Figure 3-4 shows the average subsidies across power generation technologies for the EU27 and G20 groups, for the time frame analysed. It is visible that for the EU27 solar subsidies were the highest by a large margin, followed by wind and bioenergy. Solar subsidies are also highest for Non-EU G20 countries. Average subsidies for oil are high, but the average is dominated by strong support for oil in Saudi Arabia.

Figure 3-4 Average power sector subsidies as scenario inputs by technology 2010-2018, weighted



Source: Own calculation based on the subsidies data set

Figure 3-5 Average solar power generation subsidies, weighted



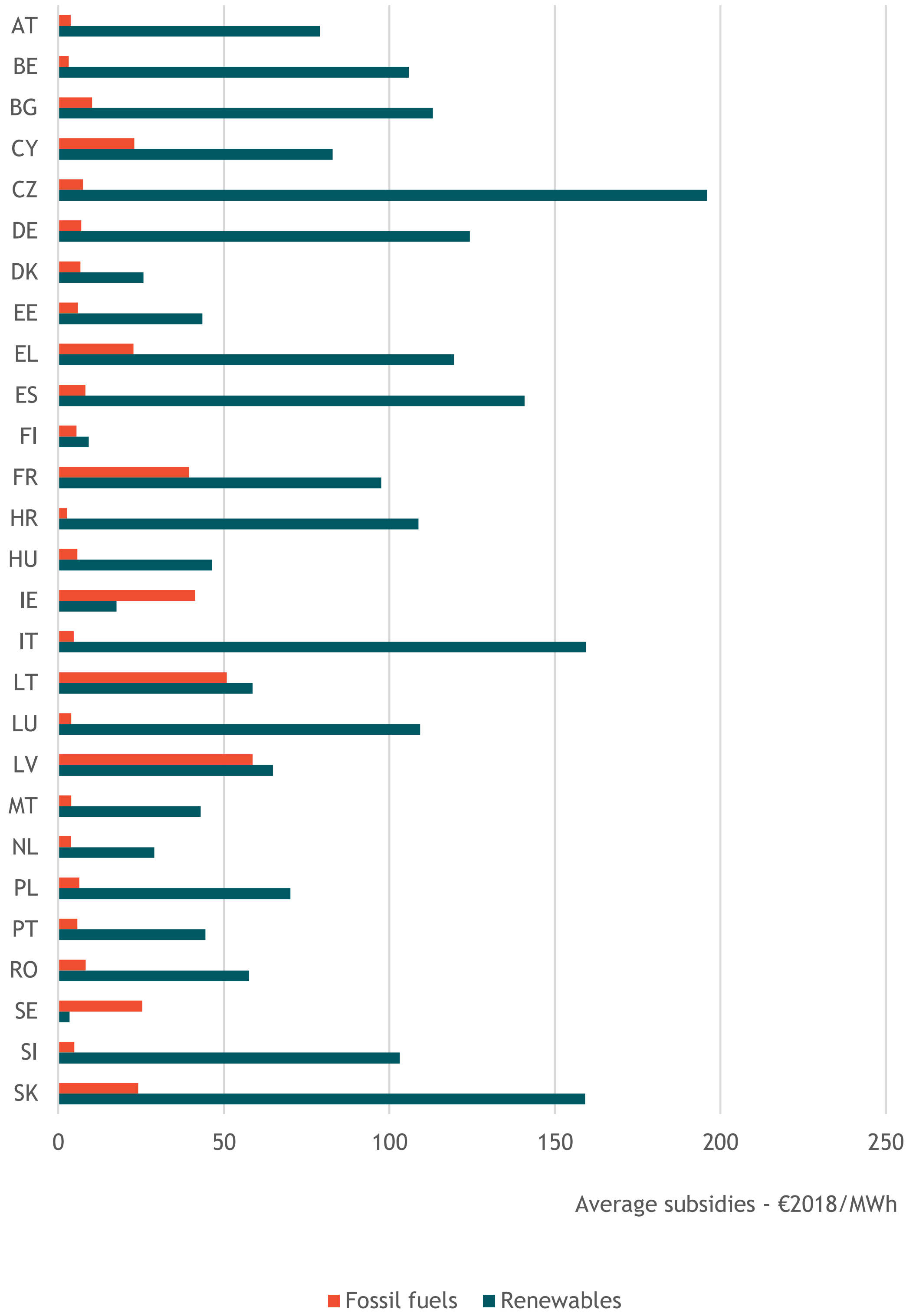
Source: Own calculation based on the subsidies data set

Figure 3-5 focuses on the evolution of the Solar PV subsidies for the EU27 and Non-EU G20 countries, which had the largest average level of support over the period. Although the average support for Solar PV has fallen for the EU27 it was still substantially higher than in Non-EU G20 countries in 2018. The high level of support in the EU27 is dominated by feed in tariffs and premiums provided across many member states.

Figure 3-6 and Figure 3-7 focus on the country level differences in the renewable share of power sector subsidies[8]. In the EU27, for most Member States, the average level of subsidies for renewables is much higher than for fossil fuels. There are some notable exceptions, including Ireland (IE) and Sweden (SE), where the support for fossil fuels was higher on average. In the case of Sweden, the overall level of fossil fuel generation is quite low because the generation mix is already dominated by hydro and nuclear so the support to the small amount of Fossil fuels in the generation mix is relatively high and additional support for other renewables is not required. However, in Ireland fossil fuels make up a large share of capacity. Figure 3-7 shows that for Non-EU G20 countries the coverage of subsides is sparser, especially for fossil fuels. While fossil fuel subsidies are only reported for two countries, renewable subsidies are reported for almost all of the non-EU G20 countries. However, for some countries the coverage over time is limited; e.g. for China subsidies are only reported for 2015 onwards. It should be noted that known missing data (e.g. the limited timeframe for China) and uneven data quality (e.g. for China data have been provided only by the central government and not by state level governments unlike in the United States) are limitations to this modelling exercise, affecting especially the non-EU G20 countries in our sample.

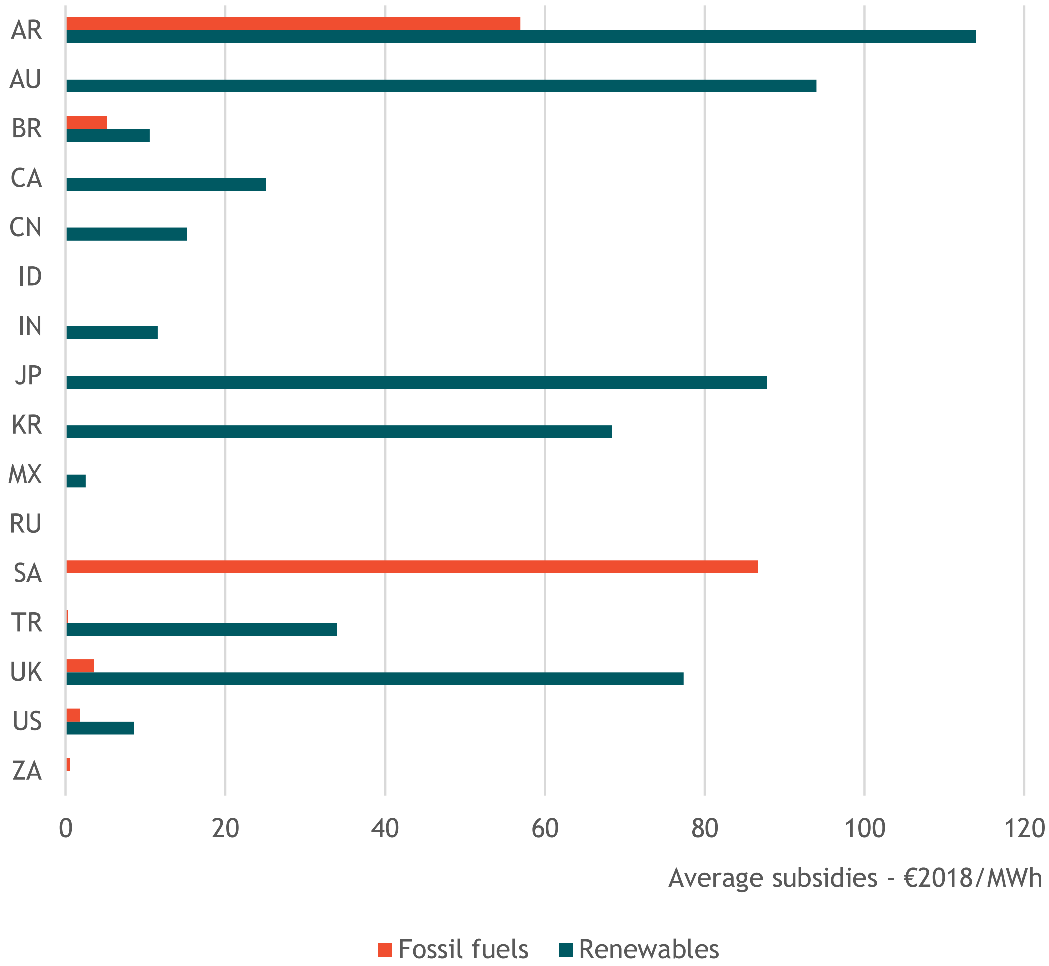
[8] Note that the subsidy values were averaged for each country over the years when at least one type of subsidy was observed.

Figure 3-6 Average fossil fuel and renewable subsidies by country in the EU27, weighted



Source: Own calculation based on the subsidies data set

Figure 3-7 Average fossil fuel and renewable subsidies by country in the Non-EU G20, weighted



Source: Own calculation based on the subsidies data set

3.1.3 Results

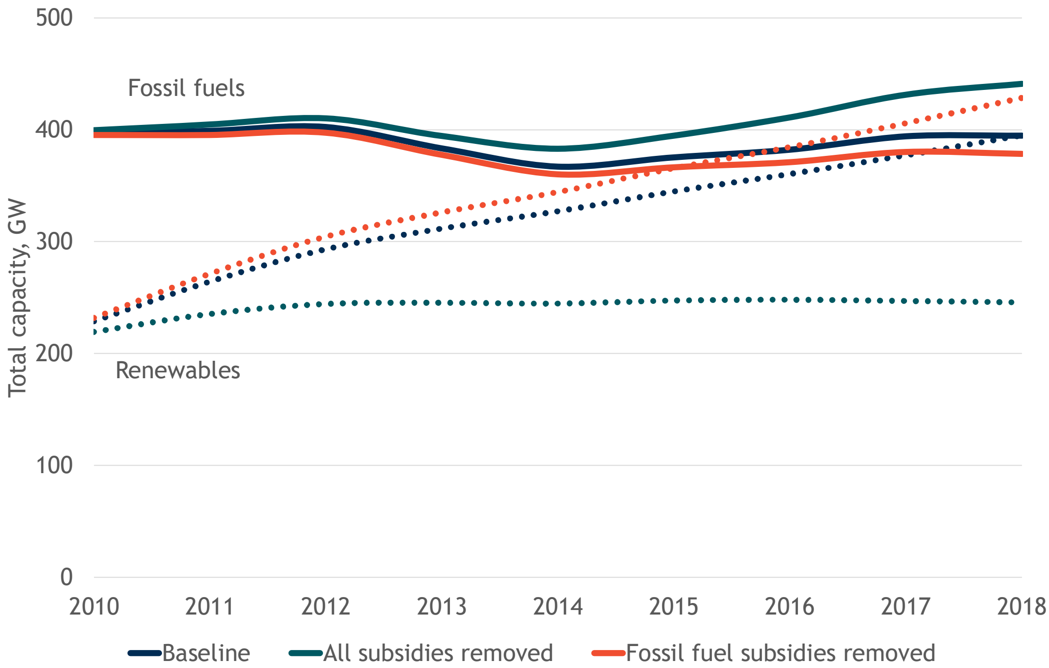
The results suggest that fossil fuel subsidies have generally had a negligible effect on technology take-up rates in the power generation sector in the EU27 and G20. This can be seen by the similar trajectories of the 'Baseline' and 'Fossil fuels subsidies removed' scenarios in Figure 3-8 and Figure 3-9. The largest effect was on EU27 renewables, which would have seen an extra 8% capacity added over the forecast period, relative to the baseline, had fossil fuel subsidies been removed.[9] It is important to recall here that only subsidies that directly promote the uptake of given technologies were included in the analysis (for example subsidies to prevent coal mine closures, despite being fossil fuel subsidies, were not included).

Renewable subsidies were found to have had a much more marked effect in encouraging the take-up of renewables. Had these subsidies been removed (as in the 'All subsidies removed' scenario), the historically observed 'Baseline' growth in renewables would not have materialised and renewable capacity would have been 40% lower by 2018.

[9] We included hydro, wind, solar, bioenergy, tide/wave and geothermal power among 'renewable' technologies, and oil, coal and gas power among 'fossil fuel' technologies. Nuclear power was not included in either category.

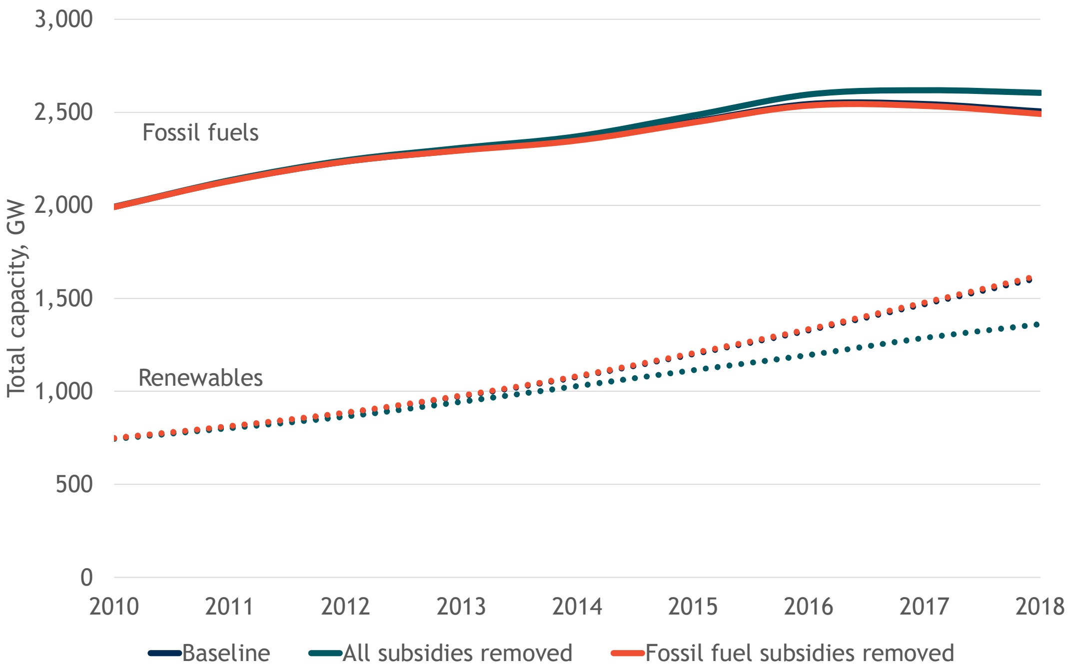
Our results suggest that renewable subsidies have played an important role in supporting the increase in renewable capacity over the period. Fossil fuel subsidies, meanwhile, did little to hinder renewables uptake in power generation over this period.

Figure 3-8 EU27 fossil fuels vs. renewables capacity, 2010-18



Source: Own calculation

Figure 3-9 Non-EU G20 fossil fuels vs. renewables capacity, 2010-18



Source: Own calculation

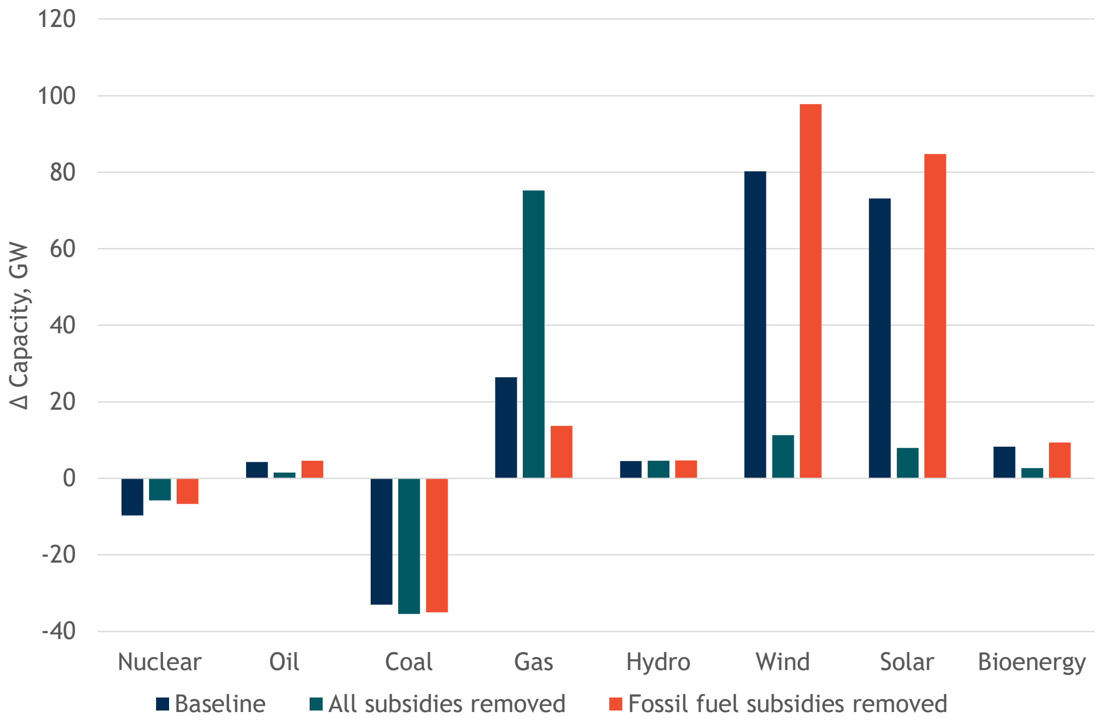
Impact of subsidies on generation capacity by technology

Looking at the impact of fossil fuel subsides on power generation technologies for the EU27, the modelling shows that removing the support for fossil fuel subsidies leads to a small increase in renewable technology capacity over the period. Most of the capacity increase is through wind and solar which see an average increase in capacity of 10% and 6%, respectively as shown in Figure 3-10. Across the fossil fuel technologies, we find a similarly small reduction of installed fossil fuel capacity which falls by around 2% mostly in coal and gas over the period.

Looking at the impact of all subsidies on generation capacity by technology, we find that solar and wind power are the most dependent on subsidies, either through feed-in-tariffs or other subsidy mechanisms. With the support of the subsidies as shown in the baseline, solar capacity increased by more than a factor of three in the baseline over 2010-2018 and wind capacity doubled over the period. When those subsidies are removed in the all subsidies removed scenario, the uptake of capacity is reduced considerably for both technologies.

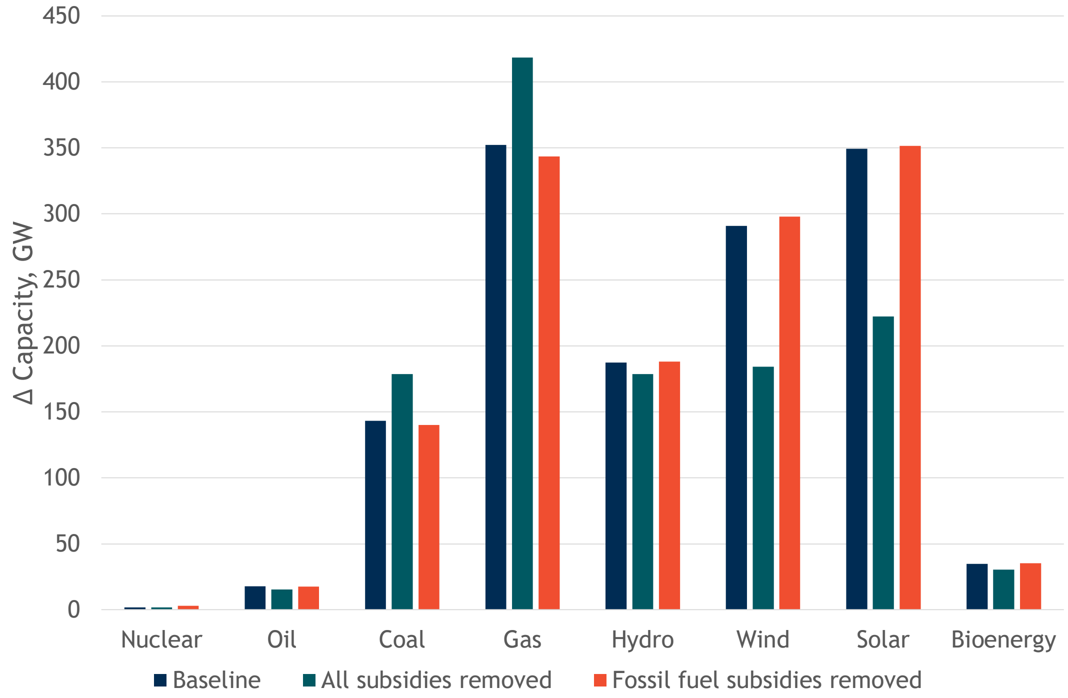
In the EU27, gas capacity would increase to substitute for some of the lost renewable capacity if all subsidies were removed.

Figure 3-10 EU27 change in capacity by technology, GW, 2010-18



Source: Own calculation

Figure 3-11 Non-EU G20 change in capacity by technology, GW, 2010-18



Source: Own calculation

For other non-EU G20 countries, as shown in Figure 3-7 the coverage of fossil fuel subsidies reported in the subsidies database are more limited and so for most countries there are no fossil fuel subsidies observed. As such we are unable to capture any substantial impact on the removal of fossil fuel subsidies for the non-EU G20 countries as a whole. For the few countries where the fossil fuel subsidies were reported, the removal of these subsidies has a very limited impact as shown in Figure 3-11.

For renewable subsides, where there is a more comprehensive coverage, we can model the impact of removing renewable subsidies on non-EU G20 countries. As with the EU27, we find that take-up of wind and solar is reliant on the support of renewable subsidies.

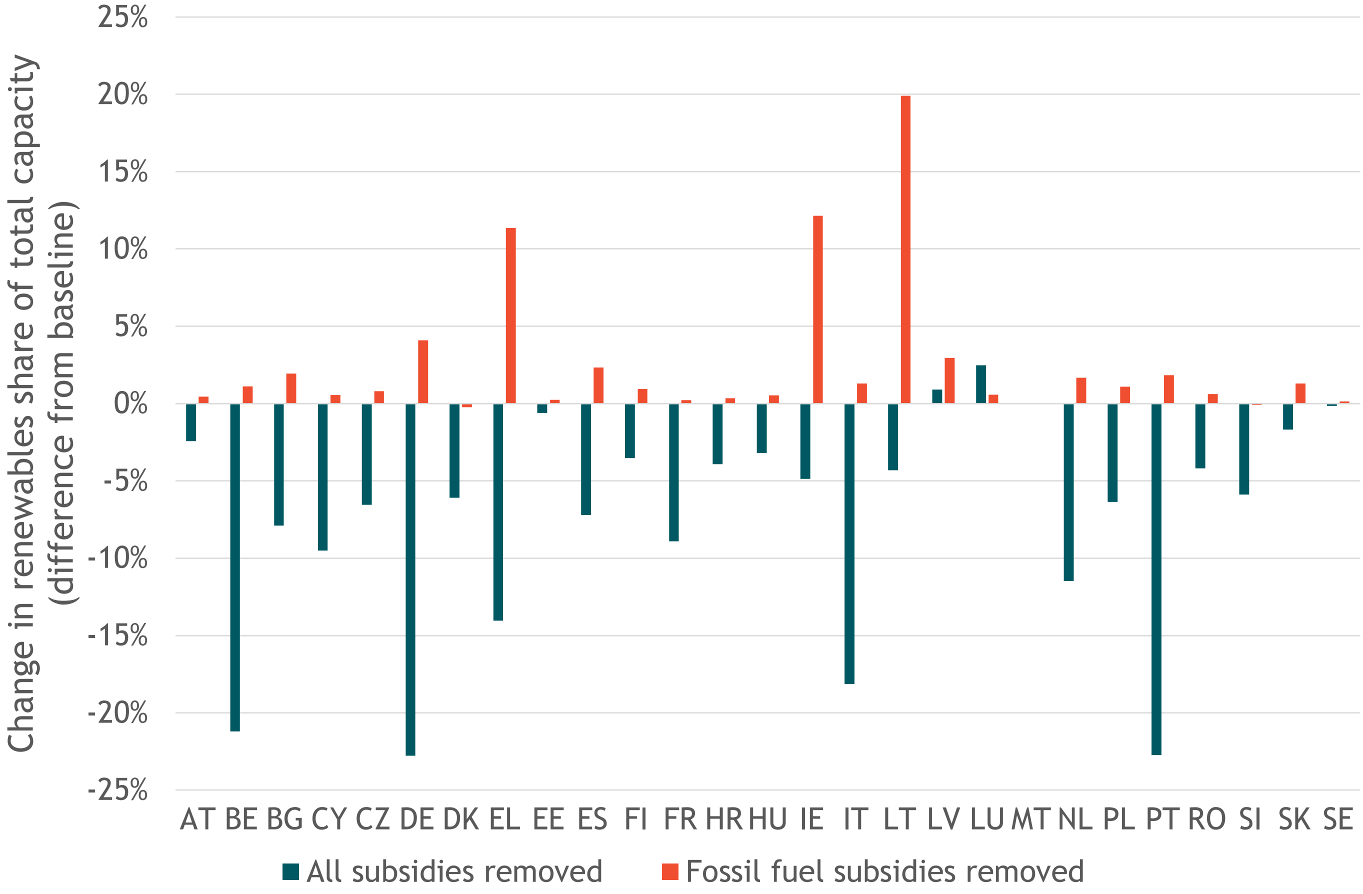
Impact of subsidies on generation capacity by country

Figure 3-12 shows how the removal of subsidies would impact the share of renewables in total capacity in 2018. The results show that many EU27 Member States followed the same pattern as the EU27 aggregate, in that renewable subsidies had a substantially larger impact on uptake of renewable capacity than fossil fuel subsides.

From the fossil fuel subsidies scenario, the results suggest that fossil fuel subsides had a limited impact on the uptake of renewable capacity in most Member States. There are a few notable exceptions to this finding, including Ireland which has a higher average rate of fossil fuel subsidy and a relatively large share of fossil fuels in the generation mix (which if removed would allow further take-up of wind). Lithuania also has a particularly high level of fossil fuel support which, if removed, would encourage additional wind capacity.

If renewable subsidies were also removed, it would lead to a substantial reduction in the share of renewables in total capacity across most Member States. The Member States that see the largest impact from removing renewable subsidies include Germany, Portugal, and Italy (which have all seen high uptakes of wind or solar capacity over the period supported by high feed-in-tariffs. Belgium also saw a substantial impact on renewable subsidies; in particular the Green Certificate scheme supporting wind and solar.

Figure 3-12 EU27 change in capacity share of renewables by member state, 2010-18



Source: Own calculation

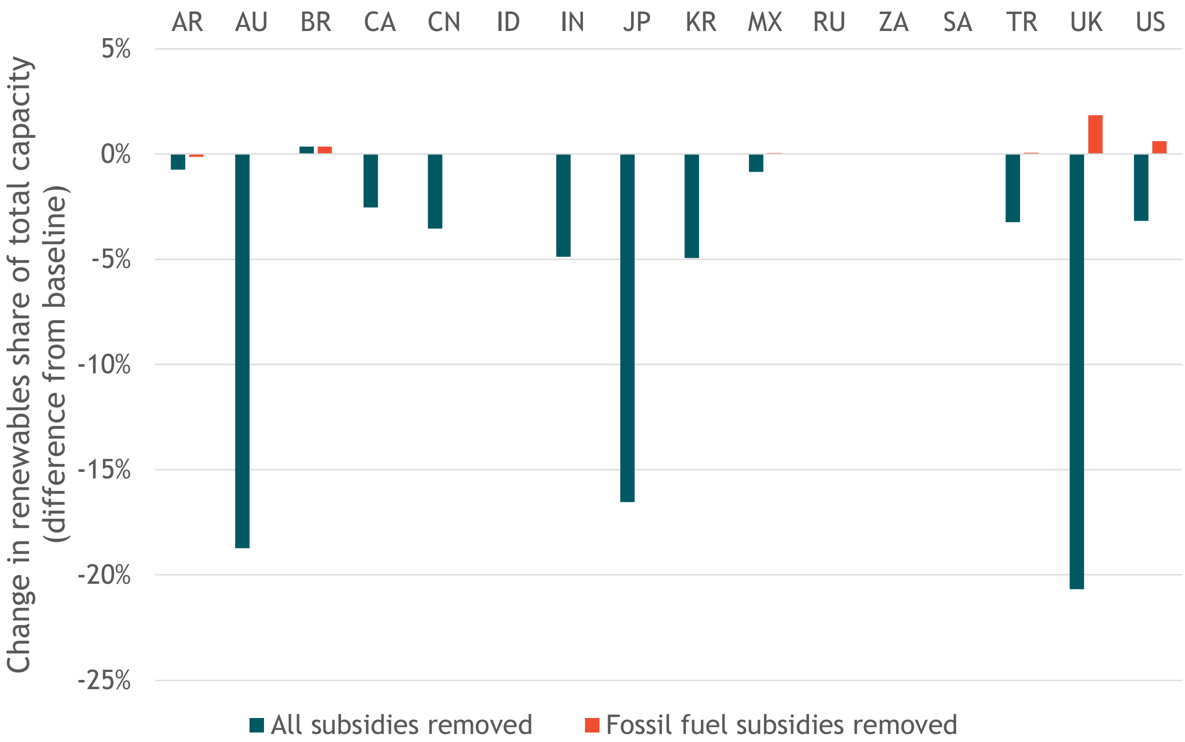
For the non-EU G20 countries, we only observed subsidies for fossil fuel support for a few countries, so the analysis of individual countries is limited. For the countries that do have data for fossil fuel subsidies, the impact on renewable capacity share is small (see Figure 3-13).

The low impact of fossil fuel subsidies reflects countries where fossil fuel subsidies are high, either:

1. The observed take-up of renewable capacity was low, which means that even if fossil fuel support is removed, renewables are not well enough established to attract investment. This is the case for countries such as Argentina and Saudi Arabia;
2. Alternatively, there are countries for which the average level of fossil fuel support is relatively low, and so removing it does not have a substantial impact on the relative cost of technologies. This is the case for the US and the UK.

When renewable subsidies are removed, the modelling shows substantial reductions in the capacity share of renewables for several non-EU regions. There are large reductions in capacity observed for Australia, Japan, and the UK, which all have large feed-in-tariffs for wind and/or solar in line with much of the EU27.

Figure 3-13 Non-EU G20 difference from baseline in capacity share of renewables by region, 2018



Source: Own calculation

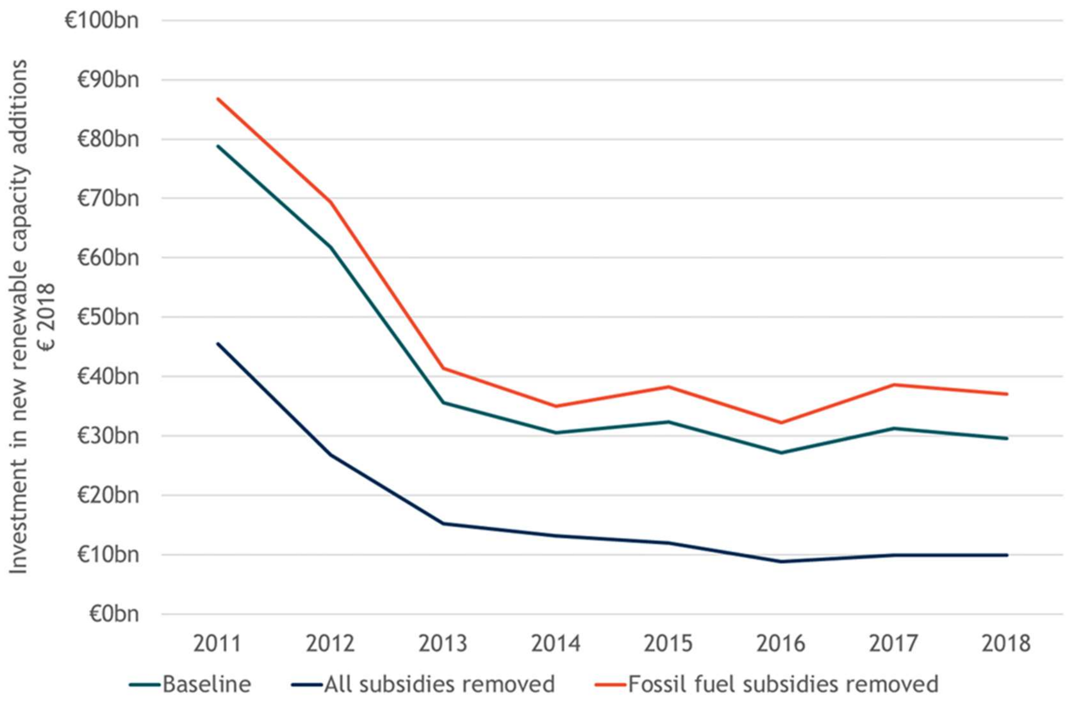
Impact of subsidies on investment in new capacity

To look at the investment in new capacity in monetary terms, we calculated from FTT:Power the annual change in capacity of each technology and multiply it by the investment cost for each unit of capacity.

Figure 3-14 shows the modelled impact of subsidies on annual investment in renewable capacity for the EU27. The figure shows that the impact of fossil fuel subsidies on hindering renewable investments was relatively consistent over the period in absolute terms; annual investment in renewable capacity would have been between €4.5bn and €8.5bn higher if fossil fuel subsidies were removed over the period.

The impact of renewables subsidies was also fairly consistent on the impact on annual investment in renewable capacity. Without renewable support, annual investment would have fallen sharply across the period, with the largest impact at the start of the period when investment in renewable capacity was highest, due to a combination of high investment costs combined with the high levels of renewable support in many Member States. The investment in new capacity would have remained substantially lower across the whole period. As shown in Figure 3-2, the average level of renewable support for renewables has remained relatively high over the whole period, which has helped to support the continued investment in renewable capacity.

Figure 3-14 Impact of Subsidies on investment in net renewable capacity additions in EU27



Source: Own calculation

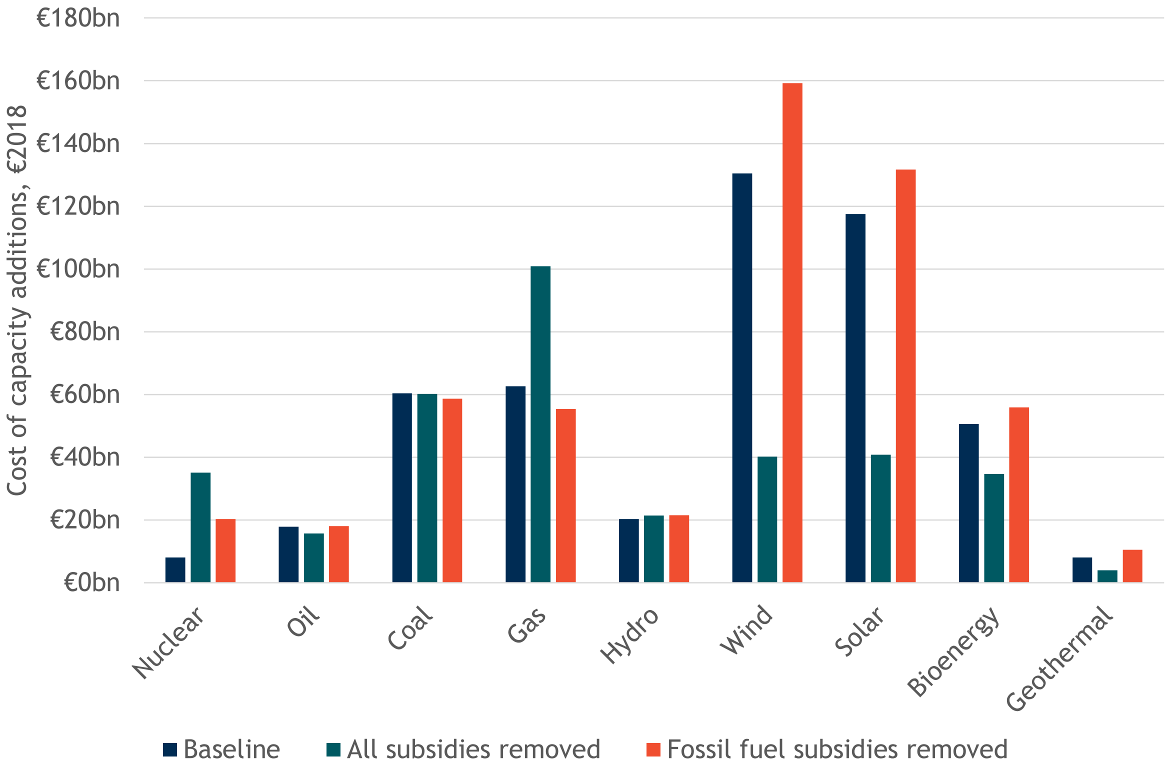
To look at the impact on investment across technologies and countries, we have summed up capacity additions to get a measure of cumulative investment in new capacity from 2010-2018, as shown in Figure 3-15 and Figure 3-16.

For the EU27, when fossil fuel subsidies are removed investment in renewable capacity over the period increases by around 7% relative to the baseline, with most of the additional investment coming from additional wind capacity, followed by solar. When all subsidies are removed for the EU27, the investment in new capacity in renewables reduces substantially, by around 60% relative to baseline. Most of the investment that would be forgone without subsidies is in solar and wind capacity. The removal of large renewables subsidies discourages further take up of additional renewable capacity. Without the uptake of renewables in the period, investments in additional gas capacity would be required. Investment in gas would be more than double the investment in gas capacity estimated in the baseline. Gas is preferred to coal partly because of lower build-time, but also its potential role in grid balancing.

Figure 3-17 shows the impact of subsidies on investment for G20 countries. The estimated impact of fossil fuel subsidies on investment in renewable capacity was relatively limited for most countries, reflecting the very few reported subsidies for fossil fuels. Even for the few countries where support is reported, such as the UK and US, the impact on cumulative investment in renewables was marginal.

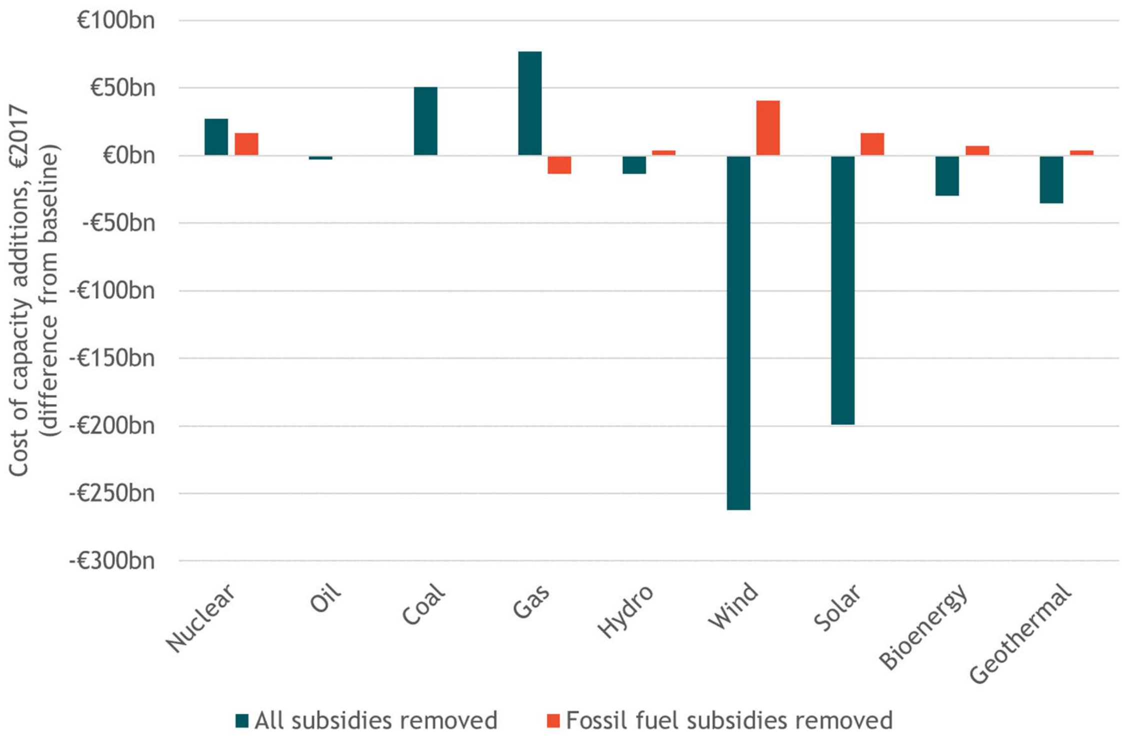
When renewable subsidies are removed in the all subsidies removed scenario, some G20 countries see a sharp reduction in investment in renewable capacity. The largest reductions are in Australia, Japan, Korea and the UK. From these four countries, solar saw the largest reduction in investment, except for the UK where wind investment was a larger share of overall renewable investment capacity.

Figure 3-15 EU27 Cumulative investment in capacity by technology, 2010-18



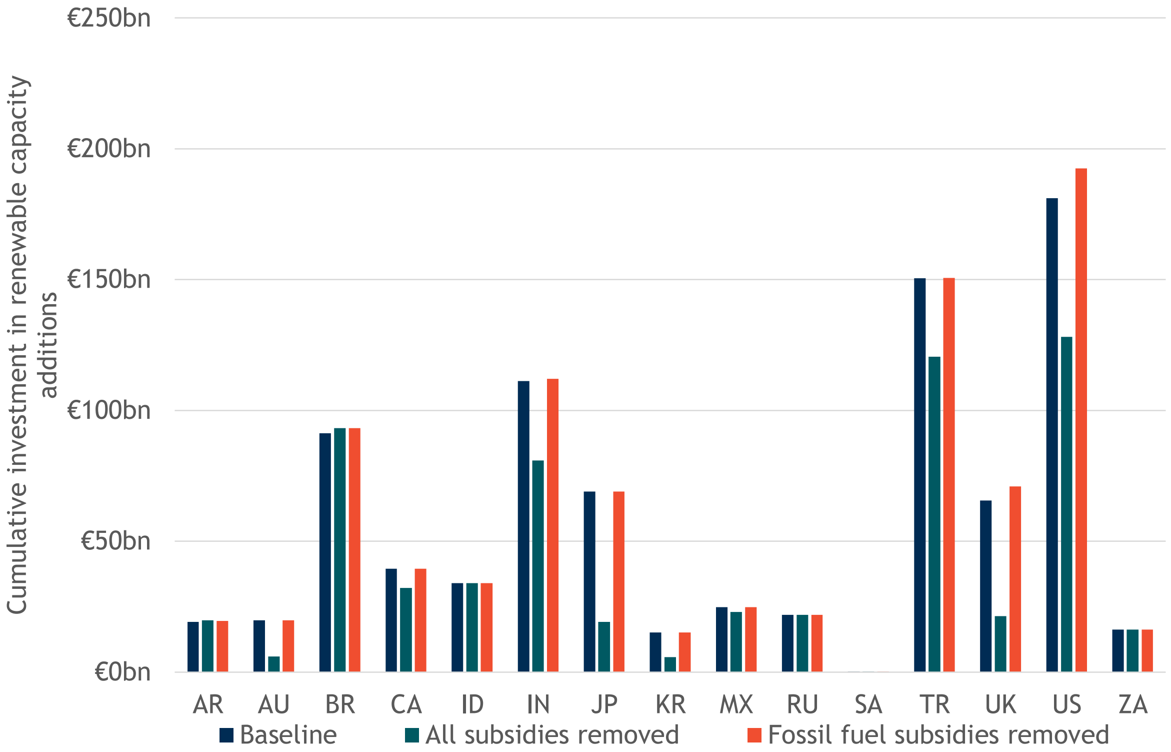
Source: Own calculation

Figure 3-16 EU27 Cumulative investment in capacity additions by technology, 2010-18, difference from baseline



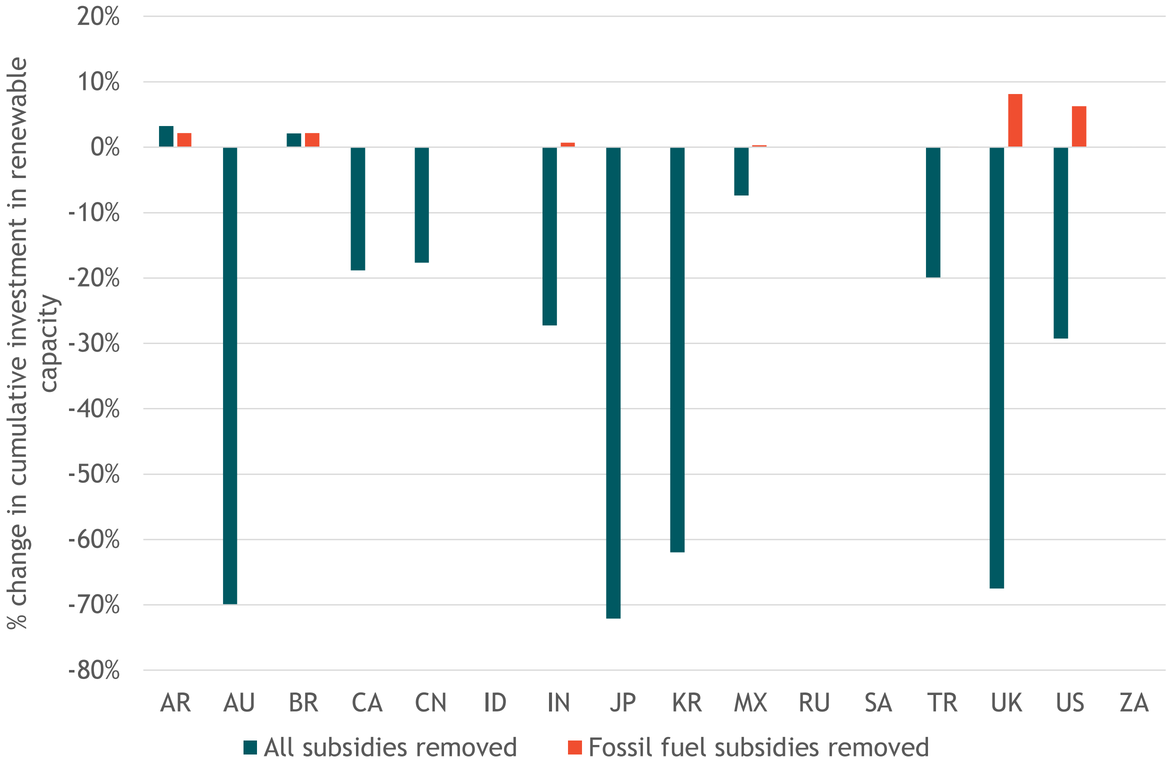
Source: Own calculation

Figure 3-17 Non-EU G20 investment renewable capacity additions by country, 2010-18



Source: Own calculation

Figure 3-18 Non-EU G20 cost of capacity additions by technology, 2010-18, difference from baseline



Source: Own calculation

3.1.4 Key messages

- Overall, the modelling results suggest that the fossil fuel subsidies have had a limited impact on hindering the installation of new renewable generation in the EU27, as total installed capacity of renewable generation would only be 6% higher by 2018 if fossil subsides were removed. This finding reflects that for most EU countries, the average level of support for fossil fuels was relatively small and so the removal of that support would not have a sufficient impact on the relative cost competitiveness of renewables compared to fossil fuel technologies;
- For G20 countries, there was limited coverage of fossil subsidies but where they were reported, their expected impact on the uptake of renewables in the power sector was relatively limited; either reflecting that the average level of support was too small to have a significant impact or that renewables were not well enough established to attract investment anyway;
- The modelling suggests that renewable subsidies had a much larger impact on supporting investment in renewable capacity across most of the EU27 and G20. For the EU27, without renewable subsidies, the growth in renewable capacity observed would have been 40% less;
- The largest changes in renewable capacity in response to the subsidies were in wind and solar, which have seen substantial growth in capacity, supported by high levels of subsidies across the EU27 and many G20 countries.

3.2 Overview of sector case studies

The following sub-chapters present three case studies that explore the relationship between subsidies and the investment in (or take-up of) low-carbon technologies across several sectors of the economy. The selection of case studies was data driven, determined by the collected information on investments in Task 8.1. The following topics are explored:

- *Fossil fuel extraction:* Do government interventions and subsidies affect the level of total investments in fossil fuel extraction and production?
- *Transport electrification: electric vehicle (EV) take-up:* Do subsidies for EVs impact the take-up of electric passenger car vehicles?
- *Heating of buildings: heat pump take-up:* Do fossil fuel, renewable and other energy efficiency subsidies for the heating of buildings have an impact on the take-up of heat pumps?

These three case studies explore the dynamics of subsidies and low-carbon investments, technology take-up in different segments of the economy. Along with the power sector analysis, these help to give a comprehensive picture on the impact and effectiveness of different subsidies.

3.2.1 Approach

As a first step, the relevant subset of investments and subsidies was selected for each case study, based on the data collection from earlier tasks (Task 3.1, Task 8.1). The data were brought to a consistent format (e.g. currency) and a processed data set was compiled for the analysis. Then the following steps were taken to better understand the key patterns, as described below:

- Descriptive statistics, visualisation, assessment of data gaps;
- Econometric analysis, regressions.

Descriptive statistics, visualisation, *assessment of data gaps*

A set of graphs and tables was created to identify the key trends and developments of investments and subsidies. Besides giving a good understanding of the data patterns and co-movements, this step also provides grounds to decide whether the data quality is good enough to proceed with a more sophisticated econometric analysis. Missing country-year observations can reduce the effective sample size to the level that regressions cannot draw robust conclusions. In these cases, data visualisation and descriptive statistics remain the core methods of the analysis. Based on our assessment of the sample size, regression analysis could be implemented for the fossil fuel extraction and heat pump case studies but not for the EV take-up analysis.

Econometric analysis, regressions

Where the sample size and the quality of the data were considered good enough, econometric analysis was undertaken to untangle the relationship between subsidies and investments.

General approach

Our model in its most general form tries to capture the effect of subsidies on investments/take-up using regression on a country-year panel data. As illustrated in the equation below, this effect is captured by the parameter $\boldsymbol{\beta_1}$. To ensure that $\boldsymbol{\beta_1}$ truly measures the impact of subsidies, other control variables have been introduced to the model to filter tendencies that can bias $\boldsymbol{\beta_1}$. Depending on the specification country (θ_i) and time (λ_t) effects may be also allowed to represent country-specific time invariant factors that influence the dynamics (e.g. level of fossil fuel resources) or shocks that affect all countries at the same time (e.g. global financial crisis).

Equation 1: General model

$$\boldsymbol{Y_{it} = \beta_0 + \beta_1\, Subsidies_{it} + Other\ Factors'_{it}\gamma + u_{it}} \quad with\ i: country,\ t: year$$

$Y_{it}:\ Investments_{it}\ or\ Sales_{it}$

$Other\ Factors'_{it}$: *a vector of control variables capturing economic conditions, prices or lagged impacts of the subsidy variable*

$u_{it} = \theta_i + \lambda_t + \varepsilon_{it}$

Consistency and robustness

To ensure the consistency of the results and the robustness of the estimated relationship, the following steps were implemented:

- *Multiple estimation methods tested:* From the available literature, several widely used estimation methods were considered for the analysis. Specification selection tests, error diagnostics and the conclusions of the literature gave guidance on which estimation method should be considered. Estimated impacts were also compared across models to ensure that the identified relationship is robust across models and well-understood. The following estimation methods were used in the analysis:
  - *Pooled OLS model.* The ordinary least squares method serves as a starting point for more sophisticated specifications and serves as a robust sense check;
  - *Panel Corrected Standard Errors (PCSE) model.* Recognising that the OLS specification might suffer from non-random errors (correlation within countries, across years, structure in variances) panel corrected standard errors have been used for adjustment;
  - *Fixed Effects (FE) panel model*. The fixed effects specification allows filtering for country and time-specific heterogeneity;

    - *Random Effects (RE) panel model.* Similarly to fixed effects, the random effects specification can also control for country and time fixed effects. Random effects estimation should be used if the independence between the error terms of entities is guaranteed, otherwise the fixed effects model is preferred. The Hausman test is used to assess whether this assumption is warranted.
- *Multiple specifications are tested for each estimation method:* Beyond using different estimation methods, each model is tested with a different set of control variables and lag structures to ensure that the best available model is selected. Omitted variable, model specification and multicollinearity tests were run to ensure the soundness of the selected models.
- *Error diagnostic:* To help select the best consistent estimation, error terms are systematically tested for non-random patterns and, wherever structure is detected, corrected errors are used.
    - *Autocorrelation:* time-dependence;
    - *Correlation within/across entities:* country effects;
    - *Heteroscedasticity:* structure in the error variance.

Validation

Even with the best effort it may be possible that no strong impacts are found in the analysis or that the impacts are difficult to understand or generalise. These problems could arise from the small size of the sample, the shortness of timeframe or undetected outliers. Whenever possible, as a quality control, the magnitude of impacts is checked against the literature to ensure credibility of the results.

3.3 Case study: Fossil fuel extraction

In 2009, the beginning of the timeframe analysed in this study, G20 leaders committed to “rationalise and phase out over the medium-term inefficient fossil fuel subsidies” including power sector, extraction, and consumption subsidies (OECD & IEA, 2020). Despite the fiscal strains on national budgets, adverse environmental impacts and international commitments, countries have been slow to eliminate such subsidies (see (Overseas Development Institute, 2017), (Carbon Brief, 2018) and (OECD & IEA, 2020). Fossil fuel extraction subsidies have remained in place in many countries across the world in the past decades. The usual arguments for the need for public expenditure are focused around energy security and affordability, keeping fuel prices low, preserving workplaces in the extraction sector and balancing the price competition created by cheap extraction in developing countries. However, based on the literature analysing this relationship, it is not clear whether these subsidies are truly efficient in attracting new investment to the sector and in boosting production (e.g. (Erickson, Down, Lazarus, & Koplow, 2017), (International Institute for Sustainable Development, 2010) (Rentschler & Bazilian, 2017)). Economic conditions determining resource prices and technological developments affecting the costs of extraction may be stronger drivers. Measuring whether and how much extraction subsidies affect investment and production is key to understanding the expected magnitude of the effects of those subsidies being phased out.

3.3.1 *Processing the extraction subsidies and investment data*

Box 3-2 explains the selection of coal, oil and gas extraction subsidies and investment included in the regression analysis, and the main steps in their processing.

Box 3-2 Processing the extraction subsidies and investment data

Selecting and processing the extraction data

The following subset of the *investment database* is used:

- *Extraction investment values* in € 2018 million values for coal, oil and gas were selected as our main investment indicator;
- Unlike the subsidies data set, this database does not include any estimates of missing values. To avoid picking up false shocks in the analysis, data gaps of at most two years were filled using the last/first available value or the simple average of the neighbours;
- Unfortunately, there are clear data gaps in the coal investment series. These series contain information for only nine countries and do not include large coal producers (e.g. the US, India, China). Therefore, when matched with subsidies data, coal subsidies were only considered for those countries for which data are available in the investment dataset (note that the figures included in Section 2 are also affected by this uneven data quality across fossil fuels);
- The coal, oil and gas extraction investment values were summed for each country year to give a total fossil fuel extraction investment value.

The following subset of the *subsidy database* is used:

- *Fossil fuel extraction subsidies* were used from the economic sectors: energy, energy-fossil fuel extraction and mining. Fossil fuel subsidies for industry restructuring were omitted because these subsidies aim to remove existing fossil fuel extraction;
- Wherever the original subsidy values are missing, they have been replaced with their estimated counterparts. Subsidies having no values for the timeframe even after the estimation were omitted;
- Subsidy values then were deflated to a common 2018 price base and converted to millions of euros;
- Table 3-3 shows a selected set of subsidies for Poland:

Table 3-3 Excerpt from the selected fossil fuel extraction subsidies included in the analysis: Poland (PL)

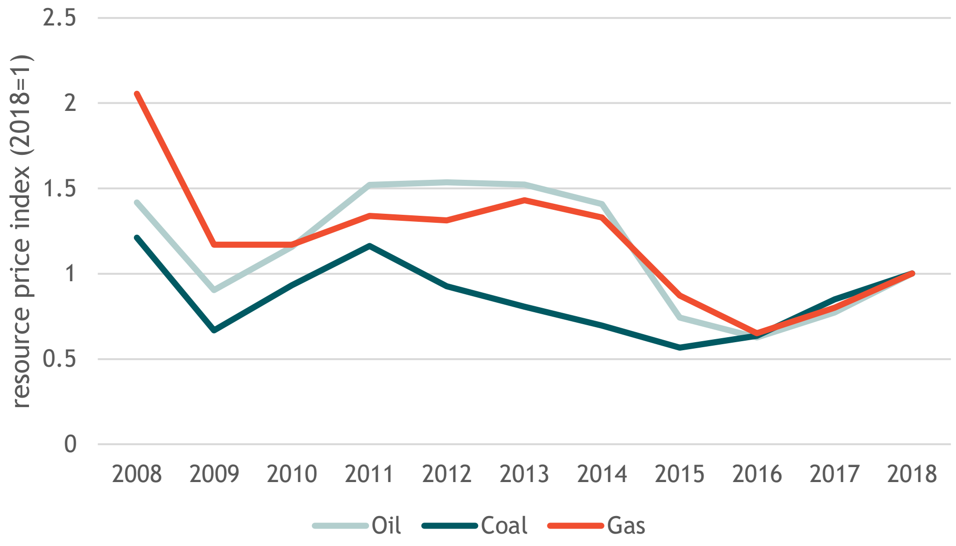
ID	Name of policy (English)	Economic sectors	Fuel	Unit	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
PL	Investment Aid for Coal Mining sector 2011-2015	Mining	FF-Coal / Lignite	2018 € m	0.0	0.0	109.8	107.3	103.1	104.8	102.0	108.1	0.0	0.0	0.0
PL	Investment Aid for Coal Mining sector 2015-2018	Mining	FF-Coal / Lignite	2018 € m	0.0	0.0	0.0	0.0	0.0	0.0	32.1	126.8	272.5	396.9	73.6
PL	Royalty exemption for hard coal mines	ENER-Fossil fuel extraction	FF-Coal / Lignite	2019 € m	0.7	0.8	1.4	0.7	0.6	0.5	0.6	0.7	0.5	0.6	0.0
PL	Reducing the nuisance resulting from the extraction of minerals	ENER-Fossil fuel extraction	FF-Coal / Lignite	2020 € m	4.5	2.4	8.3	4.8	1.7	4.4	0.0	0.0	0.0	0.0	0.0

Source: Own calculation based on the subsidies data set

- The selected subsidies were sense checked and omitted if they were not closely related to extraction activities (e.g. 'Public R&D expenditures for oil and gas'). This check ensures a conservative selection of the subsidies;

- As mentioned above, subsidies for coal extraction were dropped for those countries for which investment data were not collected (e.g. the US) to filter noise from the analysis;
- As a final step, subsidies for coal, oil and gas were summed to form a total fossil fuel subsidies value.

Figure 3-19 Coal, oil and gas prices



Source: Based on (World Bank, 2020)

Other variables used in the analysis to control for general economic conditions include GDP (World Bank, 2020) and coal, oil and gas prices, which are shown in Figure 3-19 (as an average of available prices for each resource turned into an index (World Bank, 2020)). While GDP captures the economic environment of a given country, resource prices represent global shocks for all countries. Both factors could be important drivers of extraction sector dynamics.

3.3.2 Descriptive analysis

Extraction investment and subsidies across countries

Table 3-4 and Table 3-5 shows the average yearly extraction subsidy and investment values for EU27 and non-EU G20 countries. The table includes many zero values, especially for extraction subsidies. Only 22 countries have observed fossil fuel subsidies while almost all of them invest in some form of fossil fuel extraction. It is difficult to know whether the zero observed values mean truly no subsidies or investments in place, or failure to observe their true value in a given country/year. While it is expected that the support for fossil fuel subsidies is losing ground in the EU countries, zero or low-value subsidies in some fossil fuel rich G20 countries might be caused by incomplete data coverage.

Table 3-4 and Table 3-5 also show that subsidies for EU27 and G20 countries in the data have very different characteristics and observed timeframes. Figure 3-20 and Figure 3-21 give a visualisation of the same information, and show the average subsidy and investment values for the 2008-2018 period.[10] Extraction subsidies and investments are not only more common for non-EU G20 countries but are

[10] Note that when calculating the average, the length of timeframe was set to the timeframe when data was observed in the figures. This way countries known to have a shorter observed timeframe (e.g.: China) can be better compared to countries having full timeframe (e.g.: USA). Naturally, in other cases this treatment might overweight short time series data, where zero observed values may mean true zero subsidies (e.g.: Finland). In these cases, **Error! Reference source not found.** gives the fullest information for comparison.

substantially larger too. Based on these indicators the US has the largest fossil fuel extraction investments, while Brazil, Russia and India introduced the highest subsidies. Australia and Canada show more balanced investment to subsidy ratios. Among European countries, the UK, Germany and Poland have the largest investment and subsidy values, while values for other countries are considerably smaller. In general, the fossil fuel extraction sector is a declining industry within the European Union, with a few exceptions. The UK subsidised oil and gas extraction in the North Sea to help its coal-to-gas switch in the power sector (IEA, 2019). Unlike the UK, Germany and Poland still have substantial (although decreasing) coal production (IEA, 2019). Poland's power sector is still heavily reliant on fossil fuels, especially on coal and lignite, which fuel more than half of its power generation (IEA, 2019).

Figure 3-22 and Figure 3-23 show the value of extraction investments and subsidies as a proportion of GDP, averaged over the period when data are observed. Figure 3-22 shows that subsidies as a share of GDP are small in the US. Saudi Arabia, Russia, Canada, and Australia have the largest investments relative to their GDP, and Russia, India and Mexico have the highest extraction subsidies relative to their incomes. A similar pattern shows up for the EU27 group as well. While in absolute terms Germany had the highest investments and subsidies, relative to GDP Romania and Poland dominate. Germany, along with other Member States, is lagging behind.

Table 3-4 Average yearly fossil fuel extraction investment and subsidies in the EU27 (2018 EUR millions) - 2008-2018

Country Code	Total		Average when observed		Observed	
	Subsidies	Investment	Subsidies	Investment	Subsidies	Investment
	2018 EUR millions					
AT	0	1,469	0	134	-	2008-2018
BE	0	43	0	4	-	2008-2018
BG	0	518	0	47	-	2008-2018
CY	0	446	0	41	-	2008-2018
CZ	0	239	0	22	-	2008-2018
DE	14,562	11,576	1,324	1,052	2008-2018	2008-2018
DK	0	9,725	0	884	-	2008-2018
EE	0	714	0	65	-	2008-2018
EL	0	459	0	42	-	2008-2018
ES	38	1,924	3	175	2008-2018	2008-2018
FI	7	0	1	0	2008-2009, 2015-2018	-
FR	29	3,071	4	279	2008-2012, 2017-2018	2008-2018
HR	0	1,766	0	161	2016-2018	2008-2018
HU	0	1,614	0	147	-	2008-2018
IE	5	5,012	2	456	2016-2018	2008-2018
IT	973	10,487	88	953	2008-2018	2008-2018
LT	0	172	0	16	-	2008-2018
LU	0	0	0	0	-	-
LV	0	31	0	3	-	2008-2018
MT	0	144	0	13	-	2008-2018
NL	0	21,619	0	1,965	-	2008-2018
PL	1,570	15,922	143	1,447	2008-2018	2008-2018
PT	0	270	0	25	-	2008-2018

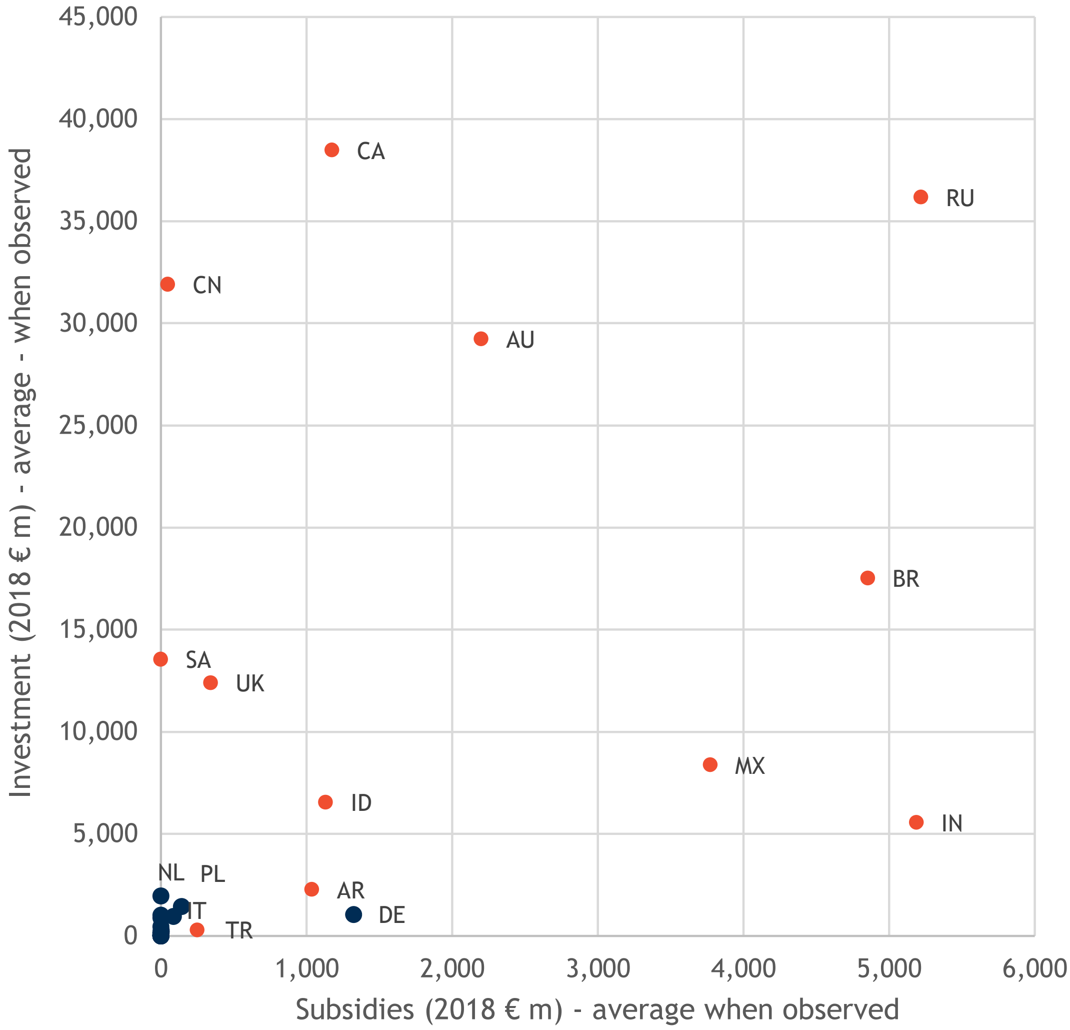
RO	0	11,176	0	1,016	-	2008-2018
SE	0	103	0	9	-	2008-2018
SI	0	422	0	38	-	2008-2018
SK	0	123	0	11	-	2008-2018

Source: Own calculation based on the subsidies and investment data sets

Country Code	Total		Average when observed		Observed	
	Subsidies	Investment	Subsidies	Investment	Subsidies	Investment
	2018 EUR millions					
AR	6,227	25,083	1,038	2,280	2013-2018	2008-2018
AU	24,200	321,593	2,200	29,236	2008-2018	2008-2018
BR	53,390	192,825	4,854	17,530	2008-2018	2008-2018
CA	12,926	423,204	1,175	38,473	2008-2018	2008-2018
CN	292	351,048	49	31,913	2011-2018	2008-2018
ID	12,444	71,945	1,131	6,540	2008-2018	2008-2018
IN	57,070	61,129	5,188	5,557	2008-2018	2008-2018
JP	0	1,455	0	132	-	2008-2018
KR	0	553	0	50	-	2008-2018
MX	18,862	92,186	3,772	8,381	2014-2018	2008-2018
RU	57,409	397,898	5,219	36,173	2008-2018	2008-2018
SA	0	149,093	0	13,554	-	2008-2018
TR	2,263	3,347	251	304	2010-2018	2008-2018
UK	3,769	136,347	343	12,395	2008-2018	2008-2018
US	13,450	1,371,714	1,223	124,701	2008-2018	2008-2018
ZA	0	2,089	0	190	-	2008-2018

Source: Own calculation based on the subsidies and investment data sets

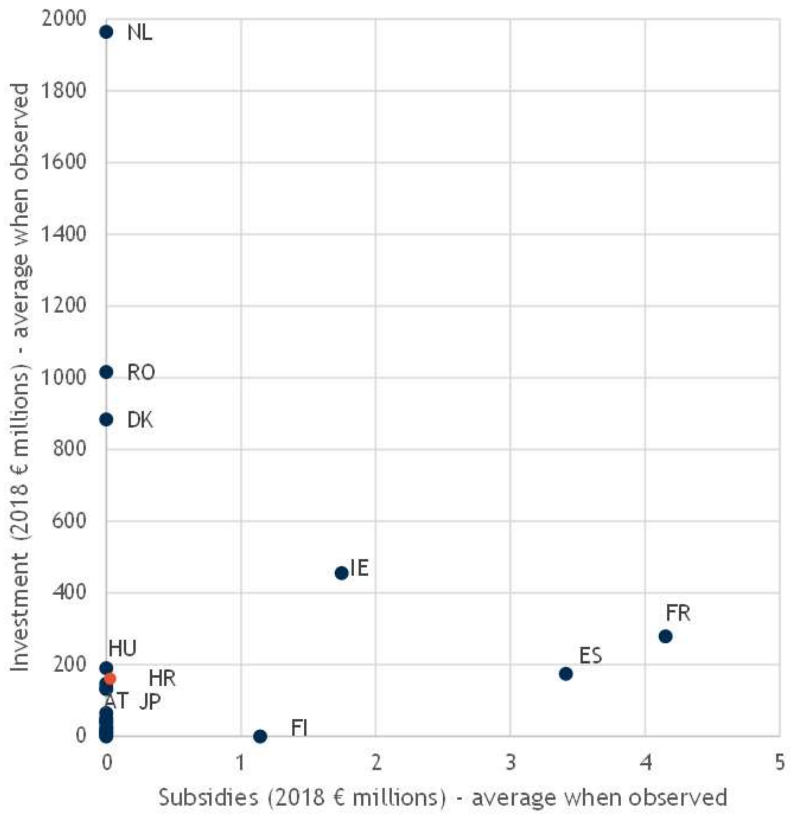
Figure 3-20 Average yearly fossil fuel extraction investment and subsidies (average over 2008-2018, for years when data is observed)



Note: Data on the US are excluded from the graphs for the better visibility of other data points. The US has exceptionally high absolute subsidy (1,223 million 2018) and investment values (124,701 million € 2018).

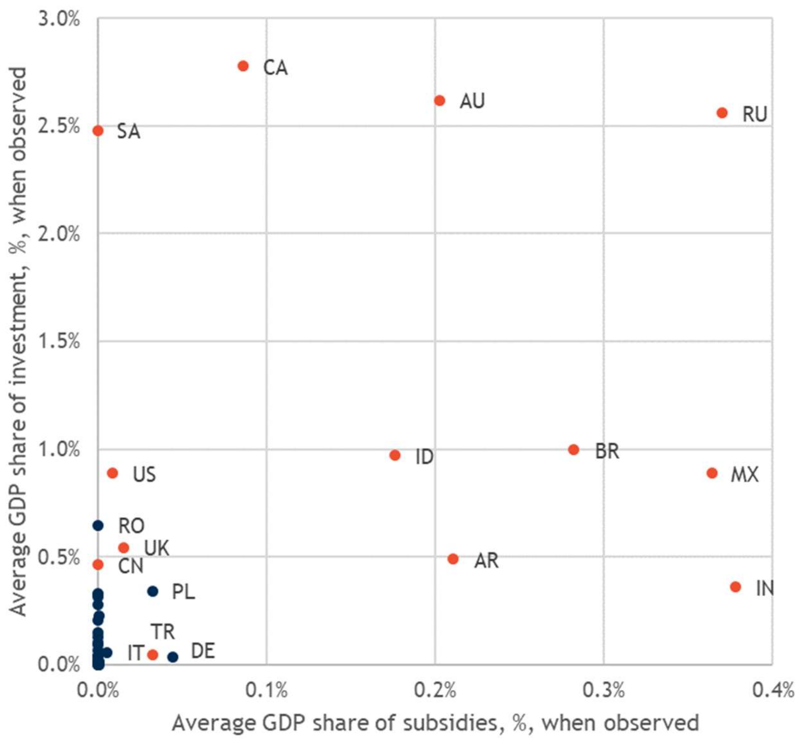
Source: Own calculation based on the subsidies and investment data sets

Figure 3-21 Average yearly fossil fuel extraction investment and subsidies, countries with small values



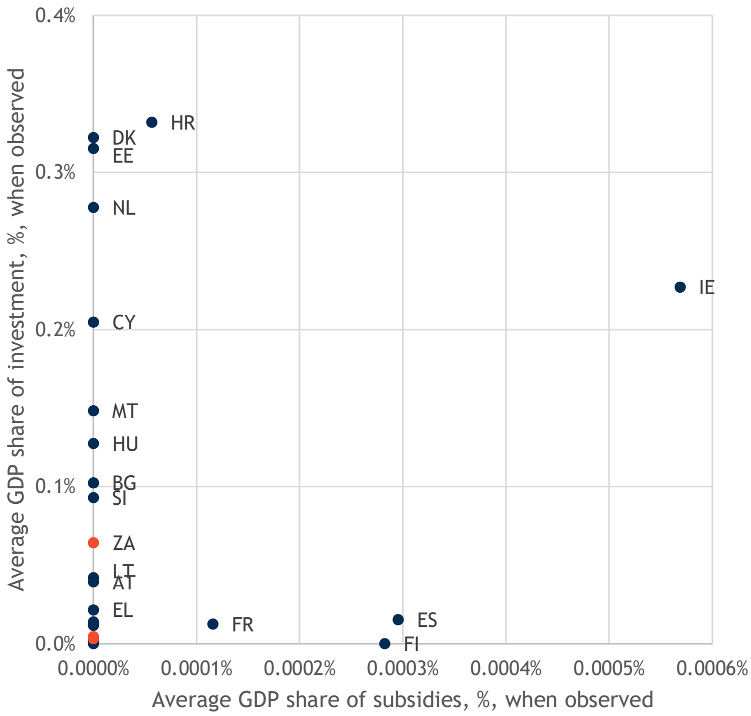
Note: Labels for countries with very small or zero subsidies and investments are not visible. The missing labels are: BE, BG, CY, CZ, EL, LT, LU, LV, MT, PT
Source: Own calculation based on the subsidies and investment data sets

Figure 3-22 GDP share of fossil fuel extraction investment and subsidies, %



Source: Own calculation based on the subsidies and investment data sets

Figure 3-23 GDP share of fossil fuel extraction investment and subsidies, small values, %



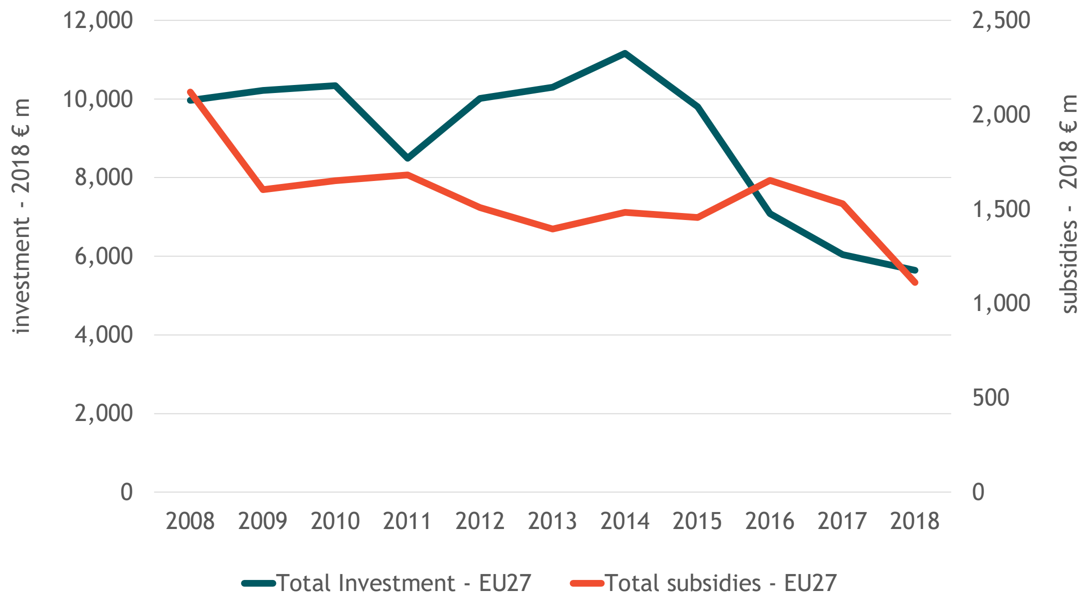
Note: Labels for countries with very small or zero subsidies and investments are not visible. The missing labels are: BE, FI, JP, KO, LU, PT, SK
Source: Own calculation based on the subsidies and investment data sets

Aggregate fossil fuel extraction investment and subsidies over time

Previous graphs gave an overview of subsidy and investment values compared between countries. Figure 3-24 and Figure 3-25 take a different angle and show the total investment and subsidy values over time. This helps to understand the co-movement of the two variables during the observed timeframe. The EU27 and G20 values are plotted separately to show patterns more clearly in the two groups. The series for both aggregate regions exhibit some co-movement, which is seemingly contemporaneous with no clear lag-lead dynamics between them. Interestingly, both country groups exhibit a peak in investments around 2014, which is not followed by the same dynamics in subsidies for the EU27, and subsidies drop at the same time for the Non-EU G20 countries. However, only limited insights can be drawn from this pooled graph because missing values and country-specific dynamics could underlie the patterns. Nevertheless, the visible co-movement provides a promising starting point for the regressions.

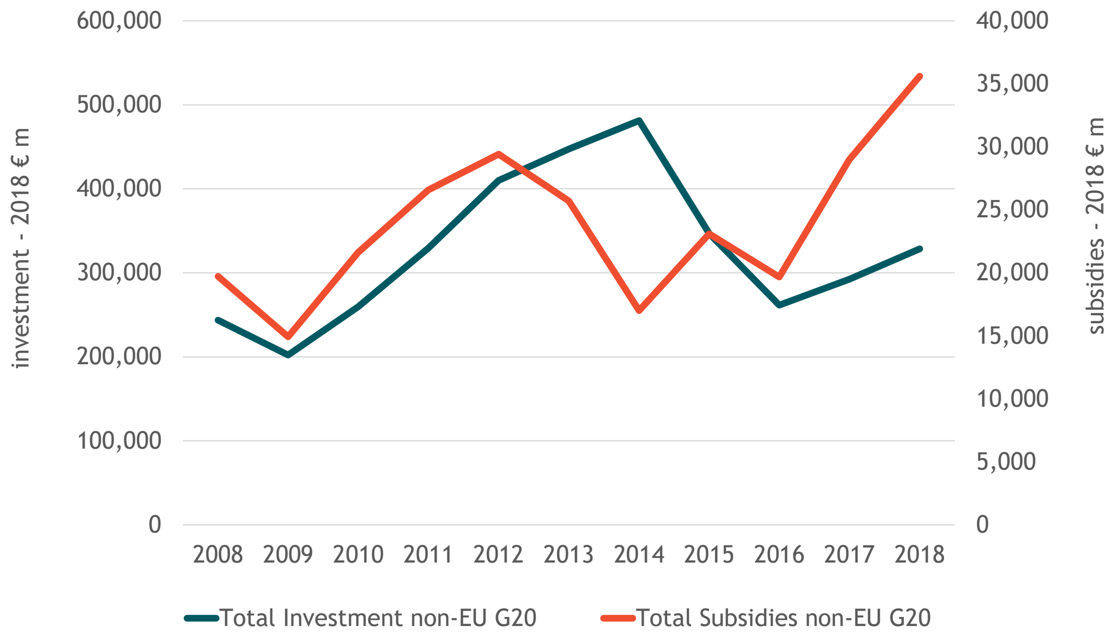
Figure 3-26 and Figure 3-27 show the extraction investment values for coal, oil, and gas for the EU and Non-EU G20 country group. The figures show that coal has little weight in the observed investment data. While for the EU27 both oil and gas investment play a role in the aggregate patterns, for the Non-EU G20 countries oil investment clearly dominates (in the subsidies data set the three fuel types cannot be clearly separated, and are therefore not shown). The separation of the subsidies by fuel also suggests a link between resource prices (Figure 3-19) and investment especially in the case of oil where the incidence of a peak in 2014 is reflected in both series.

Figure 3-24 Total investment and subsidy values for the EU27, 2018 € millions, 2008-2018



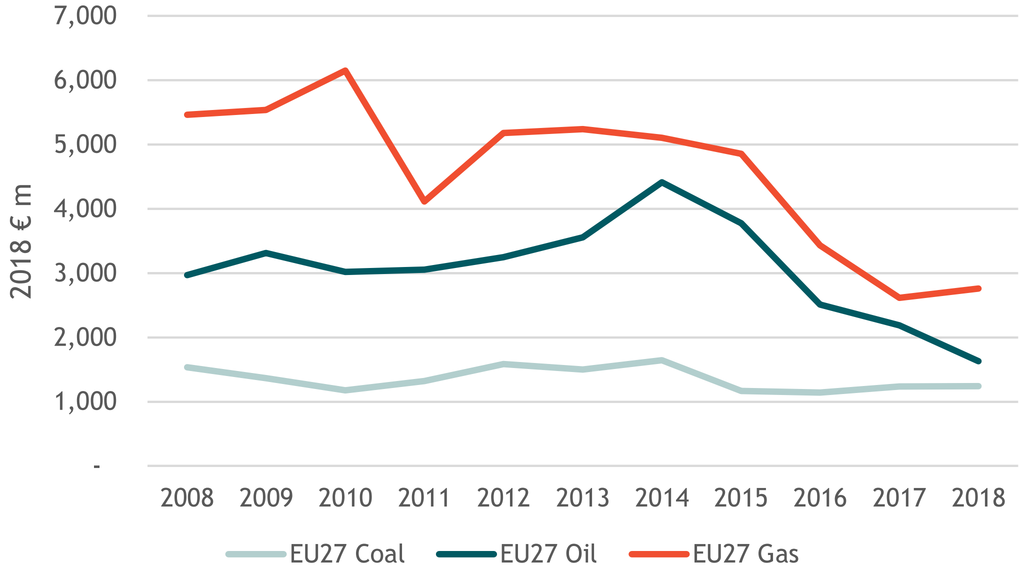
Source: Own calculation based on the subsidies and investment data sets

Figure 3-25 Total investment and subsidy values for the Non-EU G20, 2018 € millions, 2008-2018



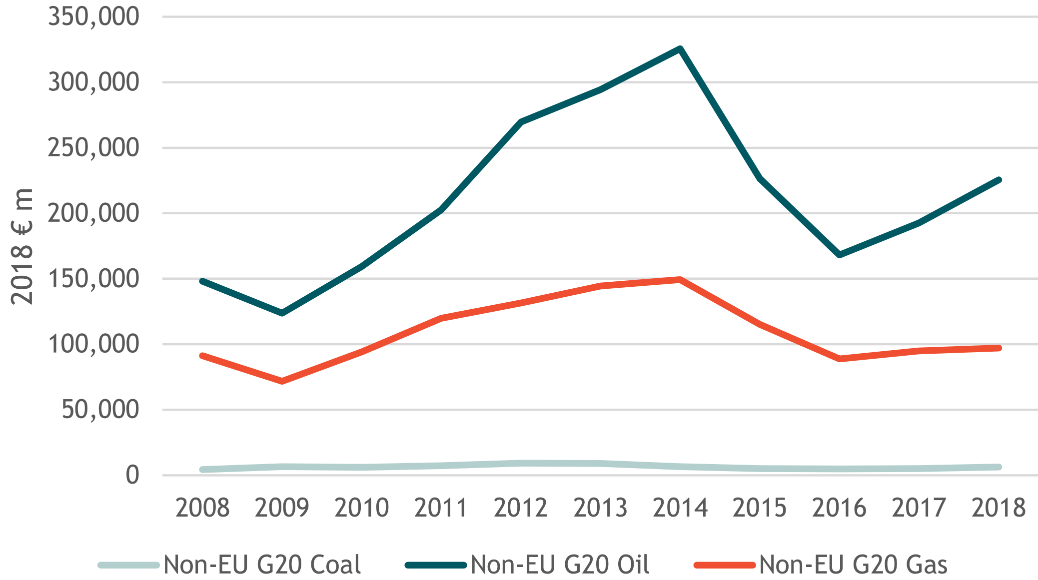
Source: Own calculation based on the subsidies and investment data sets

Figure 3-26 Total coal, oil and gas investments in the EU27



Source: Own calculation based on the subsidies and investment data sets

Figure 3-27 Total coal, oil and gas investments in the non-EU G20



Source: Own calculation based on the subsidies and investment data sets

Extraction investment and subsidies over time and across countries

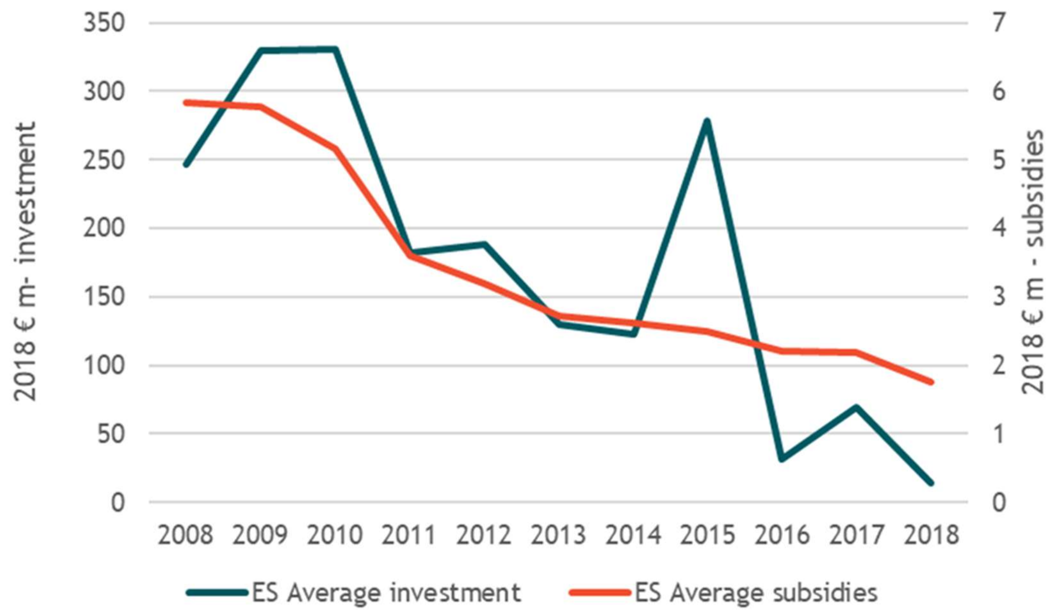
Moving beyond the pooled country and yearly dynamics, the following tables and charts illustrate country-specific trends over time. Table 3-6 shows the correlation between the investment and subsidies (and lagged subsidies) time series of countries with observed data, and reveals a mixed pattern across them. Figure 3-28 to Figure 3-31 visualise this conclusion and show that the relationship between the two variables may change country by country. Subsidies and investment for some countries show a contemporaneous or lagged co-movement, as shown by Spain and India. For other countries, negative correlations and mixed patterns seem to occur, e.g. in the UK and the US. The various observed dynamics across countries suggest that there might not be a strong uniform relationship between the investment and subsidies time series in this data set, but instead different pathways. This may stem from the differences in data availability on the subsidies and investment for countries in the sample. However, other variables might influence the evolution of investment and subsidies over time. For example, GDP and resource prices may affect investment decisions as well.

Table 3-6 Correlation between investment, subsidies and lagged subsidies (first and second lag), for countries with observed data for both indicators

Country Code	Country Group	Correlation investment, subsidies	investment, subsidies(t -1)	investment, subsidies(t -2)	investment, subsidies(-3)
DE	EU27	0.20	0.34	0.50	-0.40
ES	EU27	0.81	0.78	0.66	0.52
FR	EU27	-0.32	-0.01	0.84	0.53
HR	EU27	-0.99			
IE	EU27	-0.88			
IT	EU27	0.44	0.72	0.79	0.18
PL	EU27	0.28	-0.23	-0.23	-0.56
AR	non-EU G20	-0.32	0.78	0.47	0.98
AU	non-EU G20	0.48	0.59	0.48	-0.04
BR	non-EU G20	0.23	0.76	0.80	0.55
CA	non-EU G20	0.07	0.20	0.10	0.07
CN	non-EU G20	-0.75	-0.69	-0.13	0.37
ID	non-EU G20	0.08	0.51	0.73	0.46
IN	non-EU G20	0.04	0.58	0.78	0.37
MX	non-EU G20	-0.85	-0.60		
RU	non-EU G20	0.74	0.83	0.79	0.54
TR	non-EU G20	0.66	-0.22	-0.12	-0.14
UK	non-EU G20	-0.54	-0.38	-0.01	0.34
US	non-EU G20	-0.32	-0.56	-0.19	0.33

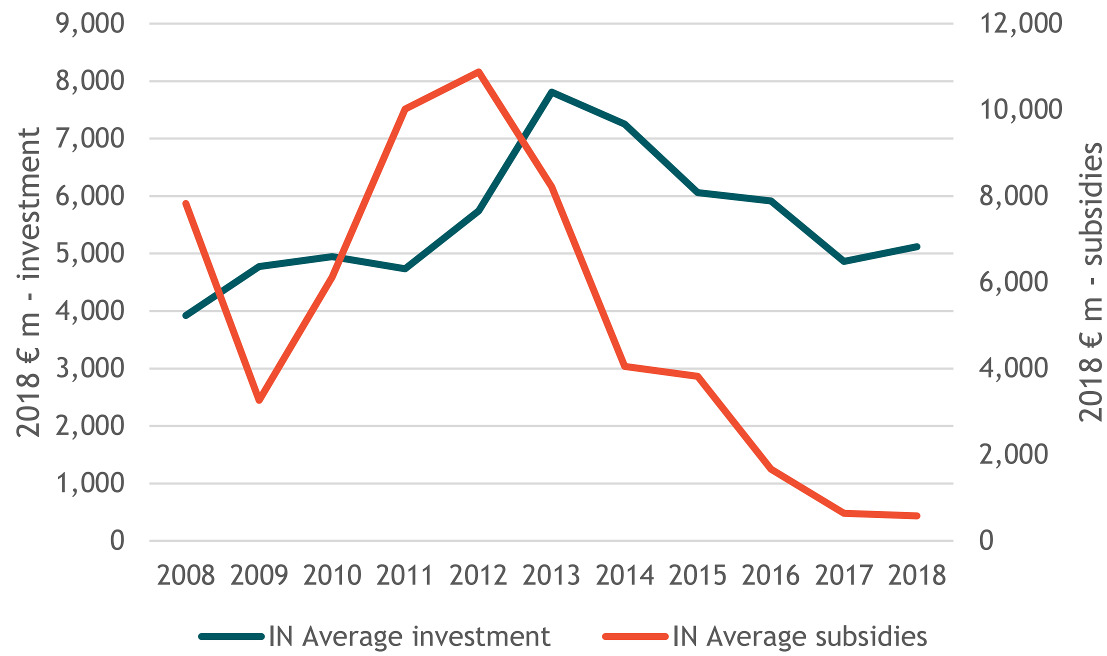
Note: Correlation between investment and subsidies(t-1) refers to the correlation between the investment and the lagged subsidies series (using the first lag). Similarly, subsidies(t-2) denotes the second lag of the subsidy series. Lagged dynamics aim to capture the delayed impacts of the extraction subsidies. Missing values mean that correlations could not be calculated due to the shortness of the time series
Source: Own calculation based on the subsidies and investment data sets

Figure 3-28 Co-movement, contemporaneous: Spain



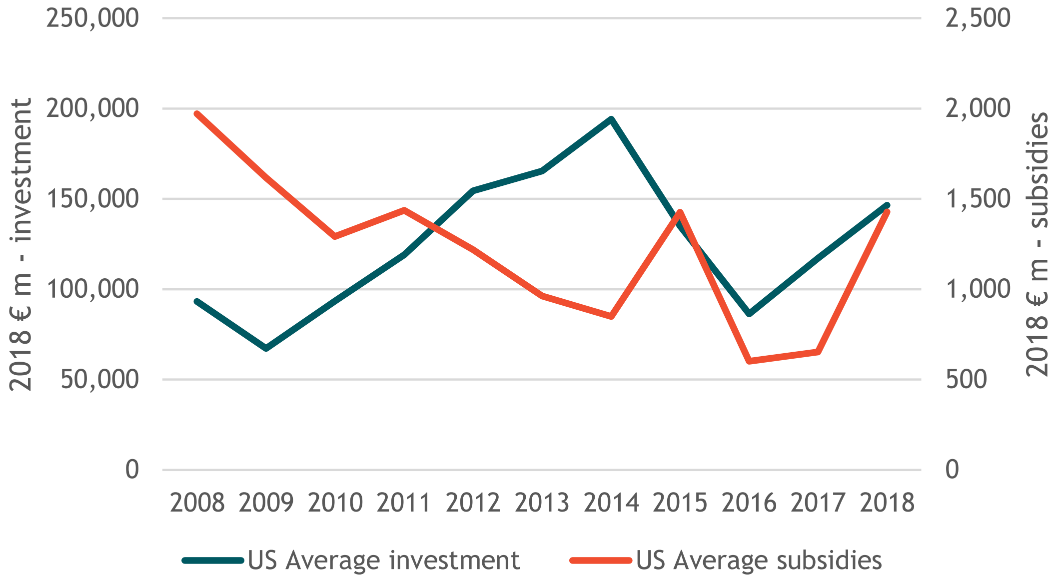
Source: Own calculation based on the subsidies and investment data sets

Figure 3-29 Co-movement, lagged dynamics: India



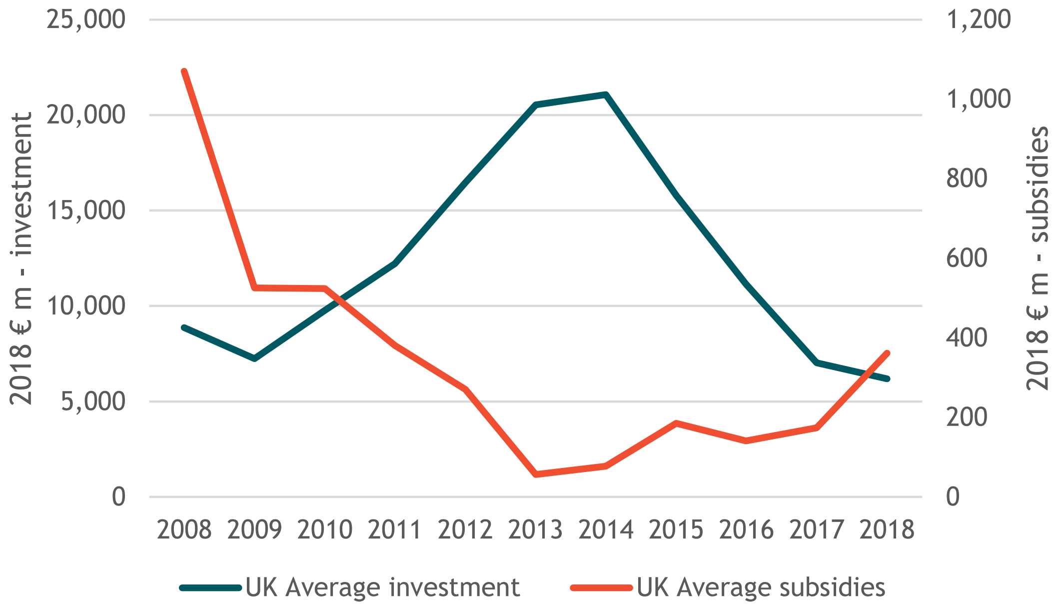
Source: Own calculation based on the subsidies and investment data sets

Figure 3-30 Mixed dynamics, US



Source: Own calculation based on the subsidies and investment data sets

Figure 3-31 Negative correlation, UK



Source: Own calculation based on the subsidies and investment data sets

3.3.3 Econometric analysis

While the descriptive analysis revealed some data gaps, it also showed that there is a subset of countries with both subsidies and investment time series that can be used in regression analysis. The general form of the estimated equation is shown below, with the β_1 parameter identifying the impact of subsidies on investment. It should be noted that because the model is estimated using variables in their natural logarithms, β_1 is interpreted as a percentage change response; if the value of fossil fuel subsidies increases by one percent, the investment is expected to change with β_1 percent (with all other factors assumed unchanged).

Equation 2: General model of fossil fuel investment and subsidies

$$\ln\left(Investment\colon FF\ extraction_{it}\right) = \beta_0 + \beta_1 \ln(Subsidies\colon FF\ extraction)_{it} + Other\ Factors'_{it}\boldsymbol{\gamma} + u_{it}$$

$$t = 1,2 \ldots T\ (years), \qquad i = 1,2 \ldots .N\ (countries)$$

$$Other\ Factors'_{it}\colon GDP, coal, oil\ and\ gas\ prices, lagged\ subsidies - all\ in\ natural\ logarithm$$

$$u_{it} = \theta_i + \lambda_t + \varepsilon_{it}$$

The impact of subsidies on investment is identified through a series of regressions, following the methodology of relevant studies of the same topic using similarly structured data sets ((Polzin, 2015) and (Aguirre, 2014) in particular).

As a benchmark and identifying overall trends, first, pooled OLS regressions were estimated. Then random and fixed effects models were specified to be able to capture country level time invariant heterogeneity and time-specific effects uniform for all countries. The fixed effects estimator is capable of identifying within-country dynamics, while the random effects estimator is formed as a weighted average of within and between-country dynamics. The random effects model assumes an independence of the country fixed effects and the rest of the error term. If this assumption is warranted, the random effects model is preferred to describe the dynamics, otherwise the fixed effects estimator is used. The Hausman test was used to decide which method is the most appropriate to be used on this case. Note that to correct for non-random error structures all models were estimated with robust errors.

When estimating pooled OLS models on panel data, it is often found that the error term is correlated within countries or over time, or has a changing variance across these dimensions. To address these non-random dynamics fully, a panel corrected standard error estimation (PCSE) was also used, following (Polzin, 2015). This estimator complements the OLS model estimation with a fully corrected, robust estimate for the error variance-covariance matrix treating the abovementioned non-randomness in the errors.

To identify the relationship between investment and subsidies, and filter out changes in the general economic conditions including GDP and prices, lagged subsidy values were also introduced in the models to see if subsidies drive future investment (as picked up in some cases from the trend analysis). Building on the conclusions of the descriptive analysis, models are run for the EU27 and Non-EU G20 groups separately and pooled as well, picking up their potentially different dynamics.

Table 3-7 and Table 3-8 show the regression results from our selected specifications. Table 3-7 shows models estimated on the subsample of the seven EU27 and twelve Non-EU G20 countries, which have both subsidies and investment data (countries listed in Table 3-6). Table 3-8 shows models estimated on the full sample. Four specifications are presented for each sample (EU27, non-EU G20 and full sample) and are shown in different columns: an OLS (1) and PCSE (2) estimates with GDP as a control variable and two fixed effects models controlling for country (3) and county-year fixed effects (4). These specifications were selected from a set of estimates based on a series of diagnostics tests.

Appendix Table C-1 shows additional OLS specifications testing the explanatory power of fossil fuel resource prices, lagged subsidies and time dummies. However, once GDP is included as a control variable, these other explanatory variables become insignificant. It is likely that the movements of GDP capture the relevant information on economic conditions and lagged impacts that affect the dynamics of the relationship between subsidies and investment. Additional panel specifications were also tested; Table C-2 shows the random effects version of the panel models and the corresponding Hausman tests. Although, the significant Hausman test value shows that the fixed effects model is the preferred estimation method, the random effects models are shown for robustness. The results from that estimation are of similar magnitude to the fixed effects estimates for most specifications.[11]

For EU27 the OLS and PCSE models have the same conclusion, one percent higher subsidies lead to 0.32-0.37 percent higher investments, suggesting that government subsidies can attract investment to the sector. However, the subsidy seems to be an inefficient one, without strong multiplier dynamics. GDP is only significant in the first model, which suggests a weaker relationship, that the lower the GDP is the higher extraction sector investment becomes. Once time fixed effects are added to the panel regression, these conclusions no longer hold. Subsidies lose their significance and GDP has a weak positive impact on subsidies. This specification confirms what the descriptive graphs suggested; while in the aggregates some co-movement was visible, once studying the trends within country and over time, patterns can be quite heterogenous. However, in this specification the number of observations is the lowest compared to the number of the estimated parameters, which substantially weakens the power of conclusions to be drawn. Unstable parameter estimates across specifications (e.g. fixed and random effects) may also occur due to the small sample size.

For the Non-EU G20 countries the results show a quite different picture. While in the pooled OLS specification subsidies seem to have a positive impact on investment (at a similar range to that which EU countries have), this effect disappears in the more sophisticated specifications. For this country group GDP has a strong and positive association with investment in the first three models, suggesting that the richer the country is, the higher the investment value we observe. However, this strong co-movement should be interpreted with caution because it could also show that the collected investment data are more complete for more wealthy economies. While for the EU data quality is quite homogenous, for Non-EU G20 countries the quality varies substantially.

Results from the pooled sample models are dominated by the Non-EU G20 patterns. The Non-EU G20 country group has substantially higher investment and subsidy values than the EU27, therefore G20 impacts show up more strongly in the estimated parameters as well.

[11] The Breusch-Pagan, BP-LM and White tests find heteroskedasticity in the OLS and panel specifications for all subsamples. The Wooldridge serial correlation test implied the presence of serial correlation. Therefore, as a first step robust errors were used in all models. To fully treat the issue for the panel corrected standard errors specification was estimated to be robust for both heteroscedasticity and correlated residuals (AR(1)). Corrected standard errors are reported for all specifications.

Table 3-7 Regression results for fossil fuel extraction, EU27 and Non-EU G20 separately

	ln(Investment)							
	EU27				Non-EU G20			
	(1)	(2)	(3)	(4)	(1)	(2)	(3)	(4)
	OLS	PCSE	FE	FE	OLS	PCSE	FE	FE
ln(Subsidies)	0.373***	0.321**	0.213	0.030	0.288***	0.009	-0.007	-0.001
	(0.042)	(0.127)	(0.174)	(0.062)	(0.050)	(0.051)	(0.042)	(0.034)
ln(GDP)	-0.321**	-0.242	-2.677	3.047	1.062***	0.966***	0.569***	0.196
	(0.121)	(0.355)	(1.691)	(2.330)	(0.101)	(0.040)	(0.180)	(0.213)
Constant	9.387***	8.453**	42.320	-36.070	-7.709***	-4.250***	1.352	6.417*
	(1.600)	(4.232)	(22.77)	(32.15)	(1.516)	(0.602)	(2.579)	(3.020)
Observations	57	57	57	57	114	114	114	114
R-squared	0.620	0.855	0.112	0.512	0.550	0.982	0.101	0.449
Sample	EU27	EU27	EU27	EU27	G20	G20	G20	G20
Countries	7	7	7	7	12	12	12	12
Country FE	no	no	yes	yes	no	no	yes	yes
Year FE	no	no	no	yes	no	no	no	yes

*Robust standard errors are in parentheses, *** p<0.01, ** p<0.05, * p<0.1*
Source: Own calculation
Notes: Each column relates to a different model estimation (1) Pooled OLS, (2) PSCE (3) Fixed effect panel to control for country effects (4) Fixed effects with year effects

Table 3-8 Regression results for fossil fuel extraction, Full sample

	ln(Investment)			
	Full Sample			
	(1)	(2)	(3)	(4)
	OLS	PCSE	FE	FE
ln(Subsidies)	0.432***	0.0443	0.009	0.0159
	(0.040)	(0.043)	(0.038)	(0.036)
ln(GDP)	0.674***	1.321***	0.483***	0.797*
	(0.114)	(0.123)	(0.161)	(0.382)
Constant	-3.611**	-9.495***	1.571	-3.016
	(1.556)	(1.443)	(2.266)	(5.371)
Observations	171	171	171	171
R-squared	0.562	0.962	0.038	0.305
Sample	Full	Full	Full	Full
Countries	19	19	19	19
Country FE	no	no	yes	yes
Year FE	no	no	no	yes

*Robust standard errors in parentheses, *** p<0.01, ** p<0.05, * p<0.1*
Source: Own calculation
Notes: Each column relates to a different model estimation (1) Pooled OLS, (2) PSCE (3) Fixed effect panel to control for country effects (4) Fixed effects with year effects

Comparison with literature

There is not much literature analysing the link between extraction subsidies and investment using econometric analysis and cross-country panel data. Most studies analysing this link, for example (Erickson, Down, Lazarus, & Koplow, 2017), focus at a micro level and calculate how subsidy schemes make extraction at different sites facing different costs profitable. (Erickson, Down, Lazarus, & Koplow, 2017) find strong impacts, suggesting that oil extraction subsidies could push nearly half of new, yet-to-be-developed oil investments into profitability. However, due to its narrow focus and the lack of econometric analysis, this result is difficult to compare to our findings. Most studies that use regression analysis on a similarly structured data set to evaluate the impact of fossil fuel subsidies have a wider focus. They either analyse different policy measures and subsidies together (e.g. consumption and production) or have a different sectoral focus (e.g. power sector, energy intensive industries). (Polzin, 2015) for instance, examined the impacts of policy measures and subsidies on power sector investment on a very similar type of data set as the one used here. The identified impacts are mostly below two percent in absolute terms for several types of subsidies, not finding strong multiplier dynamics.

3.3.4 Key messages

This case study analysed the impact of extraction subsidies on investment and, consequently, on the production of fossil fuel resources.

The descriptive analysis identified that quite different country level dynamics lie behind the aggregate pattern of co-moving investment and subsidy time series. The values of extraction investment and subsidies also vary considerably across countries, with Non-EU G20 countries having substantially larger values than EU Member States. As expected, based on the descriptive analysis, econometric modelling confirms these mixed patterns and cannot identify a robust conclusion. While in EU countries some models find a significant and positive relationship between subsidies and investments, most models do not find any impact in Non-EU G20 countries. For the G20 country group, GDP seems to be the strongest driver of investment, overshadowing all other factors included in the analysis.

It is important to note that our analysis suffers from limitations caused by the overall sample size and data quality. Even for the countries included in the analysis, time series have gaps and the observed non-zero values might not include all actual subsidy schemes or give a complete picture of investments.

Overall, our results are quite mixed and do not robustly identify a strong positive impact of extraction subsidies on investment. This may suggest that phasing out those subsidies would not have a strong detrimental effect on extraction. However, more extensive data collection would be needed on both extraction and subsidies for econometric analysis to identify more robust conclusions.

3.4 Case study: Transport electrification - electric vehicle take-up

Among the investments in the energy sector collected in this task, there are also data on the deployment of battery electric vehicles (BEV) and plug-in hybrid (PHEV) electric vehicles. From the literature it is clear that the main barriers to take-up of electric vehicles, over conventional (ICE) vehicles, are the higher upfront costs and the lack of infrastructure to charge them (Element Energy, 2009). From the subsidies data set that was collected in Task 3.1 we see that many countries have provided direct subsidies to the purchase of EVs to help reduce one of these barriers to uptake. In this case study, we look at the trend in the sales of EVs and the subsidies data on vehicles and recharging infrastructure, to see if there is any relationship between the subsidies and sales of electric vehicles.

3.4.1 *Processing the electric vehicle subsidies and sales data*

Box 3-3 explains the selection process for EV subsidies and EV sales data used in the analysis.

Box 3-3 Processing the electric vehicle subsidies and investment data

Selecting and processing the electric vehicle data

The following subset of the *investment database* is used:

- Sales data rather than investment values were used to analyse the trend in EV investment due to the lack of data on the evolution of EV prices over time.
- For EV sales two different indicators were selected:
    - The first indicator used is the original IEA EV sales series on new electric car sales (BEV and PHEV (Battery Electric Vehicles and Plug-in Hybrid Electric Vehicles)). As EV-related subsidies often impact both types of EVs, sales values for both BEVs and PHEVs are relevant.
    - To fill in gaps in the IEA coverage of EU27 countries, data on BEV and PHEV sales from the European commission Alternative fuels observatory (EAFO) was used
- Unlike the subsidies data set, the investment database does not include any estimation of missing values. To avoid picking up false shocks in the analysis, data gaps of at most two years were filled using the last/first available value or the simple average of the neighbours.

The following subset of the *subsidy database* is used:

- Two types of subsidies were used in this analysis, which were pooled together to provide the EV subsidies indicator.
    - *EV passenger car price subsidies:* providing consumer price support for buying EVs. Note that public transport subsidies were not analysed within this case study because the electrification of public transport can only have an indirect effect on personal passenger car choices.
    - *EV infrastructure subsidies*: mostly directed towards developing EV charging stations..
- Transport subsidies for fossil fuels and for biofuels or other non-EV renewables could hinder the take-up of EVs indirectly, by making alternatives cheaper. These subsidies are thought to have only a weak and indirect impact on EV take-up. For example, biofuel blends and cheaper fossil fuels affect the use and operating cost of existing ICEs, and do not necessarily affect new vehicle choices. Due to the assumed weak impact and the nature of the subsidies in the data set, both fossil fuel and biofuel subsidies have been omitted from the analysis.
    - *Fossil fuel subsidies* are scarce in the data set and they mostly aim at improving access to remote areas (e.g. islands, overseas territories). They do not target the same passenger vehicle segment in which EV purchase is an option or have a narrow regional scope; they would not substantially hinder EV take-up at a large scale.

- *Biofuel, bioenergy subsidies* are available for a few countries in the data set, covering mainly large producers (e.g. Argentina). In other countries we mainly observe subsidies to help meet biofuel blend requirements. Biofuel blends (especially low ones) may provide alternatives for standard fuel use for ICEs but will not likely impact the purchase of EVs.

- Wherever the original subsidy values are missing, they have been replaced with their estimated counterparts. Subsidies with no values for the timeframe even after the extrapolation were omitted.
- Subsidy values were deflated to a common 2018 price base and converted to millions of euros.
- The selected set of subsidies were sense checked and subsidies were omitted if they did not closely relate to electric vehicles (e.g. improvements in distribution unrelated to transport).
- The final set of subsidies covers several different policy instruments including tax exemptions, tax credits, tax reductions, grants & directs transfers.
- Table 3-9 show the selected set of subsidies for Germany:

Table 3-9 Excerpt from the selected EV subsidies included in the analysis: Germany (DE)

ID	Name of policy (English)	Economic sectors	Subsidy category	Unit	2012	2013	2014	2015	2016	2017	2018
DE	Subsidy for the construction of charging infrastructure for electric vehicles in Germany	ENER-Infra-Distribution	Direct transfers	€ 2018 m	0	0	0	0	0	1	9
DE	Subsidy for the purchase of electric passenger vehicles	TRANS - Road transport	Direct transfers	€ 2018 m	0	0	0	0	6	38	62
DE	Temporary tax exemption for first-time licensed fully-electronic vehicles	TRANS - Road transport	Tax expenditures	€ 2018 m	0	0	0	1	1	3	5

Source: Own calculation based on the subsidies data set

3.4.2 Descriptive analysis

Aggregate EV sales and subsidies over time

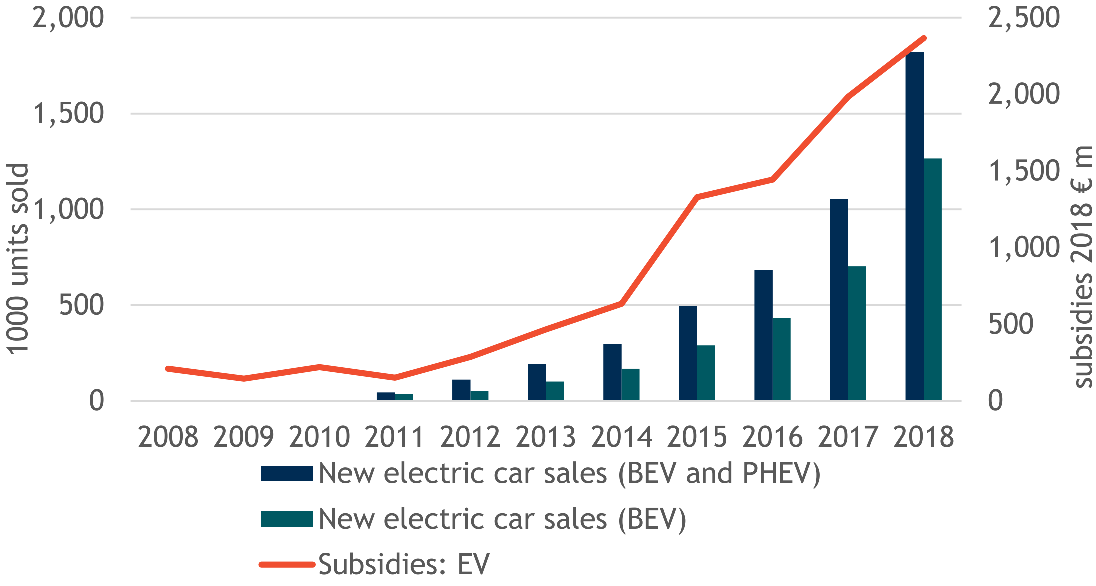
Figure 3-32 shows the total observed value of EV subsidies and the sales of battery powered and plug-in vehicles. Figure 3-33 and Figure 3-34 show the same series but separately for EU27 and Non-EU G20 countries. The graphs show an increasing trend in both the observed subsidies and sales. While the subsidies seem to have similar magnitudes for the two aggregates, sales grow more dynamically in Non-EU G20 countries.

It is important to note that these insights may be biased by missing data patterns in the subsidies dataset and should be interpreted with caution. These trends might be caused by improvements in the data quality by the end of the timeframe. This is particularly evident in Figure 3-33 where there is a jump in subsidies between 2014 and 2015 with the inclusion of Netherlands subsidies. However, it cannot be inferred whether the observed zeroes are actual values or unobserved subsidies. It is also difficult to assess whether and how data quality may change over time and across country aggregates, and how data quality may bias our assessment of the sales-subsidies relationship. The issue of data gaps is more evident for Non-EU G20 countries where data are less complete and the quality of data substantially improves towards the last available years.

Figure 3-35 shows the same aggregate data from a different angle, illustrating the total subsidy values for each EV sold (BEV and PHEV as well) where we observed both sales and subsidies data. While Figure 3-33 and Figure 3-34 show the expansion of both subsidies and sales, Figure 3-35 reveals that the relative values of subsidies and sales stayed rather stable over time in the case of the G20 and have decrease of EU27 Member states. This metric captures well that the role of state did not substantially increase in this market in terms of subsidy per unit sold.

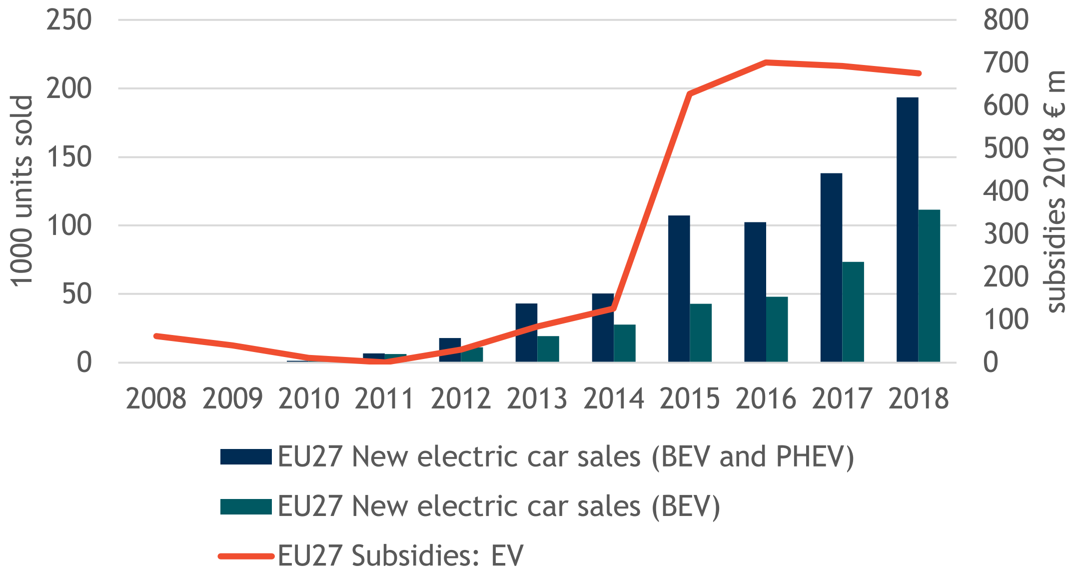
It should be noted that data are shown only for the 2012-2018 period because data on both indicators are very scarce before that period, as visible in Figure 3-33 and Figure 3-34. It is also important to add that the total value of subsidies as a ratio to the total amount spent on EVs could be a more meaningful estimate for the strength of subsidies. Based on average EV price of €54,000 in 2017, the average subsidy for the EU27 and G20 countries observed is €3,400 representing around 8% of the average vehicle price. However, our data include only a global average price estimate, without a clear indication of . Using this estimate, it would be possible to give estimates of the amount spent on EVs, but the figures would not be robust. Using these figures to show subsidies per unit of expenditure on EVs would not provide additional insights but would merely rescale subsidies to per-sales values.

Figure 3-32 Total EV sales and subsidies, EU27 and non-EU G20



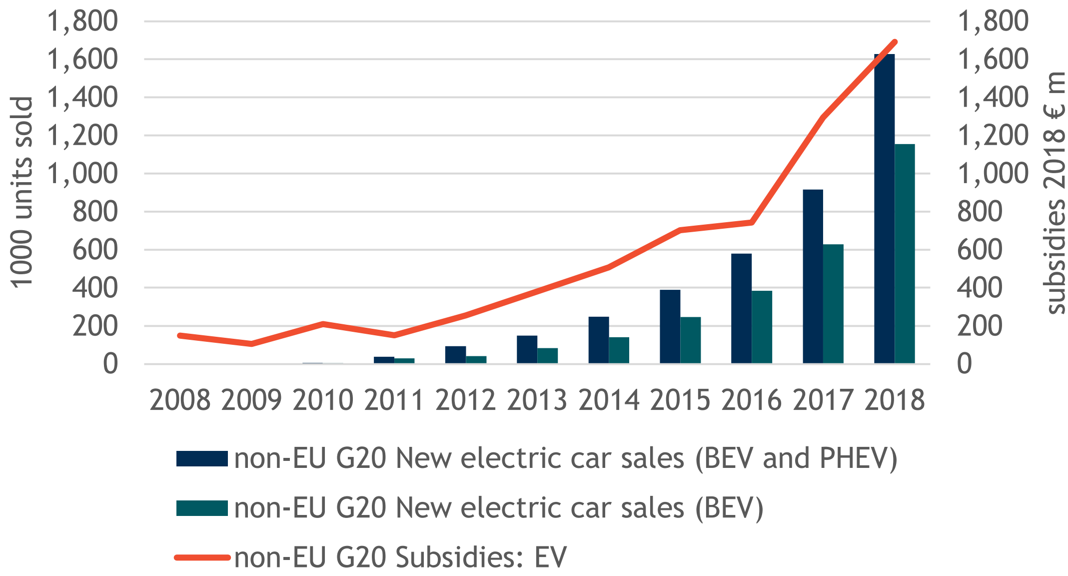
Source: Own calculation based on the subsidies and investment data sets

Figure 3-33 Total EV sales and subsidies, EU27



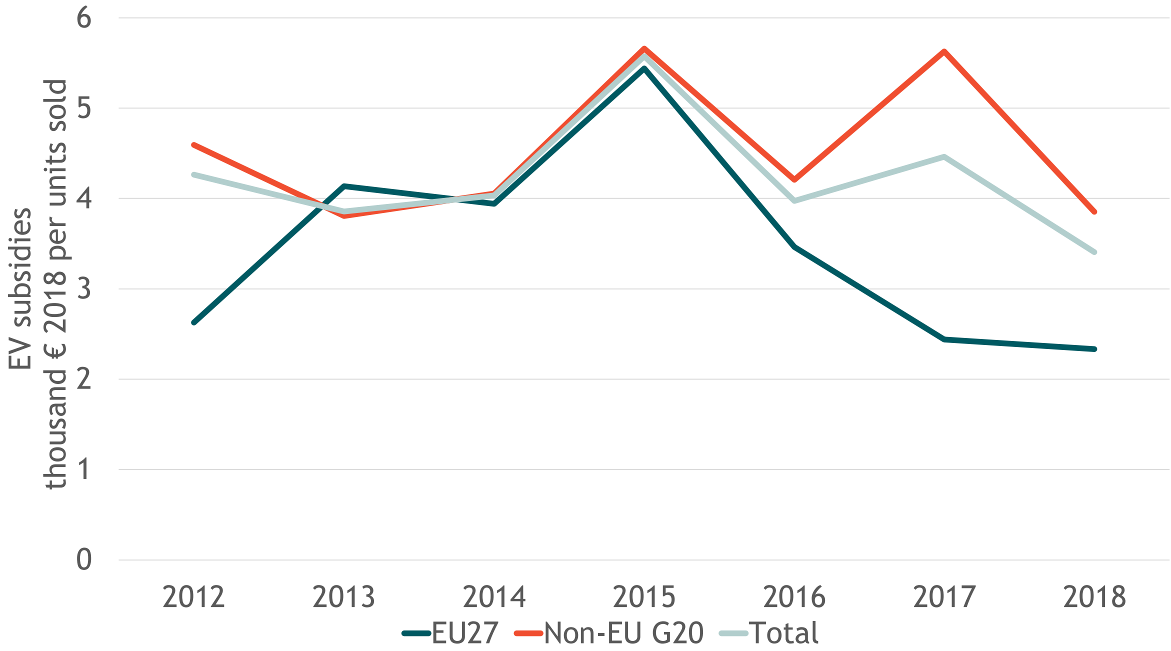
Source: Own calculation based on the subsidies and investment data sets

Figure 3-34 Total EV sales and subsidies, Non-EU G20



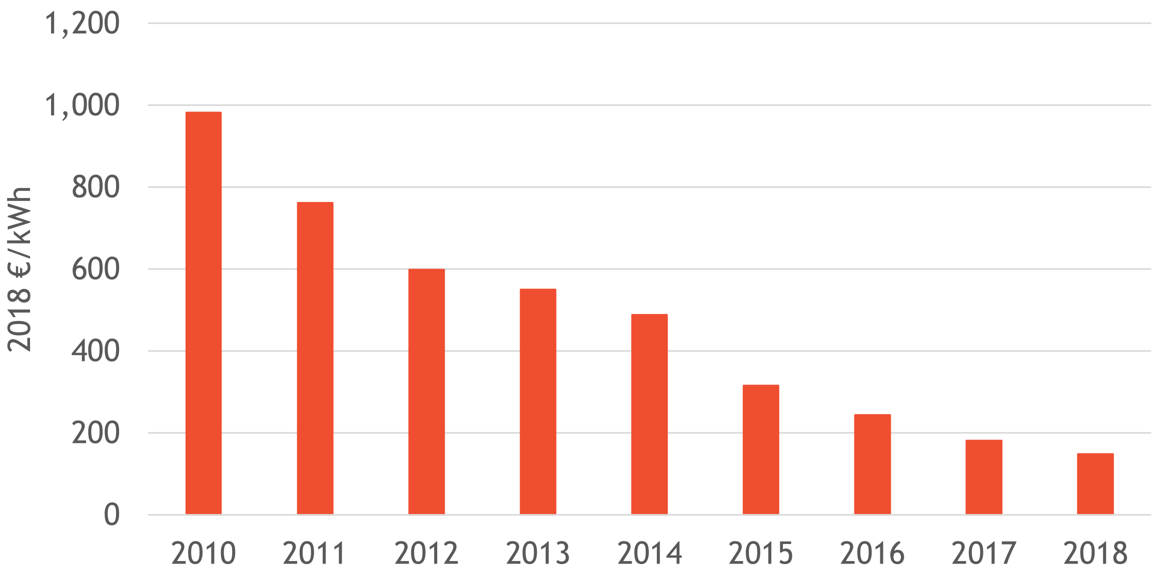
Source: Own calculation based on the subsidies and investment data sets

Figure 3-35 EV subsidies per EV sales where both are observed, 2012-2018



Source: Own calculation based on the subsidies and investment data sets

Figure 3-36 Lithium-ion battery pack price based on by BloombergNEF(2019)



Source: (BloombergNEF (BNEF), 2019) - Lithium-ion battery prices survey results: volume weighted average

It is important to note that our descriptive analysis does not cover the evolution of EV prices because of a lack of information on price dynamics in the original investment data set compiled in Task 8.1. Prices and their decreasing trend could have a substantial impact on the observed expansion of EV sales. The largest cost element that determines EV prices is the price of lithium-ion batteries. Figure 3-36 based on (BloombergNEF (BNEF), 2019) and (BloombergNEF (BNEF), 2020), shows that the price of a battery pack 'fell 87% from 2010 to 2019, with the volume-weighted average hitting $156/kWh', which means prices dropped by 8-35% each year.

While underlying material prices may counteract this trend in the future, better manufacturing techniques and pack designs have been the drivers of price reductions in the past years. With this severe cost reduction of batteries during the period of analysis, in turn driving the evolution of EV prices, it is likely a large fraction of the sales growth could be attributed to falling prices. Prices could also affect the level of subsidies for EV take-up because falling upfront costs can drive a decreasing trend in government support. Unfortunately, without additional data on final vehicle prices and a large enough sample to identify causal relationships, it is difficult to quantify the impact of subsidies on EV sales. While missing accurate EV price time series is a known limitation of this analysis, additional primary data collection is beyond the scope of this case study.

EV sales and subsidies over time and across countries

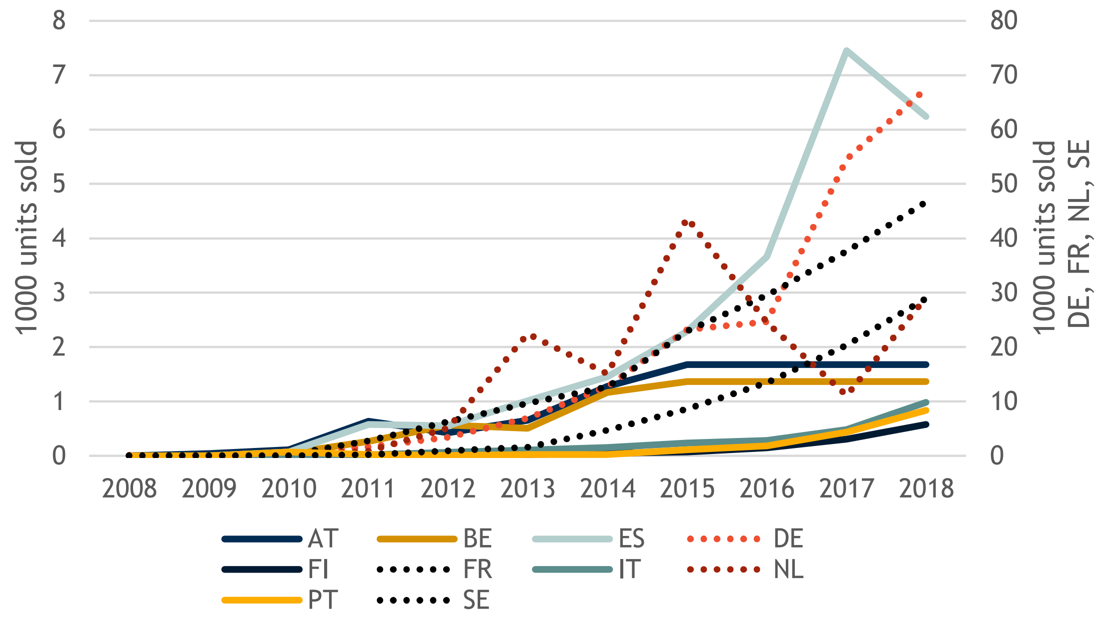
Figure 3-37 shows the EV market sizes across 10 EU countries with the largest EV markets, comparing their sales of BEV plus PHEV units as time series. Figure 3-37 presents data on absolute sales and shows that Germany, France, Sweden and the Netherlands have developed the largest EV markets. While most countries exhibit a smooth increasing trend in sales, data on the Netherlands show multiple peaks and an overall slow-down after the initial steep start.

The volatility in sales in the Netherlands is a rather interesting case because it was driven by spikes in PHEV sales just before changes in tax incentives, both in 2014 and 2016[12]. Unfortunately, the change in Dutch tax incentives are not captured in the EV subsidies data we have, which start in 2015. However, it is useful to also consider EV sales as a share of the total market. Figure 3-38 shows the market share of BEV and PHEV in total passenger car sales. The figure shows that Sweden and the Netherlands have a much larger market share and further highlights the volatility of sales in the Netherlands. Meanwhile, the sales shares among the other Member States are much closer together, except for low uptake in Austria and Belgium

Figure 3-39 and Figure 3-40 show the same information for non-EU G20 countries. While the data on most countries cannot be seen well, the figure shows clearly how fast China's EV sector is growing, reaching almost 20 times higher sales than Germany, which has the largest European market. Although the US has only the second highest sales value in the Non-EU G20 group, it is still well ahead of EU27 countries in its EV sales.

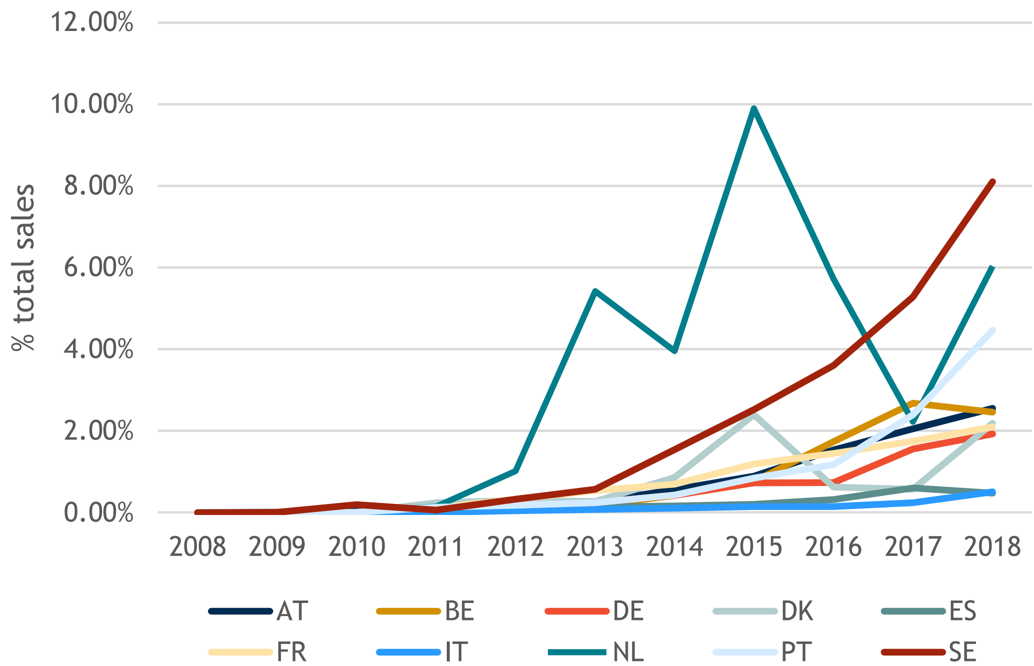
[12] https://arstechnica.com/cars/2017/06/there-are-more-than-2-million-electric-vehicles-on-the-road-around-the-world/

Figure 3-37 EV market size in EU countries with 10 highest BEV and PHEV sales in the EU27



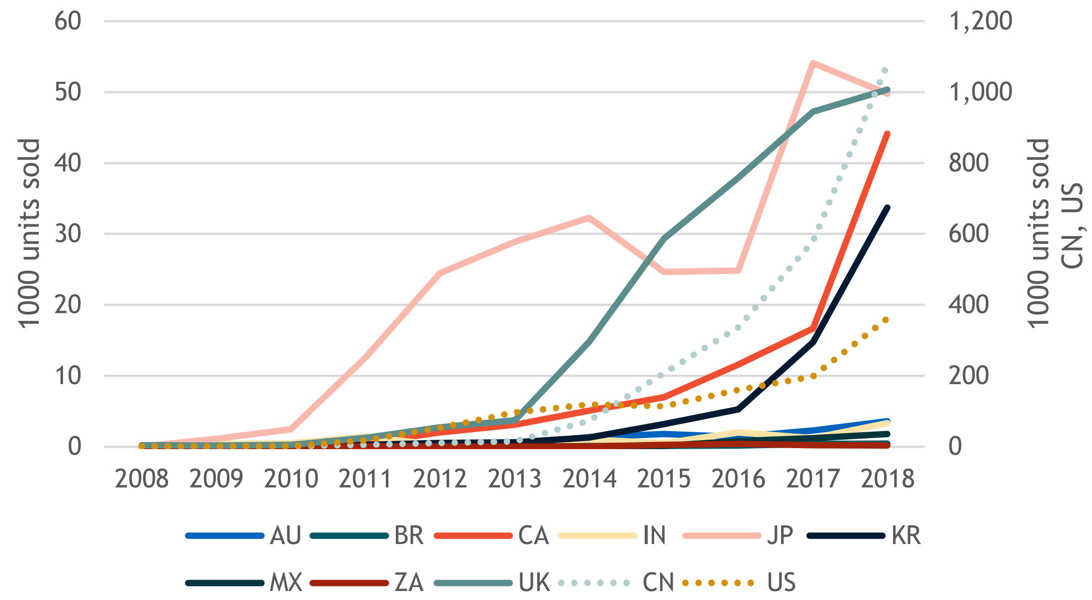
Source: Own calculation based on the investment data set

Figure 3-38 EV market share in countries with 10 highest BEV and PHEV sales in the EU27



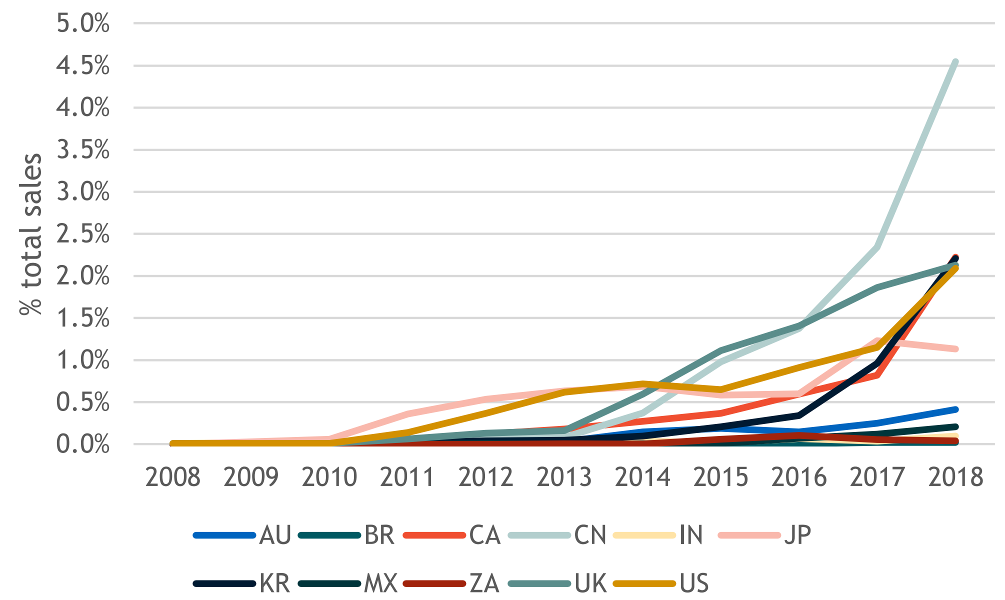
Source: Own calculation based on the investment data set

Figure 3-39 EV market size in countries with observed sales: BEV and PHEV sales in the Non-EU G20



Source: Own calculation based on the investment data set

Figure 3-40 EV market shares in countries with observed sales: BEV and PHEV sales in the Non-EU G20



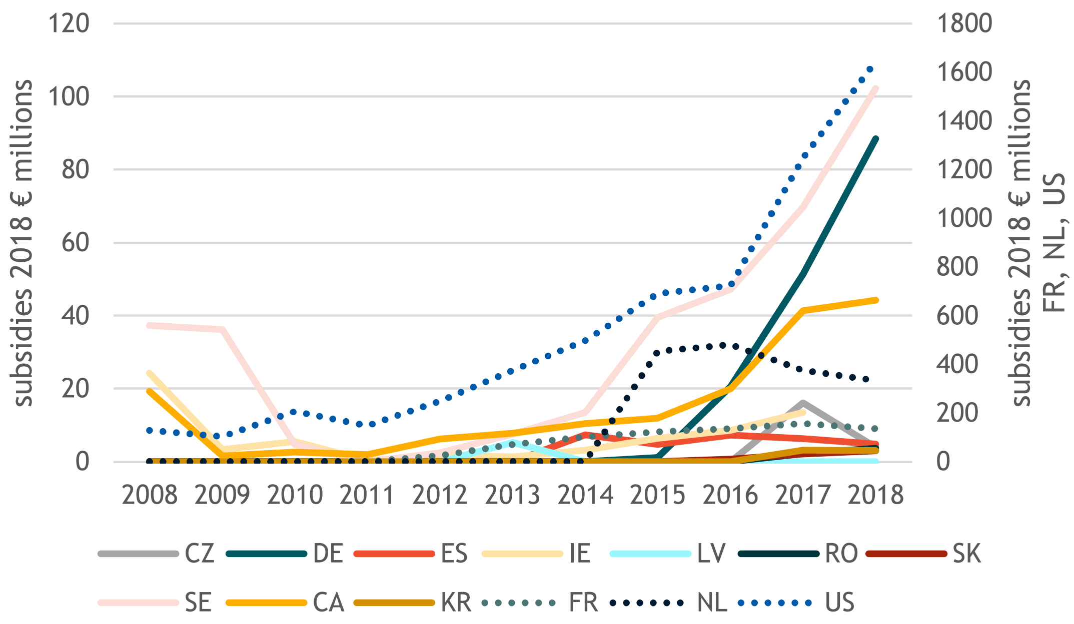
Source:
Own calculation based on the investment data set

Figure 3-41 compares the EV subsidies by country over time, showing data for all countries with non-zero observed subsidies. As before, some countries have large EV subsidy schemes. The US, the Netherlands and France stand out, followed by Germany, Canada and Ireland.

It is important to flag that, unlike in other sectors analysed (e.g. the power sector) where the total subsidy values usually build up from many different policies and tax incentives, here only a few subsidies are available for each country. Therefore, the inclusion and omission of a single subsidy can substantially change the dynamics within a single country. For example, one of the two subsidies driving the patterns seen for the US is a subsidy called 'Tax credits for clean-fuel burning vehicles and refuelling property'. The name of the subsidy suggests that it includes 'clean-fuel' vehicles, and the 'Description' explains that it is for '*plug-in electric-drive motor vehicles, alternative fuel vehicle refuelling property, two-wheeled plug-in electric vehicles, and fuel cell motor vehicles*'. Therefore, the scope of the subsidy covers more than just the purchase of EVs. As such, there is a risk of over-attributing support for EVs for the US, but the policy is still a good indication of the support available for EVs.

We should also note that that some countries only have observed sales data while others only have information on subsidies in the database. A lack of data is a observed for several other countries in both the EU27 and Non-EU G20 groups, including countries with large EV sales like China and Japan. These cases flag that incomplete data pose a serious limitation to this analysis and make it difficult to draw robust conclusions at an aggregate level especially for the G20. However, despite the limited coverage of EU countries, subsidies reported cover countries that made up 75% of total EU27 EV sales in 2018.

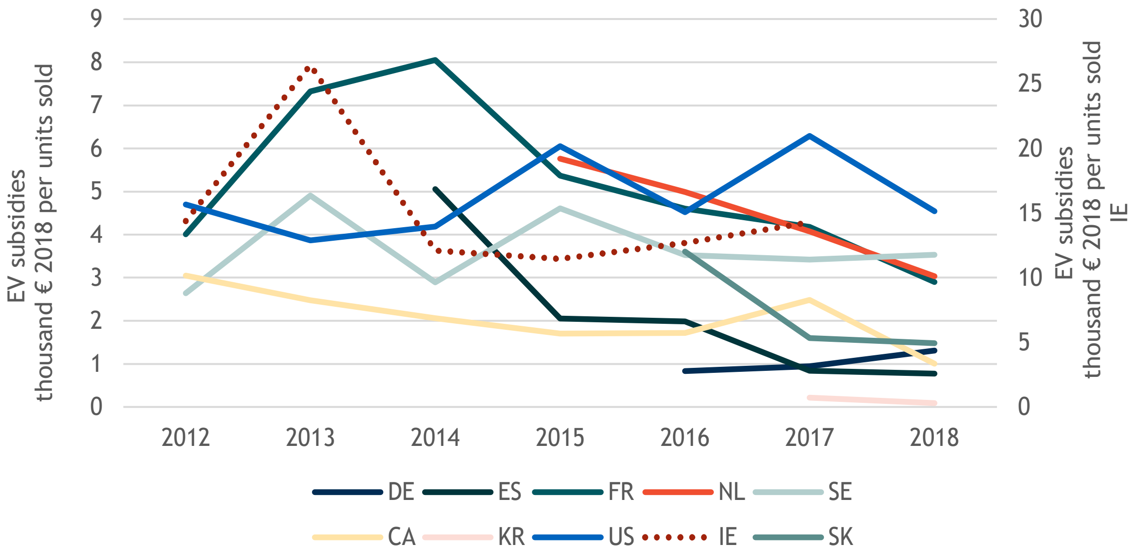
Figure 3-41 EV subsidies for countries with observed subsidies



Source: Own calculation based on the subsidies data set

Figure 3-42 show the subsidies per unit of EV sold in the countries with observed subsidies and sales. It is important to note that the number of countries plotted has shrunk substantially, and that the intersection of countries having both observed sales and subsidies is very thin. Data are shown only starting from 2012 because there are no data before that. Figure 3-42 shows that the Ireland has significantly larger support per EV followed by Netherlands and France and US with similar level of support. Ireland has had high levels of support throughout the period with generous grants and tax reliefs. The Netherlands has subsidies data only in the second half of the timeframe, mainly consisting of tax exemptions from vehicle registration taxes including large exemptions on company cars where 85% of EVs sold in 2018 where for business use. In France, the reduction in support over time reflect the changes in policy design of the Bonus-Malus system of grants and exemptions over the period with PHEV support reduced from 2016 vehicle and no longer supported in 2018. The value of subsidies is substantially smaller and more stable over time for other countries, which implies a broadly consistent level of support for each EV sale over 2012-2018.

Figure 3-42 EV subsidies per sales with countries with observed data on both 2012-2018



Source: Own calculation based on the subsidies and investment data sets

EV sales and subsidies over time and across countries

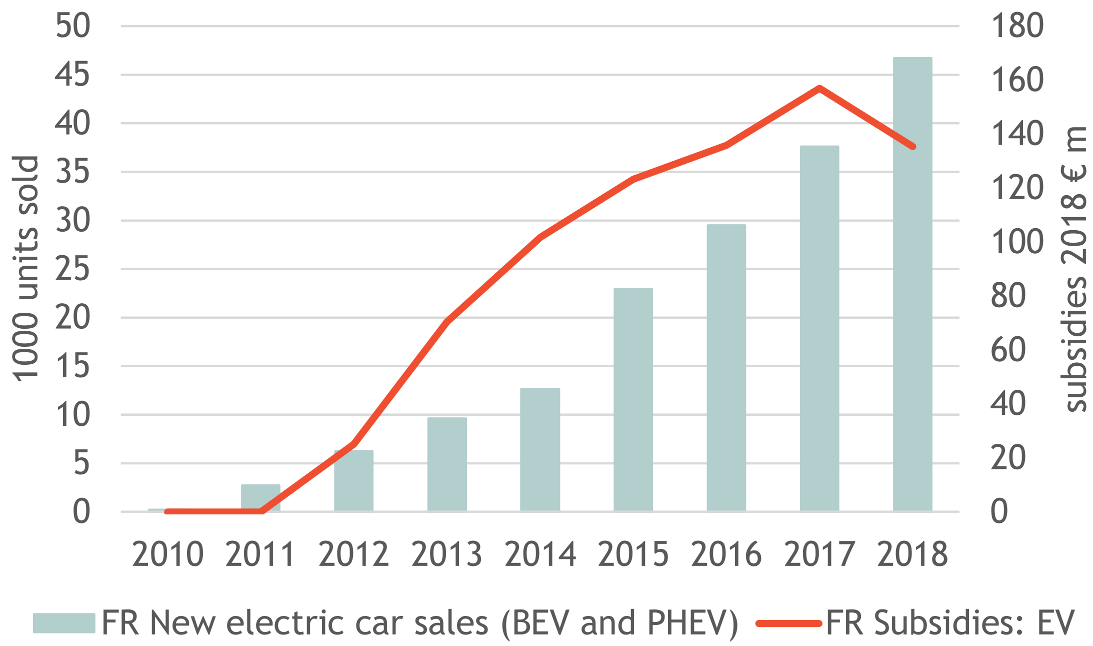
Figure 3-43 to Figure 3-48 explore individual country dynamics for countries with data on both EV units sold and subsidies**Error! Reference source not found.** and Table 3-10 shows the time series of EV subsidies and sales and their ratios. In line with the previous figures, it is visible that EV sales grow rapidly in most countries after 2010 (with the Netherlands as an exception), and sales sometimes change steeply from one year to another (e.g. Canada 2017 to 2018). EV-related subsidies across countries exhibit more heterogenous patterns and do not always grow monotonically.

France is a clear example of where the support for EVs has been revised over time where the main incentive Bonus-Malus scheme has been continually revised on an annual basis. As shown in, in 2018 total support fell while total BEV and PHEV sales increased, in part because PHEVs were made exempt from the bonus.

These figures show whether EV sales values respond to the fluctuations of EV subsidies at country level. They reveal a response for most countries. For example, in the US, Canada, the Netherlands and Germany, EV sales patterns follow the values of subsidies either contemporaneously or with some lag. It is visible that, as subsidies grow steeply in the Netherlands, EV sales follow and, as subsidies decrease, sales drop as well. Similarly, in Canada and Germany fast increases in sales as a response to faster growing subsidies in some years can be observed. In France, and for some of the timeframe in other countries, EV sales grow independently to subsidies.

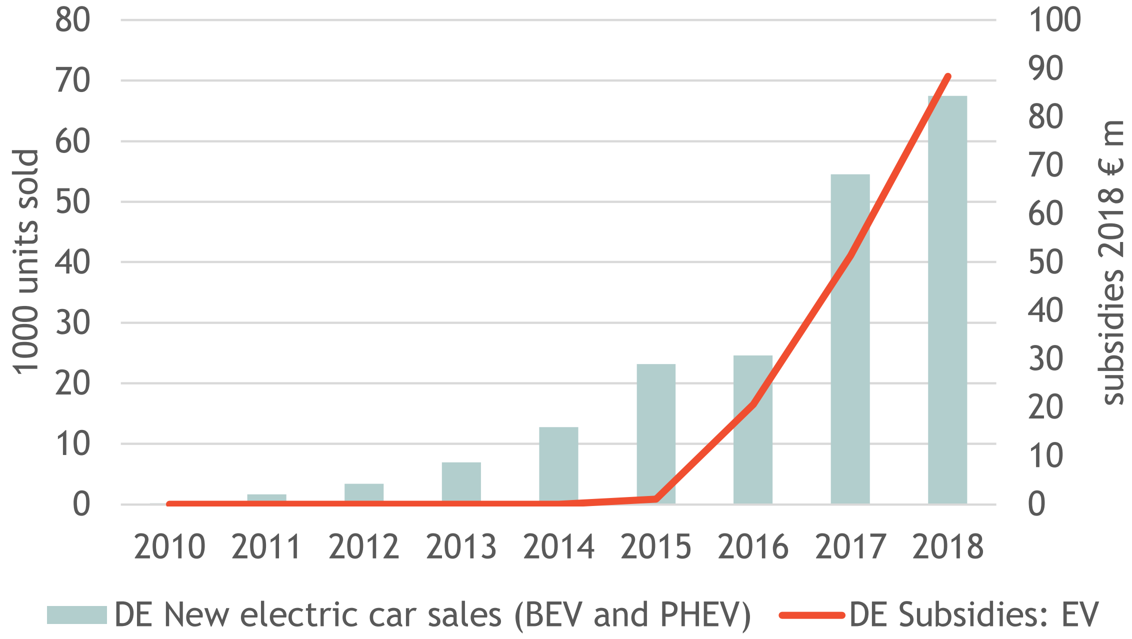
The relatively stable subsidies to EV sales ratios shown in Table 3-10 also confirm the co-movement. Overall, however, this stable ratio suggests that the level of support per EV sold either remained constant or fell over the period, while EV sales have grown rapidly. One factor that drove the reduction in EV support over the period was reductions in direct support to PHEVs which was observed clearly for France through the reduction of grants from 2016 onwards and phased out entirely by 2018. The other factor is that not all EVs are eligible or receive support. Results from the Spanish subsidies programs showed that in 2014, 70% of electric passenger cars registered in that year but in the 2018, only 20% or electric passenger cars registered received support. The reduction in proportion of EVs eligible reflected the introduction of maximum value of an EV that could receive the subsidies.
The reduction average levels of support while EVs sales fell suggest that while EV subsides may help to encourage EV sales take-up other factors must be driving the increased take up of EVs over the period.

Figure 3-43 EV sales and subsidies, France



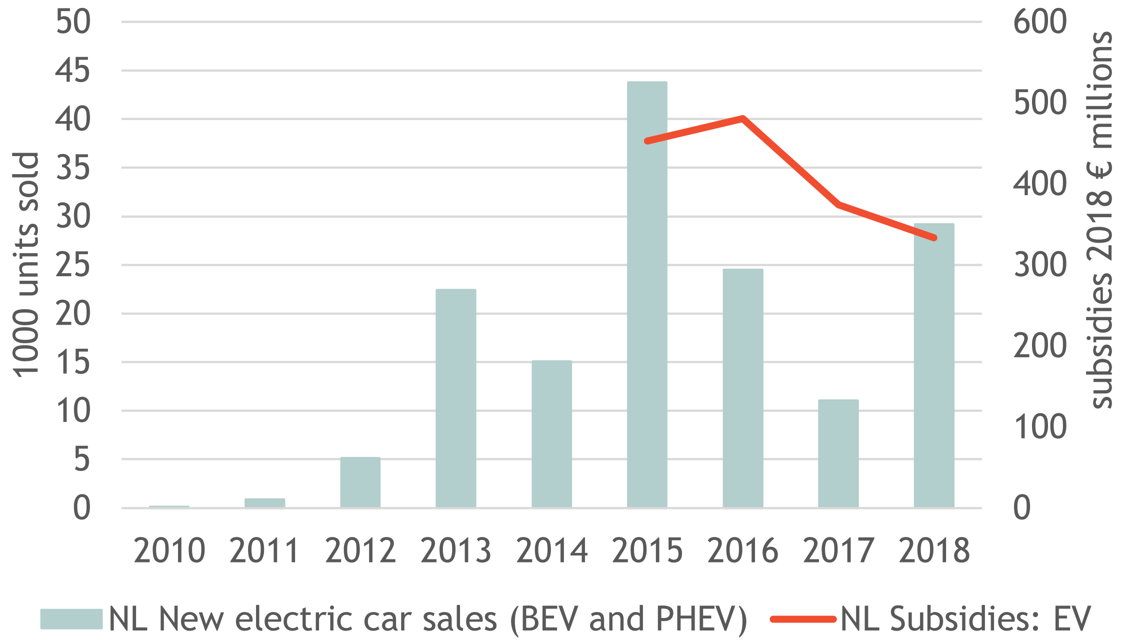
Source: Own calculation based on the subsidies and investment data sets

Figure 3-44 EV sales and subsidies, Germany



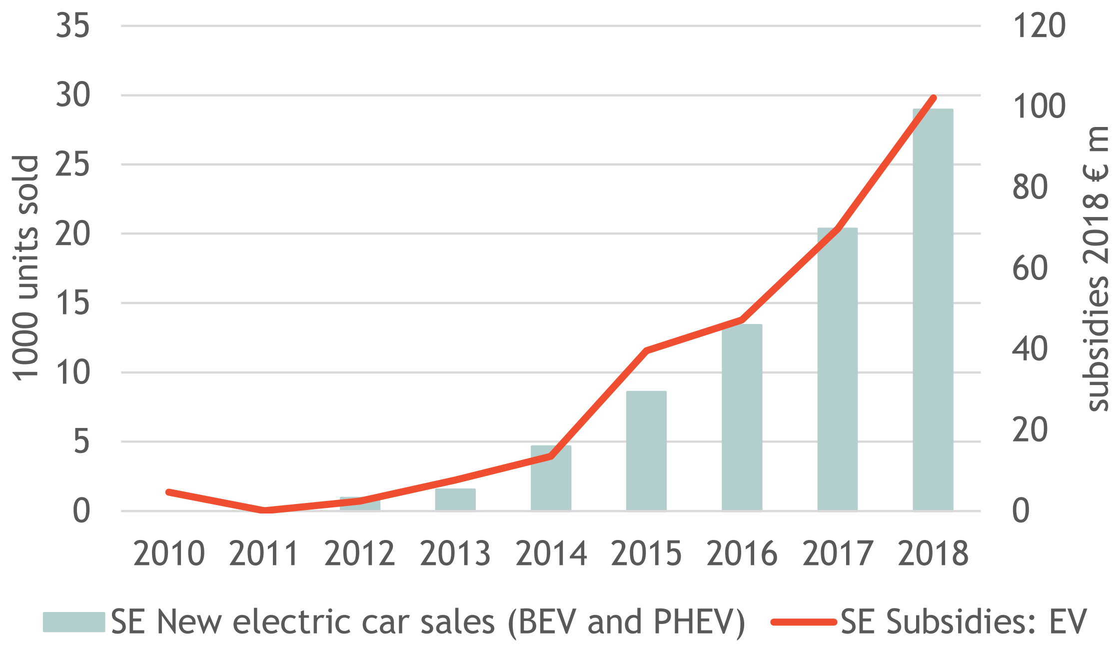
Source: Own calculation based on the subsidies and investment data sets

Figure 3-45 EV sales and subsidies, Netherlands



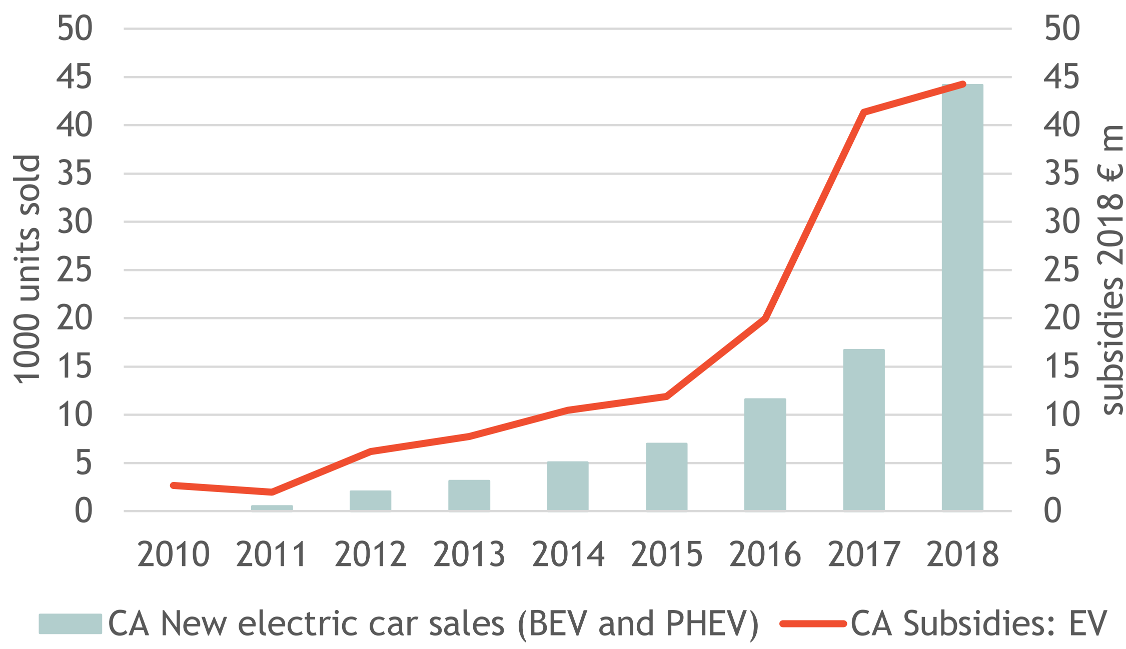
Source: Own calculation based on the subsidies and investment data sets

Figure 3-46 EV sales and subsidies, Sweden



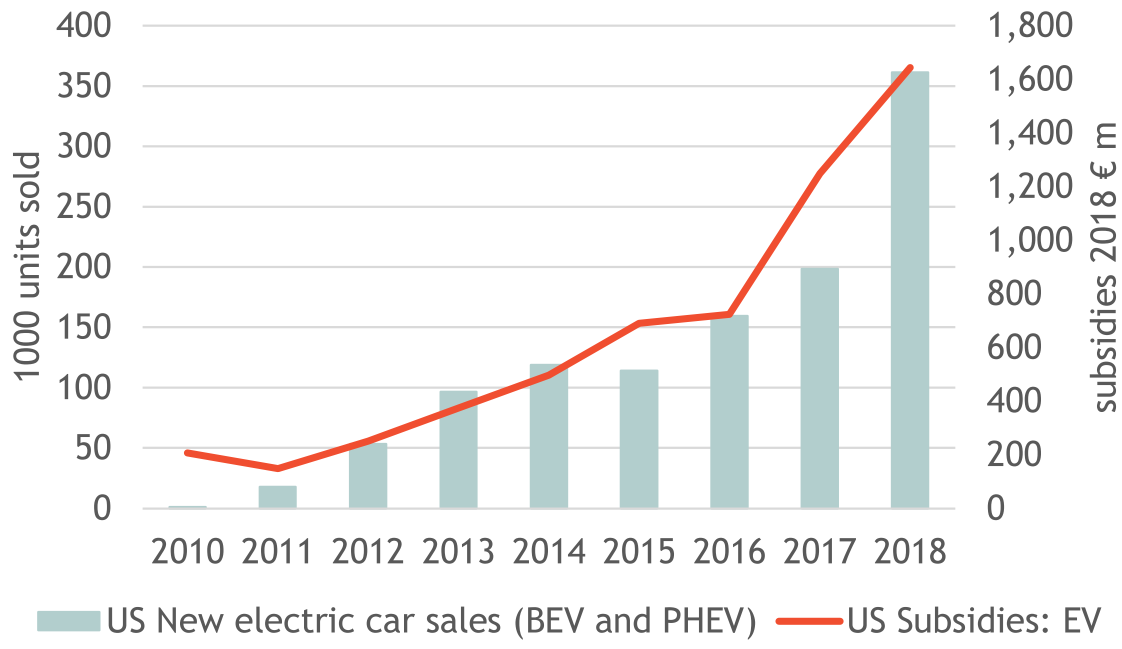
Source: Own calculation based on the subsidies and investment data sets

Figure 3-47 EV sales and subsidies, Canada



Source: Own calculation based on the subsidies and investment data sets

Figure 3-48 EV sales and subsidies, United States



Source: Own calculation based on the subsidies and investment data sets

Table 3-10 EV subsidies per EV sold for countries having data on both indicator

Country Code	Indicator	Unit	2012	2013	2014	2015	2016	2017	2018
DE	EV subsidies per sales	thousand € 2018 per units sold	-	-	-	0.0	0.8	0.9	1.3
ES	EV subsidies per sales	thousand € 2018 per units sold	-	-	5.1	2.1	2.0	0.8	0.8
FR	EV subsidies per sales	thousand € 2018 per units sold	4.0	7.3	8.1	5.4	4.6	4.2	2.9
IE	EV subsidies per sales	thousand € 2018 per units sold	14.4	26.5	12.1	11.5	12.7	14.3	-
NL*	EV subsidies per sales	thousand € 2018 per units sold	0.0	0.0	0.0	5.8	5.0	4.1	3.0
SE	EV subsidies per sales	thousand € 2018 per units sold	2.6	4.9	2.9	4.6	3.5	3.4	3.5
SK	EV subsidies per sales	thousand € 2018 per units sold	-	-	-	-	12.0	5.3	4.9
CA	EV subsidies per sales	thousand € 2018 per units sold	3.1	2.5	2.1	1.7	1.7	2.5	1.0
KR	EV subsidies per sales	thousand € 2018 per units sold	-	-	-	-	-	0.2	0.1
US	EV subsidies per sales	thousand € 2018 per units sold	4.7	3.9	4.2	6.1	4.5	6.3	4.5

Source: Own calculation

Note: Netherlands (NL) average subsidies was adjusted to reflect that tax exemptions relate to the stock of vehicles (annual motor tax or company tax exemption) rather than sales of vehicles (registration tax exemptions)

To draw stronger conclusions on the relationship between EV sales and subsidies, regression analysis would be needed. However, based on our assessment the observed sample size is not large enough to undertake this analysis. Even for the ten countries for which have some information on both subsidies and investment, data are sometimes incomplete, especially at the start of the period. Regressions on such small samples would not be able to identify robust relationships; therefore, we do not proceed to undertake econometric analysis.

Comparison with literature

From the literature, there is further evidence that subsidies have a role to play in encouraging the uptake of EVs. A study looking at consumer behaviour in the UK showed that the upfront cost of EVs relative to an equivalent ICE vehicle is one of the largest barriers to take-up, together with the availability of recharging infrastructure and the range of electric vehicles, to deciding to purchase an electric vehicle (Element Energy, 2009). Other studies have looked at the impact of the EV subsidies on the overall cost of ownership of vehicles and the negative relationship between total cost of ownership (TCO) and uptake of EV sales through pairwise analysis (Lévay, Drossinos, & Thiel, 2017).

The importance of recharging infrastructure has been highlighted in recent EU policy with the 2016 Directive of the European Parliament and of the Council on the deployment of alternative fuel infrastructure.

Also, consumer perceptions of the costs and benefits of EVs have an impact on the uptake of EVs. These behavioural/cultural factors include range anxiety and calculating the overall cost of ownership (consumers focus on the upfront costs and underestimate running costs, which disadvantages EVs).

Beyond the fiscal support of subsidies that are captured in the subsidies database for this project, many countries have provided additional incentives to help encourage EV take-up, including free and reserved parking and access to drive in bus lanes (European commission, 2019).

As well as the factors driving consumer demand, there are also factors that have influenced the supply of EVs to the market. EU policies such as the CO_2 standards for cars have actively required car makers to reduce emissions across the fleets of vehicles they sell. This policy has already been strengthened with the new post-2020 targets with active incentives to manufacturers, including zero emission vehicles. This need for regulation alongside fiscal incentives has been shown to be important for decarbonising road transport to meet 2°C target of the Paris agreement (Mercure, Lam, Billington, & Pollit, 2018)

From this literature it is clear that subsides have a role to play in encouraging take-up through lower upfront EV costs, but there are other factors driving the take up of EVs.

3.4.3 Key messages

This case study analysed the impact of EV subsidies on the sales of battery-electric (and plug-in hybrid electric) passenger vehicles.

The observed subsidies are both aimed at developing recharging infrastructure for EVs and subsidies and tax exemptions for purchases. Based on the descriptive analysis we observe that EV sales increase towards the end of the timeframe, with China and the US having the highest sales. In the EU27 The value of subsidies grows as well, with the US, France.

Where both subsidies and sales are observed, the average level of EV subsidy has have fallen or remain constant since 2015 and represents a relatively large share of vehicle cost. These subsidies play a role in incentivising EV sales, as the literature identifies that upfront costs are a key barrier to EV take-up. The rapid fall in battery prices is likely to have played a role in reducing EV vehicle costs, helping to drive a reduction in upfront costs over time. The literature also notes that there are other factors just as important as upfront costs in influencing purchase decisions, including the availability of charging infrastructure and range anxiety, as has been highlighted by the recent directive on alternative fuels infrastructure in supporting electro-mobility. EU CO2 standards have also helped to ensure that more EVs have come to market.

3.5 Case study: Heating of buildings: heat pump take-up

Heat pumps are one of the most efficient available tools to reduce the use of energy for heating and cooling buildings. Reversible heat pumps can be used for both heating and cooling, and dual-purpose types can provide hot water as well. The main types of heat pumps are air source (ASHPs), ground source (GSHPs) and hydrothermal pumps (EurObserv'ER, 2018). While heat naturally transfers from warmer to colder spaces, heat pumps can reverse this process by continuously circulating, evaporating and condensing a refrigerant substance. This process is highly efficient compared to other heating techniques, but requires some outside energy source, mostly electricity. Although, the source and carbon intensity of that electricity depends on the site of installation, the efficiency of the technology makes heat pumps important tools in achieving a decarbonised economy.

Heat pump sales have been increasing steadily in the past decades at a global scale, with the European Union leading the way. The growing consumer awareness of heat pumps and recurrent summer heat waves in Europe helped the market expand. Energy efficiency subsidies accelerated this process but in most Member States there is still strong fossil fuel price support in place, which could work against take-up. Fossil fuel price subsidies are tools for reducing poverty in the short run, yet by hindering the take-up of heat pumps they could lock households in energy poverty in the medium and long run.

This case study analyses the role of fossil fuel and non-fossil fuel subsidies in the take-up of heat pumps, taking into account the price of heat pumps and energy, and the energy demand of households.

3.5.1 *Processing the buildings energy efficiency subsidies and heat pump sales data*

Box 3-4 explains the selection process of subsidies and variables from the investment data set used in this case study to better understand the main drivers of heat pump take-up.

Box 3-4 Processing the heat pump sales and buildings heating subsidies data

Selecting and processing data on heat pump sales and building heating subsidies

The following subset of the *investment database* is used:

- *Total heat pump sales (units sold)*: Data on heat pump units sold are only available for EU27 countries and for the UK, for 2011-2017. This regional coverage and timeframe determine the scope of this case study. The data set only includes aerial and ground source heat pumps, and most reported sales data refer to the aerial type.
- *Heat pump price (average per unit sold):* Data on heat pump prices were used as another potential driver of take-up. This price estimate is a calculated average price based on the total revenue and unit sold data published by the European Heat Pump Association (EHPA). The real price estimate differs across countries

but is constant over time in the data set. While the unit price change of heat pumps over 2011-2017 is less well-documented than the fall in EV prices, heat pumps' efficiency (measured by the coefficient of performance (COP)) has substantially increased in the past decade. The average price includes both aerial and ground source units sold, which may have different capacities and efficiency in given geographies. As the price estimate mask these differences and might not capture prices adjusted for performance over time, they should be interpreted with caution.

- Unlike the subsidies data set, the investment database does not include any estimation of missing values. To avoid picking up false shocks in the analysis, data gaps of at most two years were filled using the last/first available value or the simple average of the neighbours.

The following subset of the *subsidy database* is used:

This case study uses energy efficiency subsidies directed to the heating of buildings. It is assumed that all heating-related subsidies could affect the take-up of heat pumps either positively or negatively. From the available set of economic sectors, subsidies for households, low-income households, the public sector, services and business sectors, and cross-sector subsidies were selected, as all these segments can play an important role in take-up. The set of subsidies was then restricted to those supporting energy efficiency and energy demand.

Two types of subsidies were selected for analysis here:

- *Fossil fuel subsidies:* These subsidies are expected to hinder the take-up of heat pumps. By supporting the energy bill, they reduce incentives to invest in alternative technologies.
- *Other subsidies (Non-fossil fuel subsidies):* These subsidies are non-fossil fuel heating energy efficiency subsidies. A small subset of those are aimed at heat pumps; others are more general and subsidise more efficient heating systems. Focusing only on heat pump subsidies would reduce both the coverage and the insights gained. Only a few countries have explicit heat pump subsidies and general support for modernising heating could boost uptake as well. It is important to note that in this subsidy group it is not possible to separate subsidies directed to solar, geothermal or other non-heat pump renewable heating systems. Therefore, some of these subsidies will increase the use of alternatives to heat pumps.

- Wherever the original subsidy values were missing they have been replaced with estimated values. Subsidies with no values even after the extrapolation were omitted.
- Subsidy values then were deflated to a common 2018 price base and converted to millions of euros.
- The selected subsidies were sense checked and subsidies not closely related to building heating were omitted. For example, subsidies for non-heating efficiency (e.g. lighting, computers, greenhouse cultivation), doing consultancy or supporting specific groups (e.g. armed forces) were omitted. This check ensures a conservative selection of the subsidies used in the analysis, focusing on general building heating purposes and market segments for which heat pump investment is relevant. However, miscellaneous unrelated subsidies may still be present in the filtered data due to the size of the data set and the specificity of the subsidies.
- Table 3-11 shows a selected set of subsidies for Romania:

Table 3-11 Excerpt from the selected heating related subsidies included in the analysis: Romania (RO), million EUR2018

Name of policy (English)	Economic sectors	Main product and carrier	2010	2011	2012	2013	2014	2015	2016	2017	2018
Green House - Program regarding the installation of heating systems using renewable energy, including the replacement or completion of the classic heating systems (beneficiaries - natural persons)	Households	Heat	13.3	35.3	16.0	4.5	0.9	6.2	7.3	2.9	8.1
Monetary aid for partly covering the expenses for the procurement, installation and putting into service of an individual gas boiler or automatic burner	Households - Low Income	Gas	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Excise tax exemption on natural gas consumed by households	Households	Gas	33.1	34.5	35.5	35.9	32.8	33.5	33.5	34.6	38.9
Excise tax exemption on electricity consumed by public institutions	Public	Electricity	1.6	1.5	1.4	1.4	1.4	1.4	1.4	1.3	1.3
Excise tax exemption on natural gas consumed by public institutions	Public	Gas	6.2	6.1	5.8	6.0	6.4	6.3	6.2	6.0	5.8
Allowance for the heating of dwellings in the cold season - heating with thermal energy supplied by the centralized system	Households - Low Income	Heat	34.7	19.7	24.1	20.3	11.9	10.0	6.1	5.1	2.9
Allowance for the heating of dwellings in the cold season - heating with natural gas	Households - Low Income	Gas	67.1	37.7	29.1	24.8	19.0	16.7	11.6	9.5	6.0
Allowance for the heating of dwellings in the cold season - heating with firewood, coal and mineral oil fuel	Households - Low Income	Coal	121.3	56.1	34.9	43.1	2.2	18.2	15.3	11.7	7.2
Allowance for the heating of dwellings in the cold season - electric heating	Households - Low Income	Electricity	0.0	0.0	0.0	0.0	1.1	1.1	0.9	0.7	0.5
Social tariff for Electricity	Households - Low Income	Electricity	52.1	54.7	50.0	49.8	47.5	47.4	42.1	32.7	0.0
National Programme for Energy Performance Improvement of Apartment Buildings	Households	Heat	39.0	38.4	4.4	3.4	13.7	11.6	5.7	2.3	4.3
Regional Operational Programme - Priority Axis 1 - Intervention 1.2. Support investments in energy efficiency in block of flats	Households	Heat	0.0	0.0	0.0	0.0	0.0	0.0	56.7	125.3	0.0

Source: Own calculation based on the subsidies and investment data sets

As additional variables used in the analysis to add to the narrative are the following:

- *Household energy prices:* Gas and electricity prices play a big role in investment decisions in heat pumps. To proxy country-level differences in energy prices, per kilowatt hour electricity and gas prices for medium-sized households were used (Eurostat, 2020), (Eurostat, 2020). High gas prices might increase the investment in heat pumps in countries where gas is normally used for heating, while in other countries it might be irrelevant. Electricity prices may have mixed effects. If electricity is used for heating and especially for cooling, high prices may boost take-up. On the other hand, as heat pumps are operated with electricity high prices may turn households towards other investments, for example towards solar thermal heating;

- *Energy demand for buildings:* This variable is used to normalise the subsidy values and control for the fact that countries with high absolute subsidies tend to have high energy demand as well. In such cases, despite the high absolute values, the subsidy amount relative to energy use could be low. Therefore, a normalised subsidy value is a better indicator when comparing the level of support across countries. Energy demand for households and buildings (other use) is measured in kilotonnes of oil equivalent (ktoe) (based on the Energy Balances data from the IEA (IEA, 2018)). Energy demand is highly correlated with both population and GDP, and thus proxies for both to some extent. It captures the fact that larger countries have a larger buildings sector and richer countries tend to use more energy.
- *Population:* Population (Eurostat, 2020) is used to normalise the heat pump unit sales data, to get a better picture of take-up rates across countries.

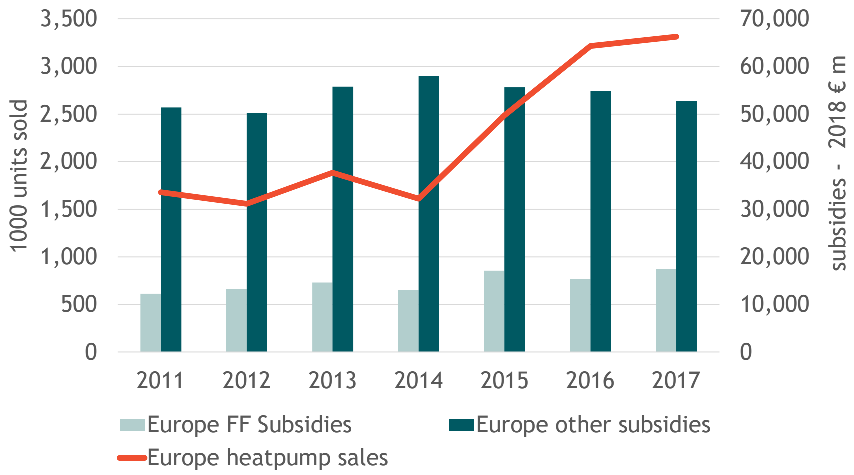
3.5.2 *Descriptive analysis*

Aggregate heat pump sales and subsidies over time

Figure 3-49 shows the aggregate heat pump subsidies for Europe. It should be noted that data on total heat pump sales are only available for EU27+UK and for the years 2011 to 2017. It is also important to note that, even in a sample reduced to Europe, some countries do not have full time series for all variables. Although subsidies are available for a wider range of countries and a longer time frame, for identifying their role in the take-up data are needed for both indicators.

While heat pump sales have increased in aggregate over time, especially in the second half of the time period, the increase is not clearly related to changes in the level of subsidies. Neither type of subsidy exhibits a strong trend at aggregate level; non-fossil fuel subsidies remain four to five times higher than fossil fuel support.

Figure 3-49 Total heat pump sales and subsidies



Source: Own calculation based on the subsidies and investment data sets

Heat pump sales and subsidies across countries

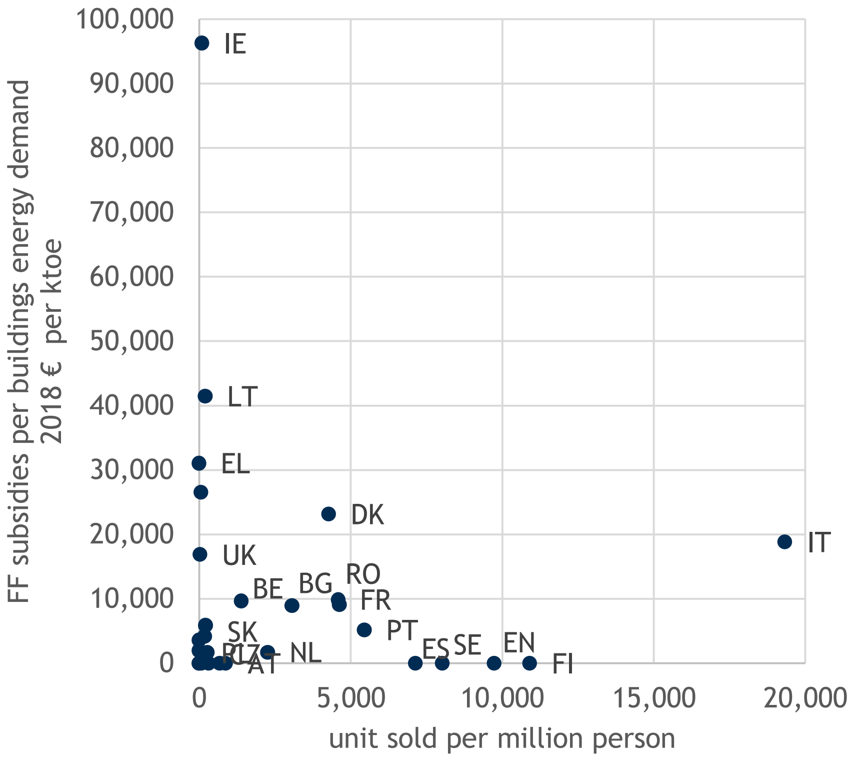
Figure 3-50 to Figure 3-53 compare countries in terms of their normalised average subsidies and heat pump sales (Appendix C Figure C-1 to Figure C-4 presents the absolute values as well). The subsidy values are presented relative to the energy demand of the buildings and heat pump sales are relative to the population of countries. The absolute values mask the fact that large countries tend to have higher subsidy values and sales. The normalised values filter this factor out, and thus reflect better the intensity of subsidies and take-up across countries. For most countries, heat pump sales increase slightly and subsidies show no clear trend. The averages thus help to compare countries without hiding important conclusions.

Figure 3-50 shows the average value of fossil fuel subsidies against sales and Figure 3-51 shows the same but concentrates on countries with small values.[13] The figures reveal that the relationship between fossil-fuel subsidies and sales can vary substantially across countries. Italy has the highest take-up rate with mid-level subsidies, while Sweden, Spain, Finland and Estonia have substantial take-up with no or low-level fossil fuel subsidies. Ireland, Lithuania and Greece show an opposite pattern; high subsidies without substantial sales. Focusing on the non-normalised equivalent figures (Figure C-1 and Figure C-2), countries seem even further apart, with the large EU economies standing out. Italy and Spain have high sales and low subsidies and the UK has the opposite pattern. This figure does not show a clear negative correlation, that countries with low fossil-fuel subsidies have the highest take-up on the average.

Similarly, Figure 3-52 focuses on the average value of non-fossil fuel subsidies against sales, and Figure 3-53 shows countries with small values.[14] In terms of non-fossil fuel subsidies Italy and Estonia have large sales and mid-level subsides while Sweden, Finland and Spain have high take-up with low subsidies. In contrast, Latvia, Austria, the Netherlands and Malta have high subsidies and limited take-up. As before in absolute terms (Figure C-3 and Figure C-4) the large economies stand out. Italy pairs high sales with high subsidies, France takes the middle ground, and the United Kingdom, the Netherlands and Austria have the highest subsidy values. This scatter plot does not suggest a strong correlation for the average indicators either. It is not visible that countries with high non-fossil fuel energy efficiency support for heating have higher investments in heat pumps.

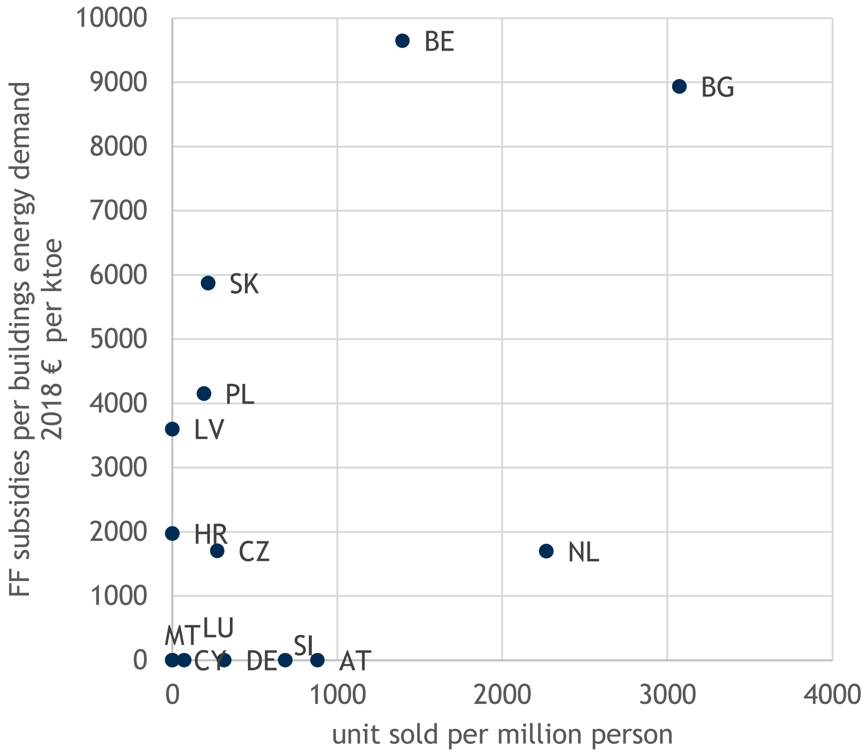
[13] Note that averages are calculated over the years when value was observed to avoid biases from gaps in the data collection (e.g: two years of subsidies are missing in the middle of the timeframe).
[14] Note that averages are calculated over the years when value was observed to avoid biases from gaps in the data collection (e.g: two years of subsidies are missing in the middle of the timeframe).

Figure 3-50 Normalised average fossil fuel building heating subsidies and heat pump sales - subsidies per energy demand and sales per population values (average over 2011-2017)



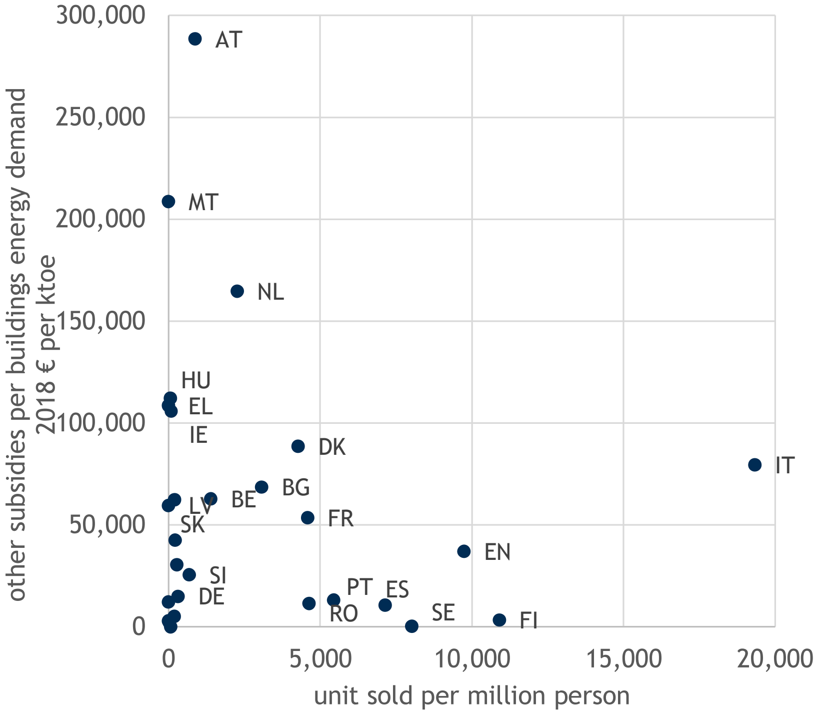
Source: Own calculation based on the subsidies and investment data sets

Figure 3-51 Normalised average fossil fuel building heating subsidies and heat pump sales - small subsidies per energy demand and sales per population values (average over 2011-2017)



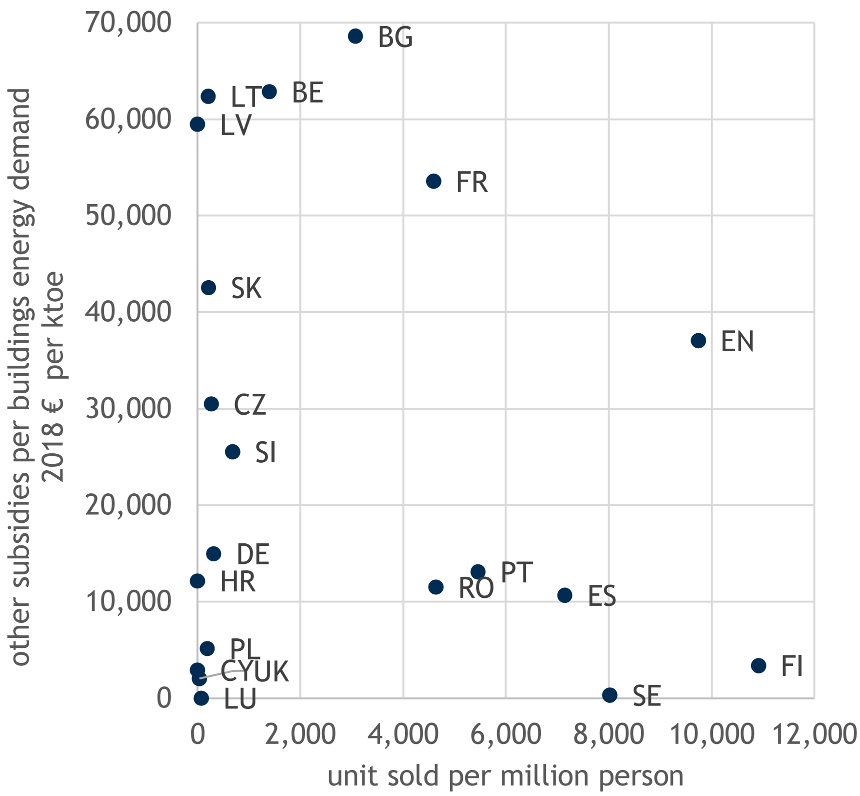
Source: Own calculation based on the subsidies and investment data

Figure 3-52 Normalised average non-fossil fuel building heating subsidies and heat pump sales (average over 2011-2017)



Source: Own calculation based on the subsidies and investment data

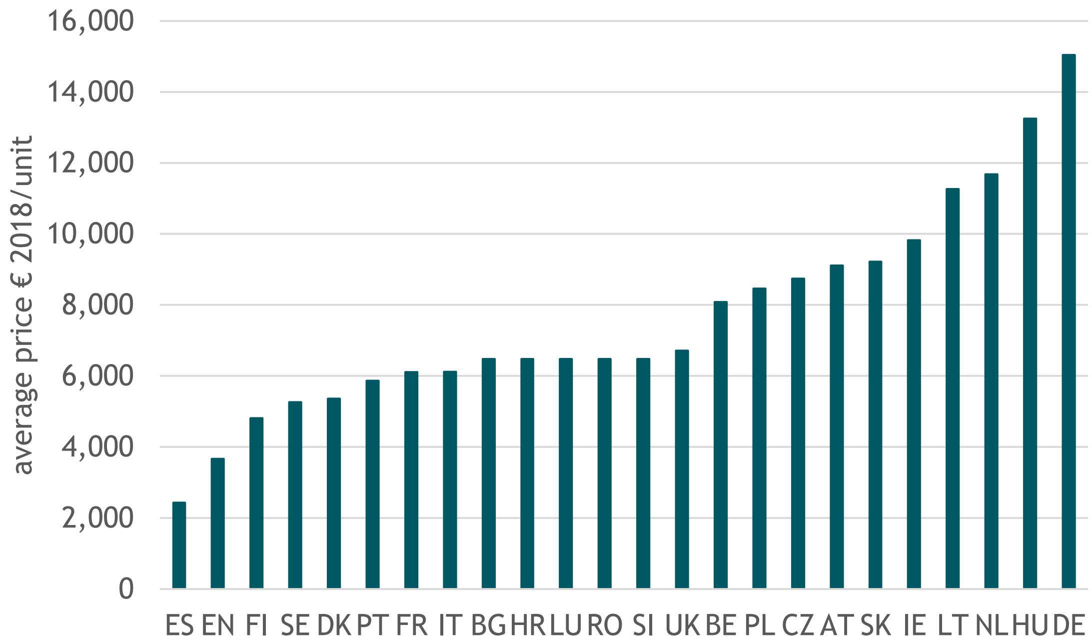
Figure 3-53 Normalised average non-fossil fuel building heating subsidies and heat pump sales - small subsidies per energy demand and sales per population values (average over 2011-2017)



Source: Own calculation based on the subsidies and investment data

Heat pump markets differ substantially across countries not only in their subsidy incentives. The price of heat pumps is a key driver of take-up, which may differ across countries based on geographical factors and the average capacities of units. Figure 3-54 shows a high variation in prices across Europe. For example, Germany with relatively low take-up compared to its market size, faces high costs, while Italy and France have lower average prices and higher take-up.

Figure 3-54 Average heat pump price per unit sold

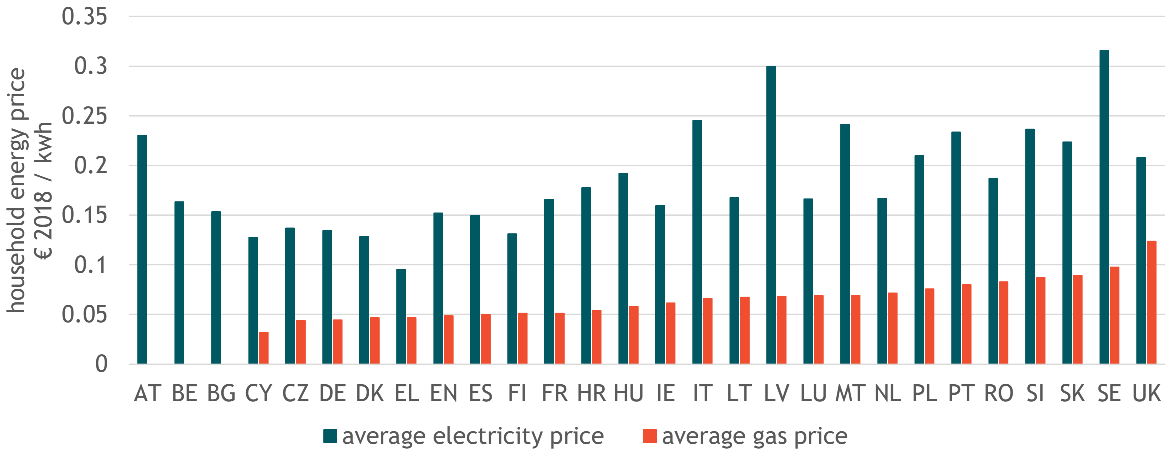


Source: Own calculation based on the investment data

Figure 3-55 shows another important determinant of take-up rates, household energy prices for natural gas and electricity. As noted above, high household gas prices can provide an incentive for installing heat pumps, but high electricity prices may have mixed effects. The connection between prices and take-up is not clear. Some high take-up countries, for example Sweden, have both high electricity and gas prices which may boost take-up. Italy has high electricity prices, which due to its substantial costs in cooling, might boost take-up.

Other policies and market characteristics may differ across countries too, creating country-specific investment incentives. These patterns can be better examined in country-specific charts plotting the evolution of sales and subsidies over time, as shown in the next section.

Figure 3-55 Household gas and electricity prices



Source: (Eurostat, 2020), (Eurostat, 2020)

Heat pump sales and subsidies over time and across countries

This section focuses on economies with large markets to give an overview of the potential relationship between heat pump take-up and subsidies over time. Figure 3-56 to Figure 3-59 show a mixed pattern. In most cases there is no clear link between subsidies and heat pump take-up rates.

In Italy, which is the country with the highest take-up, sales slightly decrease from a very high initial level, then take off again in the second half of the period. This trend is accompanied by slow growth in both fossil fuel and other non-fossil fuel subsidies. In Italy, air source heat pumps are the most widespread, which are usually used for cooling purposes only, whose purpose otherwise would be served by electric air conditioners (EurObserv'ER, 2013). Therefore, fossil fuel subsidies may not play as strong a role in Italy as in other countries where fossil fuel use for heating is important. The initial decrease compared to the high installed capacities, is likely to be caused by slow-down in the Italian economy, the construction sector and low heat pump subsidies. As subsidies pick up in later years, including three different support schemes for heat pumps, sales start to grow (EurObserv'ER, 2015).

In Germany, heat pump sales are low and relatively stable, except for a spike in 2015. There are no fossil fuel based building heating subsidies and only a relatively low-level non-fossil fuel based support is in place. In Germany, mostly reversible air source heat pumps are used both for heating and cooling. However, they are not included in renewable energy targets; therefore, the scope of explicit subsidy schemes for them are limited (EurObserv'ER, 2018). Weak subsidies paired with low heating fuel prices led to a limited take-up of heat pumps during the observed time frame.

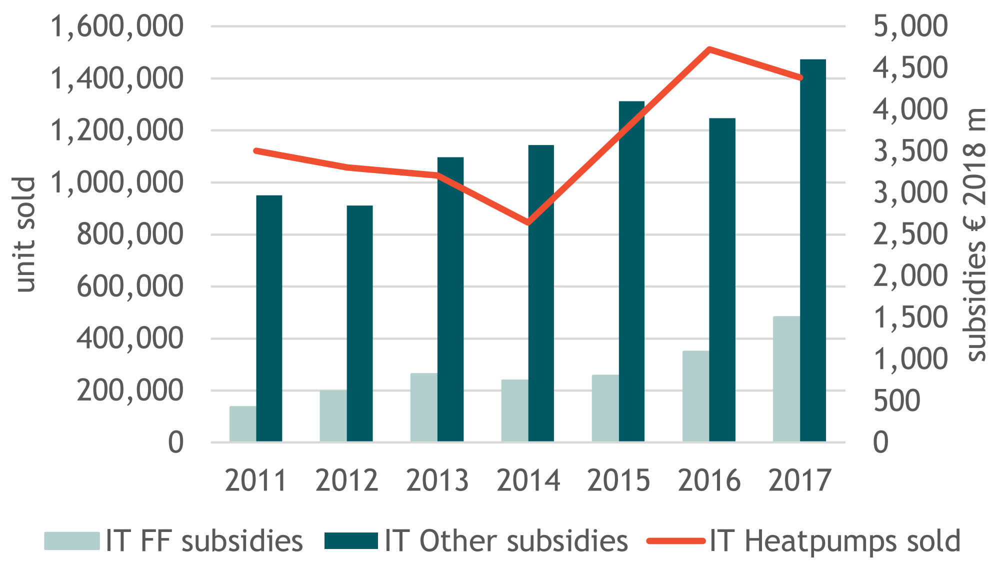
France experiences a large jump in heat pump sales, accompanied by growth in other subsidies and stagnating fossil fuel support. Based on (EurObserv'ER, 2018), in France heat pumps are mostly used for cooling only and take-up increased due to a combination of a 2012 thermal regulation and allowance for heat pumps, improving consumer awareness and a slight price decrease.

The UK is one of the few countries in our sample with higher fossil fuel than non-fossil fuel heating subsidies over the observed period, which are mainly directed to help low-income families which would not buy heat pumps . The level of heat pump sales is relatively low and does not have a clear upward or downward trend. Despite the increasing subsidy for installation provided by the Renewable Heating

Incentive, sales do not increase substantially. Other alternatives, for example gas boilers, are still more attractive based on their lower initial costs, especially for landlords (Fawcett, T., 2011), (Greenmatch, 2020). It should be noted that the Renewable Heating Incentive also covers other renewable heating options, for instance biomass and solar thermal heating. Therefore, instead of investments in heat pumps, retrofitting, building insulation and low-carbon electricity provision remain the main tools of decarbonising the heating in buildings.

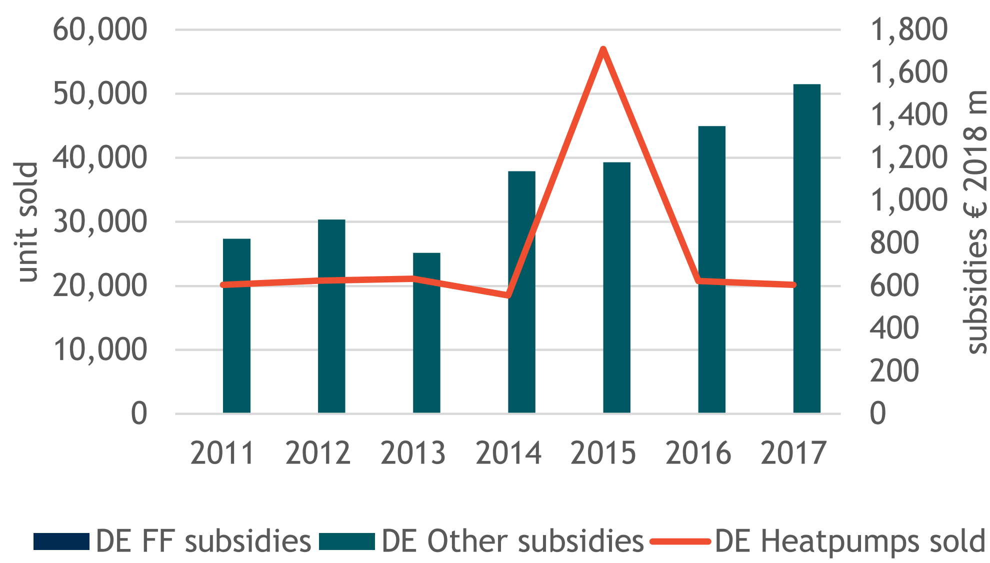
Although, the country graphs do not show a strong relationship between the subsidies and sales indicators, the next section will proceed to regression analysis. Controlling for other important determinants of the sales clears up the relationship between the subsidies and heat pump take-up.

Figure 3-56 Heat pump sales and building energy efficiency subsidies: Italy



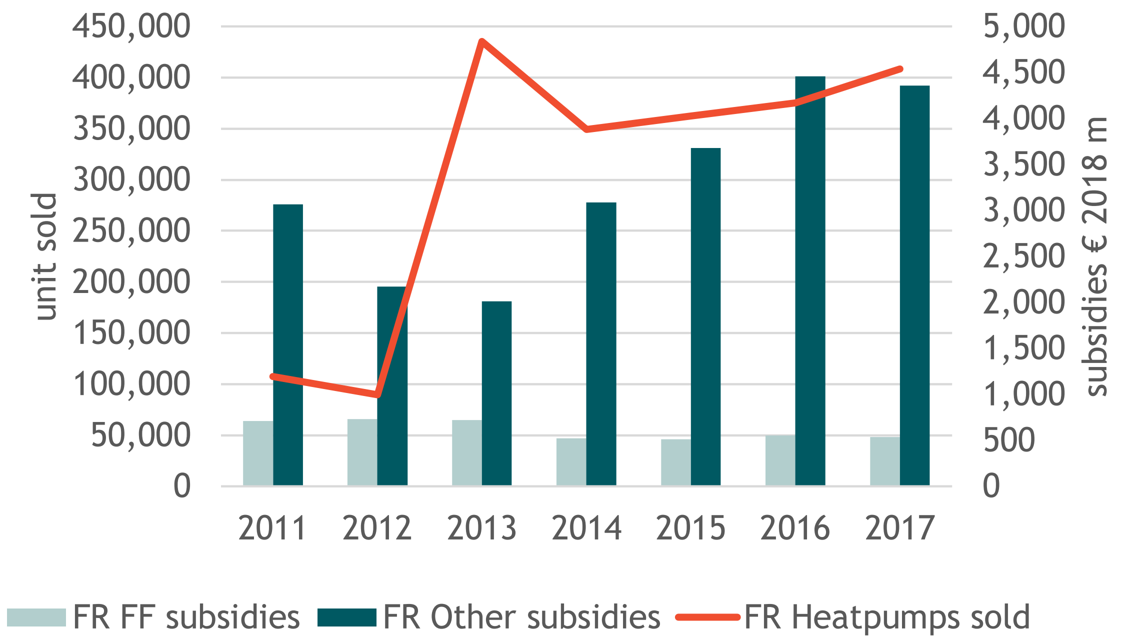
Source: Own calculation based on the investment data

Figure 3-57 Heat pump sales and building energy efficiency subsidies: Germany



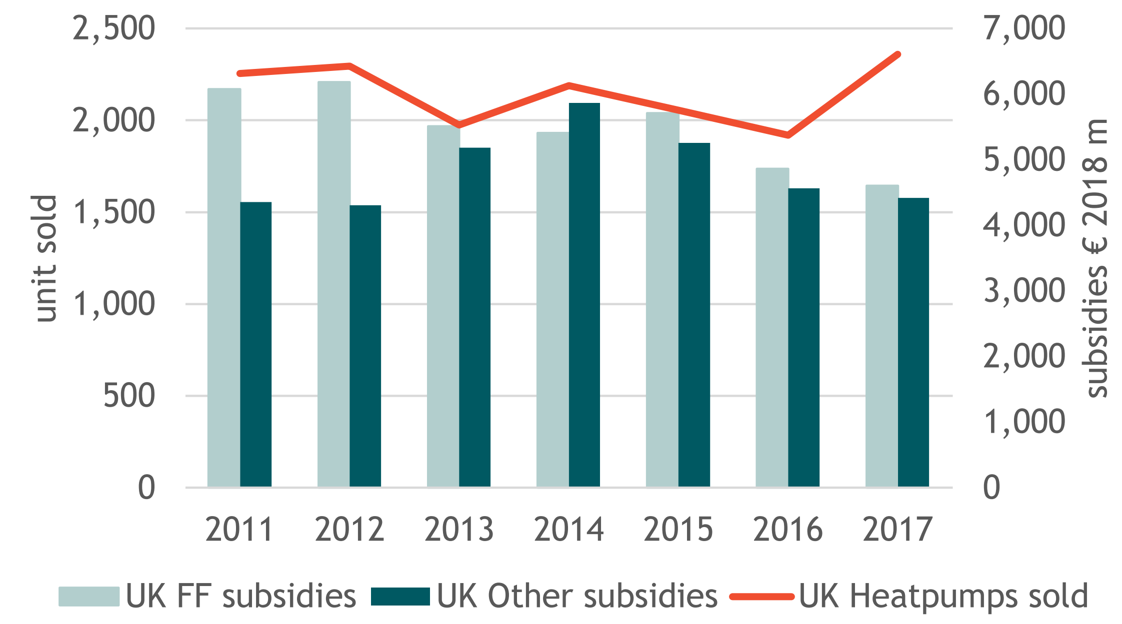
Source: Own calculation based on the investment data

Figure 3-58 Heat pump sales and building energy efficiency subsidies: France



Source: Own calculation based on the investment data

Figure 3-59 Heat pump sales and building energy efficiency subsidies: United Kingdom



Source: Own calculation based on the investment data

3.5.3 Econometric analysis

The general form of the regression model is shown below. It captures all potential variables which the specifications control for. In this case study only pooled OLS regressions are estimated, due to the reduced timeframe and country coverage. The sample size is considered too small for more sophisticated analysis, which would not give robust results with such few observations. Because in pooled OLS models the error term is often correlated over time and across countries, robust errors are used.

Equation 3 General model of buildings heating subsidies and heat pump sales

$$\ln\left(Heat\ pumps\ sales_{it}\right) = \beta_0 + \beta_1 \ln(Subsidies{:}\ FF)_{it} + \beta_2 \ln(Subsidies{:}\ Other)_{it} + \beta_3 \ln(Energy\ demand)_{it} + \beta_4 \ln(Heat\ pump\ price)_i + \beta_5 \ln(HH\ gas\ price)_{it} + \beta_6 \ln(HH\ electricity\ price)_{it} + \lambda_t + \varepsilon_{it}$$

$$t = 1,2 \ldots T\ (years), \qquad i = 1,2 \ldots .N\ (countries)$$

The key parameters are β_1 and β_2. β_1 identifies the impact of fossil fuel subsidies and β_2 captures the effect of non-fossil fuel subsidies on heat pump sales. As the model is estimated using variables in their natural logarithms β_1 is interpreted as a percent change response: if the value of fossil fuel subsidies increases by one percent, heat pump sales are expected to change by β_1 percent (with all other factors assumed unchanged). Fossil fuel subsidies are expected to have a negative impact on take-up rates, while non-fossil fuel subsidies can have positive or mixed effects. Negative impacts for non-fossil fuel subsidies may arise because the subsidies included in the category are mixed.

Other factors that are potential drivers of heat pump take-up are included:

- *Energy demand for buildings* is included as a proxy for the potential market size of heat pumps in each country. The larger the energy demand, the more that sales could grow. Controlling for energy demand is also important, because the size of subsidies can be captured better in terms of per unit of energy used. Here, a positive impact is expected in that absolute sales are higher in larger markets. Energy demand is highly correlated with both the population and GDP of a country, and thus proxies for both to some extent. It captures the fact that larger countries have a larger buildings sector and richer countries tend to use more energy. With the energy demand variable in the regression, there is no need to control for national income or for population (it would cause statistical problems (multicollinearity) to do so) The multicollinearity issue also explains why we don't also account for heating & cooling days which are also highly correlated with energy demand for buildings;
- *Heat pump prices* control for the variation in average investment cost differences across countries, accounting for geographical differences. It is expected that prices will have a negative effect on sales;
- *Household gas and electricity prices* are used to capture incentives to invest in heat pumps. In principle, high household energy prices are expected to boost investment in heat pumps but heat pumps require electricity to run as well;
- λ_t captures annual effects in the regression. The year effects control for shocks which hit all countries uniformly in a given year, for instance a changing economic environment. Controlling for this also helps to purge potential autocorrelation from the residuals often cause problems in pooled OLS models.

Estimation Sample

The descriptive analysis showed that information on heat pump sales is available for 2011-2017 for most of the EU27 (except Croatia, Latvia, Cyprus, and Malta) and the UK. While non-fossil subsidies are observed for all countries, Austria, Germany, Estonia, Spain, Luxembourg, Finland, Slovenia and Sweden do not have any heating-related fossil fuel subsidies. However, it is difficult to tell whether these countries truly do not have fossil fuel subsidies for heating or their subsidy schemes in place are not observed in our data set. Depending on the source of zero subsidies, different models describe the drivers of take-up better. Therefore, we provide regression estimates on two different samples:

- *Fossil fuel subsidies subsample (countries with both fossil fuel and non-fossil subsidies observed).* For these countries both types of support is observed, and their impact could be identified. In the cases where zero subsidies are data collection errors, estimations conducted in this subsample identify the true relationship better.
- *Full sample*. This sample includes all countries, even those without fossil fuel subsidies for heating. If countries with no observed fossil fuel support truly do not have any schemes in place, this regression provides a more comprehensive analysis.

Estimation results

Table 3-12 shows the regression results for the selected specifications estimated on the two subsamples. For each subsample three OLS models were selected, which differ in the control variables used. The first model only controls for subsidies, heat pump prices and energy demand; the second adds household gas and electricity prices while the third controls for time effects.

The direction of the impacts is the same in all models for the two subsamples and is in line with our expectations. However, the strength of the effect and the significance of parameters differs for them, which may stem from the small sample size. In the subsample of countries having both fossil fuel and non-fossil fuel subsidies, the models find moderate but similar effects for fossil fuel subsidies: 1 percent higher fossil fuel subsidies for buildings heating reduce heat pump sales by 0.35-0.43 percent, with all other factors held constant. However, when estimated on the full sample this impact loses significance and the parameters have smaller values. Non-fossil fuel subsidies only have a significant positive impact in one of the specifications, which could be due to the mixed nature of these subsidies. In line with expectations, heat pump sales are higher with higher energy demand, and lower when heat pumps are more expensive. Both variables are highly significant and have very strong impacts. Household energy prices also have mixed effects; although gas prices have a positive coefficient the impact is not significant. The electricity price has a significant and negative impact. As explained before this could stem from the attractiveness of alternative investments or the importance of high operation costs in the investments (Fawcett, T., 2011).

Our estimations using two different samples did not lead to a uniform conclusion on whether fossil fuel subsidies hinder the take-up of heat pumps, finding negative to no impacts. However, due to the small sample size and the potential omitted variables (e.g. missing information on types, capacities and the alternatives to heat pumps) the strength of this conclusion is limited and should only be generalised cautiously. The regression results did show a consistently strong relationship between heat pump prices and take up, suggesting that upfront costs are a key driver of heat pump uptake and other factors have a limited role.

Table 3-12 Regression results for heat pump take-up

	ln(Heat pump sales)					
	Fossil fuel subsidies subsample			Full sample		
	(1)	(2)	(3)	(1)	(2)	(3)
ln(FF subsidies)	-0.425**	-0.348**	-0.429***	-0.0924	-0.0835	-0.0980
	(0.172)	(0.171)	(0.162)	(0.0615)	(0.0608)	(0.0615)
ln(Other subsidies)	0.194	0.166	0.182	0.122	0.134*	0.125
	(0.121)	(0.117)	(0.116)	(0.0812)	(0.0711)	(0.0801)
ln(Heat pump price)	-5.244***	-5.268***	-5.215***	-3.014***	-2.739***	-3.015***
	(0.413)	(0.442)	(0.416)	(0.340)	(0.354)	(0.329)
ln(Energy demand)	1.000***	0.971***	1.033***	1.236***	1.288***	1.248***
	(0.152)	(0.150)	(0.150)	(0.102)	(0.102)	(0.102)
ln(Electricity price)		-1.608**			-2.000***	
		(0.755)			(0.578)	
ln(Gas price)		1.273			1.799***	
		(0.863)			(0.623)	
Constant	47.77***	48.84***	47.10***	24.24***	22.77***	23.69***
	(3.942)	(3.673)	(3.969)	(2.686)	(2.735)	(2.643)
Observations	103	103	103	161	161	161
R-squared	0.596	0.611	0.621	0.568	0.598	0.591
Type	OLS	OLS	OLS	OLS	OLS	OLS
Sample	FF	FF	FF	Full	Full	Full
Countries	15	15	15	23	23	23
Country effects	no	no	no	no	no	no
Year effects	no	no	yes	no	no	yes

Robust standard errors in parentheses, *** p<0.01, ** p<0.05, * p<0.1
Note: AT, DE, EN, ES, FI, LU, SI, SE do not have fossil fuel subsidies for heating, they are not included in the FF subsample, only the full sample analysis. In the full sample regression subsidy values were converted to natural logarithms using ln(x+1) formula to include countries with missing observations for fossil fuel subsidies in the regression.
Source: Own calculation

3.5.4 Key messages

This case study analysed the take-up of heat pumps in Europe and its main drivers. The focus was on how fossil fuel and non-fossil fuel subsidies for the heating of buildings affected the take-up of heat pumps, taking into account the energy demand of the sector, heat pump prices and energy prices.

The descriptive analysis identified strong differences between countries. Some countries have high sales without considerable non-fossil subsidies or despite high fossil fuel subsides. The regression analysis reveals that this relationship cannot be meaningfully assessed focusing on these two indicators only. Investment costs, energy demand and energy prices could all play an important role in take-up patterns. Controlling for all these factors, the pooled OLS regression models found that fossil fuel subsidies have a small negative impact on subsidies, which is a robust result across specifications. However, due to our limited geographical coverage, short time frame and variables used it should be generalised with care. Additional data on specific heat pump support schemes and the alternatives would make the analysis more robust.

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Annex A - Definitions

Table A-0-1: Country abbreviations list (ISO 2-digit codes)

EU28	Code	Non-EU G20	Code
Austria	AT	United Kingdom	UK[15]
Belgium	BE	Argentina	AR
Bulgaria	BG	Australia	AU
Croatia	HR	Brazil	BR
Cyprus	CY	Canada	CA
Czech Republic / Czechia	CZ	China	CN
Denmark	DK	India	IN
Estonia	EE	Indonesia	ID
Finland	FI	Japan	JP
France	FR	Mexico	MX
Germany	DE	Russia	RU
Greece	EL / GR	Saudi Arabia	SA
Hungary	HU	South Africa	ZA
Ireland	IE	South Korea	KR
Italy	IT	Turkey	TR
Latvia	LV	United States	US
Lithuania	LT		
Luxembourg	LU		
Malta	MT		
Netherlands	NL		
Poland	PL		
Portugal	PT		
Romania	RO		
Slovakia	SK		
Slovenia	SI		
Spain	ES		
Sweden	SE		

[15] UK is used in this work (as this is the EC convention) noting that the ISO code is GB

Annex B - Detailed methodology description

This annex provides additional technical detail to what is provided in the report on the scope and methodology of the data collection and analysis of investments.

Definition of investments

Within the scope of this study 'investments' are defined as overnight investments in new capacities or capitalised refurbishments, measured in monetary terms (e.g. Euros). Investments include both public and private sector investments. Investments are counted in the year in which the installation/project becomes active, i.e. investments are not spread out over the construction period.

Scope and definition of investment categories

The definitions of the investment categories in scope are provided in Table B-1.

Table B-1 Definition of investment categories in scope

Supply chain link & technologies	Definitions
Extraction (only upstream excluding midstream and downstream)	
Coal extraction	CAPEX and exploration CAPEX in coal mining and infrastructure
Gas	CAPEX and exploration CAPEX in Gas and Natural Gas Liquids (NGL)
Oil	CAPEX and exploration CAPEX in Oil and Condensate
Production	
Biofuel production	Investments in production capacities for liquid bio-based transportation fuels including biodiesel and bioethanol
Bio-power from biogas	Investments in capacities to generate power from biogas, including combined heat and power (CHP)
Bio-power from solid biomass	Investments in capacities to generate power from solid biomass, including combined heat and power (CHP)
Bio-power from waste	Investments in capacities to generate power from waste, including sewage gas
Coal-fired power plants	Investments in coal-fired power plants, including combined heat and power (CHP)
Gas and oil-fired power plants	Investments in gas and oil-fired power plants. Includes utility-scale plants as well as small-scale generating sets and engines, including combined heat and power (CHP)
Geothermal direct use, heat	Investment in capacities for direct use of deep geothermal resources for heating, irrespective of scale. This is excluding heat from shallow geothermal resource utilisation (such as ground-source heat pumps) and excluding geothermal resources for electricity production
Geothermal - electricity	Investments in capacities for electricity production from geothermal resources, including combined heat and power (CHP)
Hydro power - large (>50MW)	Investments in large hydropower plants (>50 MW), excluding pumped hydro
Hydro power - small (>50MW)	Investments in small hydropower plants (<50 MW)

Supply chain link & technologies	Definitions
LNG liquefaction and/or regasification	Annual spending on LNG liquefaction and/or regasification projects (LNG terminals)
Modern bio-heat	Investments in bioenergy heat plants, excluding combined heat and power (CHP), excluding residential bio-heat
Nuclear power plants	Investments in nuclear power plants
Oil refining	Investments in new refining capacities and capitalised maintenance expenditure
Ocean energy power plants	Investments in marine and ocean power installations, including wave energy, tidal energy, ocean thermal energy conversion (OTEC) and salinity gradient, excluding offshore wind
Concentrated Solar Power (CSP)	Investments in CSP installations to generate electricity
Solar (PV) power - rooftop	Investments in solar (PV) power on rooftops (either residential or commercial)
Solar (PV) power - utility scale	Investments in solar (PV) power in utility scale projects (industrial/utility projects)
Solar thermal heating	Investments in solar collectors for space and water heating
Wind power - offshore	Investments in offshore wind farms
Wind power - onshore	Investments in onshore wind farms
Storage	
Battery storage	Investments in stationary electro-chemical storage capacities (excluding portable batteries and batteries of electric passenger vehicles)
Pumped hydro	Investments in pumped hydro plants
Underground gas storage[16]	Investments in facilities to store gas in depleted oil/gas fields, salt caverns or aquifers. Including infrastructure (e.g. pipelines) to connect to the gas grid
Transmission and distribution	
Transmission – electricity	Per definitions used in task 4
Transmission – gas	Per definitions used in task 4
Distribution – electricity	Per definitions used in task 4
Distribution – gas	Per definitions used in task 4
Distribution – heat	Investments in district heating networks
Energy efficiency / consumption	
Building - heat pump aerial	Investments in air-air heat pumps, including reversible heat pumps
Building - heat pump ground	Investments in ground heat pumps (geothermal)
Transport: electric passenger vehicles	Investments in all-electric passenger vehicles

Refurbishments are only included in the estimates of certain technologies (extraction: oil, gas and coal extraction; production: oil refining, LNG liquefaction and/or regasification, coal fired power plants, gas and oil-fired power plants, nuclear power plants and hydro power - large). For all other technologies, investment data refers to new capacities only. This difference in approach is due to data availability limitations. However, the categories for which there was insufficient data on refurbishments are

[16] For underground gas storage no reliable method could be found to estimate investments in monetary (EUR) values. Hence, only investments in terms of capacity additions are available in the dataset

generally categories where we expect limited refurbishments as the deployment of these technologies at scale only happened recently (if at all). Hence, we do not consider the omission of refurbishments to have a major impact.

Investments in combined heat and power production installations (CHP) are included in the relevant power production technology. Investments in gas-fired CHP installations are for instance captured under 'gas and oil-fired power plants'.

Data on investments in transmission and distribution infrastructure for electricity and gas are collected in task 4. For any information on definitions and scoping, please refer to the main report and annex texts for that task.

Incremental spending on more energy efficient equipment in households, industry and transport were excluded from our scope of analysis for several reasons. First, there is a lack of publicly available data on these investments and the privately held information is very expensive. Secondly, incremental spending cannot be directly compared to full investments in new capacities (i.e. the measure in the other categories) and definitions vary across sources. Thirdly, methods to estimate incremental spending use highly aggregated data and various assumptions to estimate a high-level figure of the likely investment volumes. These estimates are not robust enough to be useful for evaluating the impact of policies on investments, and presenting such high-level figures alongside our other, much more robust data, could lead to unintended interpretations and uses.

Monetisation of capacity estimates

In cases where no investment data in monetary terms could be found from transversal or national sources, we have estimated investments based on capacity additions. Our approach for this uses gross capacity additions per year and multiplies this value with an estimate of the investment cost per unit of capacity. The investment cost could be differentiated over time and per country to account for trends and country-specific factors. But such differentiating may also lead to less robust figures due to smaller sample sizes, and so it is not always appropriate to do so. To determine the appropriate level of differentiation we assess the following dimensions of each technology:

1. Scale of deployment: a minimum volume of new capacity needs to be installed to allow for sufficiently robust figures;
2. Cost trend: for technologies with a strong trend in their costs, investment costs need to be differentiated per year. If no such trend exists, the same costs can be applied for all years;
3. Geographical differences: if country-specific factors lead to significant differences in investment costs, estimates need to be differentiated per country or region.

Based on these dimensions, we developed four main approaches to monetise capacity estimates, as summarised in the table below.

Table B-2 Monetisation approaches

Dimension			Approach
Scale of deployment	Cost trend	Geographical differences	
Insignificant	Yes/No	Yes/No	1. Global average
Significant	No	No	1. Global average
Significant	Yes	No	2. Global average per year
Significant	No	Yes	3. Regional / country-specific average
Significant	Yes	Yes	4. Regional / country-specific average per year

In the next sections we discuss the assessment of these dimensions, the chosen approach and any relevant details per technology. For each technology, we present the resulting investment cost estimates, too. It is important to stress that this approach is primarily used for gap-filling for smaller markets. For the largest markets (e.g. China) we generally have investment data. Hence, there is in some cases no need (and often no data) for a highly sophisticated approach.

Conventional electricity generation

Conventional electricity generation sources (gas, coal and nuclear) are mature technologies with relatively stable investment costs. As a result, there is less literature on investment cost developments than for renewable electricity generation. The main source that we used to estimate investment costs was the IEA's World Energy Outlook series, and in particular the underlying cost assumptions in the 2016 edition.

Coal-fired power plants

The IEA does not assume a learning rate for coal-fired power but does assign significantly different estimates per region/country. Hence, we also assign different values per country/region but the same values for all years. Not all countries in the scope of our analysis are covered by the countries/regions that are available in the IEA assumptions.[17] For the missing ones we have assumed investment costs equal to the average of the other countries/regions, excluding the values for China and India which are very low probably due to the large scale of deployment in these countries, which we do not consider representative for the missing countries. We distinguish the same three types of coal-fired power plants that the IEA distinguishes (subcritical, supercritical and ultra supercritical).

The investment costs that we apply are listed in the table below.

Table B-3 Applied investment costs for coal-fired power plants

Country/region	Investment cost (€/kW)		
	Subcritical	Supercritical	Ultra supercritical
Europe	1700	2000	2200
United States	1800	2100	2300
Japan	2100	2400	2600
Russia	1700	2000	2200
China	600	700	800
India	1000	1200	1400
Middle East	1300	1600	1600
Africa	1300	1600	1900
Brazil	1300	1600	1800
Rest of world	1600	1900	2086

[17] Argentina, Australia, Canada, Indonesia, Mexico, South Korea, and Turkey are missing.

Gas and oil-fired power plants

For gas and oil-fired power plants we use the same approach as for coal-fired power. We have taken three types of gas-fired power plants that the IEA distinguishes (combined cycle, combined cycle CHP and gas turbine). Aside from this, we added diesel generators as an extra category. This category was not distinguished by the IEA, but appeared to be relevant based on the data on capacity additions. We assume that the costs for diesel generators do not vary significantly over time / between countries. We used the value from Timera Energy UK[18]. The resulting investment costs are listed in the table below.

Table B-4 Applied investment costs for gas and oil-fired power plants

Country/region	Investment cost (€/kW)			
	Combined cycle	Combined cycle CHP	Gas turbine	Diesel generator
Europe	1000	1300	500	344
United States	1000	1300	500	
Japan	1100	1440	500	
Russia	800	1040	450	
China	550	720	350	
India	700	920	400	
Middle East	800	1040	450	
Africa	700	920	400	
Brazil	700	920	400	
Rest of world	871	1137	457	

Nuclear power plants

For nuclear we use the same approach as for coal, gas and oil-fired power. For nuclear the IEA does not specify different sub-technologies, so there is no need for averaging. The resulting investment costs are listed in the table below.

Table B-5 Applied investment costs for nuclear power plants

Country/region	Investment cost (€/kW)
Europe	6600
United States	5000
Japan	4000
Russia	3800
China	2000
India	2800
Middle East	3500
Africa	4000
Brazil	4000
Rest of world	4414

Renewable electricity generation

Renewable electricity generation cost trends are well documented. For our assessment, we use two major publications which together cover all renewable electricity technologies:

- IRENA (2019) – Renewable power generation costs in 2018[19];
- Trinomics et al. (2019) – Study on impacts of EU actions supporting the development of renewable energy technologies.

[18] Timera Energy UK – July 2014. Available at https://timera-energy.com/investment-in-uk-peaking-assets/
[19] Including more details from the underlying dataset

For assessing geographical differences, we also draw on the estimates of the IEA from the World energy Outlook (2016 edition).

Solar PV

Solar PV investments are assessed for utility scale and rooftop solar PV projects separately. For both technologies, a clear downward cost trend has been identified, with a decrease in total investment costs of approximately 70% between 2008 and 2018. Hence, there is a clear need to differentiate the estimates per year. There are also clear geographical differences in investment costs, with the highest cost countries facing investment costs three times as high as the countries with the lowest costs. Developing specific estimates per country/region is not straightforward, however, as there is not always a similar pattern and ranking over the years, potentially due to project-specific factors in regions with small data samples. Using such fluctuation values as investment cost estimates may not be a robust approach.

In the approach that we chose we use the IRENA data to estimate the global average cost reduction over time. The PV utility scale data concerns global weighted averages for 2010-2018 and simple averages of country estimates for 2008 and 2009. For rooftop PV, simple averages of country estimates have been used for all years. The resulting investment costs are shown in the table below.

Table B-6 Applied investment costs for solar PV

Technology	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Utility scale (€/kW)	6229	5186	4621	3891	2933	2569	2323	1825	1609	1389	1210
Rooftop (€/kW)	8824	7850	6831	6634	4799	3681	3293	2715	2453	2199	1986

Next, multipliers per country/region were developed by scaling the country/region-specific IEA estimates for 2015 to the IRENA estimates for 2015. The resulting values are shown in the table below. The 'rest of the world' estimates apply to the G20 countries that are not covered by the countries/regions that the IEA distinguishes[20] and is calculated as an average of the other countries/regions, excluding the most developed and low cost markets of China, India and Europe. This is because we do not consider these representative for the smaller, less mature markets in the 'rest of the world' countries.

Table B-7 Applied multipliers per country/region for solar PV

Country/region	Multiplier utility scale	Multiplier rooftop
Europe	0.72	0.59
United States	1.22	1.28
Japan	1.11	1.06
Russia	1.41	1.28
China	0.75	0.55
India	0.73	0.54
Middle East	1.29	1.10
Africa	1.31	1.05
Brazil	1.08	0.99
Rest of world	1.24	1.13

[20] Argentina, Australia, Canada, Indonesia, Mexico, South Korea, and Turkey.

Wind power

For wind power, there is also a clear cost reduction trend as well as geographical differences. We distinguish onshore and offshore due to significantly different investment costs and use the same approach and data sources as for solar PV to arrive at time and country/region-specific estimates.

The investment cost trends are displayed in the table below. For 2010-2018 the values are global weighted averages. For 2008 and 2009 the values are simple averages of all available country estimates.

Table B-8 Applied investment costs for wind power

Technology	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Onshore (€/kW)	2164	2092	1915	1905	1938	1797	1757	1612	1611	1600	1498
Offshore (€/kW)	5246	4426	4572	5397	4784	4982	5354	5086	3764	4642	4353

The multipliers per country/region are shown in the table below. The rest of world estimate is calculated as an average of all countries/regions, excluding China, India and Europe, similar to the approach used for solar PV.

Table B-9 Applied multipliers per country/region for wind power

Country/region	Multiplier onshore	Multiplier offshore
Europe	1.14	0.90
United States	1.07	1.02
Japan	1.38	1.06
Russia	1.33	1.00
China	0.77	0.87
India	0.84	0.91
Middle East	1.25	0.95
Africa	1.17	0.92
Brazil	0.86	0.95
Rest of world	1.17	0.99

Hydro power

For hydropower there is no clear cost trend visible in the data so we assume the same investment cost for all years. The data shows large variation in costs between countries but also within countries, due to the high impact of project-specific factors. As a result, we do not consider it appropriate to differentiate the costs per country. The relation between the size of the installation and the investment cost is also not very clear from the data, with large fluctuations between the weighted average per capacity range. While the conventional wisdom is that small scale projects (<50 MW) face higher costs, the numbers reported by IRENA do not confirm such a finding.[21] Overall, we conclude that it is best to use one investment cost estimate for all hydropower capacity additions, for which we use the average value of the investment cost estimates of IRENA for the 2008-2018 period: 1533 USD/kW.

[21] Weighted average investment cost of projects < 50 MW: 1490 €/kW. Simple average of weighted averages of capacity ranges > 50 MW: 1586 €/kW. Source: IRENA (2019) - Renewable Power Generation costs in 2018.

Biopower

For biopower we distinguish three investment categories: biopower from solid biomass, biopower from biogas and biopower from waste. The investment cost data shows large variation in costs between technologies but also for data points of the same technology. Furthermore, no clear cost trend over time can be discerned from the data. There are also substantial inconsistencies between the scope of technological categories in the different sources, which complicates estimating investment costs at sub-technology level. Overall, we conclude that it is best to use the average values of the IRENA 2008-2018 investment cost estimates for all years, countries and technologies: 2436 USD/kW.

Concentrated solar power (CSP)

For concentrated solar power there is a clear downward trend in the investment costs so we assume different values per year. As the capacity additions have been limited, there is little data to develop robust estimates of differences between countries. So we use the global weighted average investment cost[22] per year for all countries/regions. The values are shown in the table below.

Table B-10 Applied investment costs for concentrated solar power

Concentrated solar power	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Investment cost (€/kW)	13611	6866	9333	10710	8555	7255	5851	8200	8541	9004	5204

Geothermal

For geothermal electricity generation there is limited data which does not show a clear trend over time and does not allow to make robust country or region-specific estimates. Hence, we use the average of the 2008-2018 global weighted averages as our estimate for investment costs per unit of capacity: 3713 USD/kW.

Ocean

For ocean energy there has been very little capacity installed overall. We use the average of the regional values used by the IEA in their World Energy Outlook (2016 edition) as our estimate for investment costs per unit of capacity: 6719 USD/kW.

Renewable heat and transport fuels

Solar thermal heating

Data on solar thermal heating is relatively scarce compared to electricity generation. Additionally, there are many different applications and technologies which complicate the identification of trends. Based on the data that we gathered in a previous study[23], no clear cost trend could be discerned. Hence, we take the same investment costs estimate for all years.

The main markets for solar thermal heating are China (71% of global capacity in operation) and Europe (11% of global capacity in operation), also when looking at newly installed capacities (2016: China 76%, Europe 9%).[24] There are clear differences in technologies applied, with China mainly choosing for

[22] For 2008 and 2009 IRENA does not report global weighted average but only per country. We take the average of the country values as the global weighted average.
[23] Trinomics et al. (2019) – Study on impacts of EU actions supporting the development of renewable energy technologies
[24] IEA-SHC (2018) – Solar Heat Worldwide 2018

evacuated tube collectors and thermosiphon systems, while Europe chooses for flat plate collectors and pumped systems. Furthermore, there is a group of countries (US, Canada, Australia) which primarily uses solar heating for swimming pools, which applies technology (unglazed collectors) with a much lower investment cost per unit of capacity. The applications and technologies in other parts of the world (Latin America, Africa) are more mixed, with limited capacity additions. Overall, we consider it appropriate to apply different investment cost estimates for China, Europe, the group of US/CA/AU, and the rest of the world. Based on the benchmark information in Solar Heat Worldwide 2018 for the dominant technology in each group of countries, we arrive at the following estimates:

- China:
  - Range: 160 – 310 €/m^2 (small domestic thermosiphon system);
  - Mid-point: 235 €/m^2.
- Europe:
  - Ranges: (small domestic pumped system):
    - Austria: 840 – 1100 €/m^2;
    - Denmark: 880 – 1320 €/m^2;
    - Germany: 440 – 1210 €/m^2;
    - France: 1180 – 1760 €/m^2.
  - Average mid-point: 1091 €/m^2.
- US/CA/AU:
  - Ranges:
    - Australia: 40 – 80 €/m^2;
    - Canada: 90 – 160 €/m^2.
  - Average mid-point: 93 €/m^2.
- Rest of the world:
  - Average mid-point of three other regions: 473 €/m^2.

Modern bio-heat

For modern bio-heat there is limited growth in installed capacities and consequently also little data on costs. As a result, there is no proper basis to distil a cost trend or geographical differences, nor a strong need for sophisticated assumptions. Hence, we have chosen to estimate investment costs based on a simple average of the capex data from task 2 of this study: 391 €/kW.

Geothermal direct use

For direct use of geothermal heat there are very few capacity additions and hence no need for sophisticated assumptions. An earlier assessment shows values ranging from 500 to 3500 EUR/kW, depending on the technology and application. For this analysis, we take the mid-point of the range: 2000 €/kW.

Biofuel production

For biofuel production there is limited data available and limited investment volumes overall. Due to these limitations, there is no clear view on trends and geographical differences with respect to investment costs.

For the largest markets (US, Brazil) investment data in monetary terms is directly available through the data provided by the IEA. For the other, smaller markets of interest we apply a simple average investment cost estimate based on EU data for the period from 2008-2018:

- EU capacity additions (2009-2018): 17 667 834 tonne/a [25];
- EU investment (2008-2018): USD 8.234 billion;
- Investment cost: USD 466 / (tonne/a).

Electrification

Electric vehicles

When estimating investments in electric vehicles (EVs) based on units sold and average sales prices, the most important distinction to make is to differentiate between China and the rest of the world, because electric vehicles in China are on average much cheaper[26]. As a result, the increasing market share of the Chinese market has resulted in a strong decline in the average global sales price too[27].

A more complex factor is the development of electric vehicles over time. While there have been undoubtedly advances in the EV market, it is less clear whether these have led to lower average sales prices. In particular in Western Europe and the US, it could very well be that the main impact has been better EVs on average (for example, with larger range), rather than lower average sales prices, as markets have been dominated by high-end models until recently. A lack of data makes it difficult to assess and quantify these developments in a robust way. Hence, we have applied the same sales price for all years but differentiate between the Chinese market and other markets.

Both prices are estimated based on the IEA's World Energy Investment Report (2018). Following the report, the average global price in 2017 was 36 920 USD per unit sold and the average global price is about 40% lower than the US price. Following the IEA's Global EV Outlook (2019), 49% of the EVs sold in 2017 were Chinese. Based on these three parameters, we calculate the average price in China 2017 and the average price in the US in 2017 (which we assume to be the global price). The calculations are shown in the table below.

Table B-11 Calculations to construct monetisation value for EVs

Global price	Market share China	Price difference globally and US	Price US	Price China
36 920	49%	40%	61 533	11 607

Heat pumps

For heat pumps we used data from the European Heat Pump Association (EHPA). EHPA publishes data on the revenue resulting from heat pump sales (including installation) and data on the sales per country. Based on this, we derived a country specific revenue per unit sold estimate for the year 2018, which has been used in the analysis to monetise heat pump sales figures (in units sold). For countries which were not included in the EHPA statistics, the average of all available countries has been used. We acknowledge that this approach does not allow to differentiate between prices for aerial heat pumps and ground heat pumps. However, this is not problematic as we use country specific estimates. The values are shown in the table below.

[25] Eurostat: Liquid biofuels production capacities [nrg_inf_lbpc]
[26] Note that this is not a like-for-like comparison as the sales in China include much more smaller / basic models, whereas other markets are dominated by high end models.
[27] IEA (2018) – World Energy Investment. Available at: https://www.iea.org/reports/world-energy-investment-2018

Table B-12 Applied investment costs for heat pumps

Country	Costs per unit (2018 EUR)
Belgium	8 085
Czech Republic	8 740
Denmark	5 363
Estonia	3 666
Finland	4 808
France	6 106
Germany	15 045
Hungary	13 250
Ireland	9 825
Italy	6 119
Lithuania	11 265
Netherlands	11 681
Poland	8 463
Portugal	5 868
Slovakia	9 219
Spain	2 436
Sweden	5 265
United Kingdom	6 712
Rest of the world	6 479

The database

In this section, we elaborate on the (structure of) the database. Throughout this section we will refer to six different types of data:

1. **Investment data based on transversal investment sources** – Data on investments in monetary units based on sources identified by the core team;
2. **Investment data based on country expert investment sources** - Data on investments in monetary units based on sources identified by the country experts;
3. **Capacity additions data based on transversal capacity sources** - Data on capacity additions (in non-monetary units) based on sources identified by the core team;
4. **Capacity additions data based on country expert capacity sources** – Data on capacity additions (in non-monetary units) based on sources identified by the country experts;
5. **Investment data based on transversal capacity sources** – Data on investments in monetary units calculated by multiplying data on transversal capacity additions by the corresponding monetisation estimates (as explained in section 0);
6. **Investment data based on country expert capacity sources**- Data on investments in monetary units calculated by multiplying capacity additions data from country experts by the corresponding monetisation estimates (as explained in section 0);

Data collection and sources

The data collection for this task consisted of three main steps:

1. Collecting data from transversal sources;
2. Verification of data from transversal sources by country experts and filling data gaps using national sources;
3. Various feedback rounds between core team and country experts to understand differences between data from transversal sources and data from country experts.

Various sources were used for different technologies and countries, on which we elaborate below.

Investment data based on transversal investment sources

Three different transversal sources were used to collect data on investment in monetary units:

- IEA: For several G20 countries (Australia, Brazil, Canada, China, India, Indonesia, Japan, Russia, South Africa, South Korea and the United States), IEA (2019)[28] data on investments was obtained through direct communication with the IEA;
- Rystad Energy: Data on oil and gas extraction was obtained from Rystad Energy (2019)[29]. Data is available for all countries, except Finland and Luxembourg;
- Task 4: For investments in distribution and transmission of gas and electricity, data on investments from Task 4 (2020)[30] was used.

Capacity additions data based on transversal capacity sources

Various transversal sources were used to collect data on capacity additions:

- PLATTS: S&P Global PLATTS (2019)[31] was used as the primary source for electricity generation technologies (coal and gas fired power plants, nuclear power plants, hydro power and pumped hydro). PLATTS data was available for all countries, except Argentina, Brazil, Croatia and Cyprus;
- IRENA: IRENA's Renewable Energy Statistics (2019)[32] was used as the key source for electricity generation from renewable sources (wind power, solar PV, hydropower, bio-power, concentrated solar power, geothermal (electricity) and ocean energy). Data was available for all countries (although there are gaps for certain technologies in certain countries);
- Eurostat: For biofuel production (*Liquid biofuels production capacities*) and solar thermal heating (*Infrastructure - solar collectors' surface - annual data*), data from Eurostat (2018)[33] was used. Data was only available for various EU countries;
- Eurobserv-er: Data on the sales of heat pumps (in number of units sold) was extracted from Eurobserv-er (2018)[34];
- IEA (IEA): Data on the sales of Electric Vehicles (in number of units sold) was extracted from the IEA's Global EV Outlook (2019)[35];
- Frauenhofer: Data on heat distribution networks and data on heat pumps (in MW) from Frauenhofer (2016)[36] was used;
- Gas Infrastructure Europe: GIE (2018)[37] was used as the source for underground gas storage;

[28] International Energy Agency, 2019. Retrieved October 21, 2019, from personal communication with the IEA.
[29] Rystad Energy, 2019. Retrieved September 20, 2019.
[30] Trinomics et al., 2020. Study on energy costs and investments. Retrieved May 7, 2020.
[31] S&P global PLATTS, 2019. Retrieved October 19, 2019.
[32] International Renewable Energy Agency, 2019. Electricity Statistics. Retrieved March 24, 2020 from: https://www.irena.org/Statistics/Download-Data
[33] Eurostat, 2018. Solar thermal collectors' surface. Retrieved November 20, 2020 from: https://ec.europa.eu/eurostat/web/energy/data/database and Eurostat, 2018. Liquid biofuels production capacities. Retrieved November 20, 2020 from: https://ec.europa.eu/eurostat/web/energy/data/database
[34] Eurobserv-er, 2018. Capacity & Generation - Statistics Time Series. Retrieved August 13, 2019 from: https://www.eurobserv-er.org/online-database/
[35] International Energy Agency, 2019. Global EV Outlook. Retrieved from https://www.iea.org/reports/global-ev-outlook-2019.
[36] Frauenhofer ISE, 2016. Mapping EU Heat Supply – Mapping and Analyses of the Current and Future (2020 - 2030) Heating/Cooling Fuel Deployment (Fossil/Renewables). Retrieved from: https://www.ise.fraunhofer.de/en/research-projects/mapping-eu-heat-supply.html
[37] Gas Infrastructure Europe, 2018. Storage Database. Retrieved on December 2, 2020 from: https://www.gie.eu/index.php/gie-publications/databases/storage-database

- Trinomics (2019): Data on geothermal direct use is from Trinomics' Study on impacts of EU actions supporting the development of renewable energy technologies (2019)[38].

Construction of master database

After the data collection exercise, we ended up with four preliminary data categories:

1. Investment data based on transversal investment sources;
2. Investment data based on country expert investment sources;
3. Capacity additions data based on transversal capacity sources;
4. Capacity additions data based on country expert capacity sources.

Data on capacity additions was monetised, using the methodology explained in (and estimates from) section 0. After this step, the four final data categories were constructed (in monetary units):

1. Investment data based on transversal investment sources;
2. Investment data based on country expert investment sources;
3. Investment data based on transversal capacity sources;
4. Investment data based on country expert capacity sources;

As a last step, all observations were corrected for currency differences and inflation so that all data was expressed in 2018 Euros.

Final database

Data hierarchy

A default data hierarchy was used to construct a draft final dataset. In this hierarchy, investment data based on transversal investment sources was the preferred source, followed by , investment data based on country expert investment sources, investment data based on transversal capacity sources and investment data based on country expert capacity sources (respectively). Based on the reality checks (explained in the next paragraph), we deviated from the default hierarchy in case there were clear reasons to believe the preferred option was less accurate than any of the other options.

Reality check

The four final data categories allowed us to perform reality check by comparing the values from different sources on investments in a certain technology, country and year. For each observation (a certain technology, country and year), it was indicated when the highest value was more than 40% higher than the lowest value. If this was the case, we manually assessed the observations. For some cases, verification questions were asked to country experts. If (1) the deviations between investments over the entire period (2008-2010) were not significant (i.e. sometimes investments were reported under different years in different sources, which caused large variations when comparing individual years), or if (2) no convincing reasons were identified to deviate from the default data hierarchy, we used the default data hierarchy. If deviations were large and/or if, based on our expert opinion and country expert input, convincing reasons were identified to deviate, we used another option. This has been clearly indicated in the Excel file.

[38] Trinomics, 2019. Study on impacts of EU actions supporting the development of renewable energy technologies. Retrieved from: http://trinomics.eu/wp-content/uploads/2019/03/Trinomics-et-al.-2019-Study-on-impacts-of-EU-actions-supporting-the-development-of-RE-technologies.pdf

Multiple sources for a certain technology in a certain country over various years

For some technologies and countries, the preferred source only provided data on investments for a limited number of years. Following the approach described above, the second preferred data source was then used to complement the final dataset by filling the data gaps. We only allowed the use of multiple sources for a certain technology in a certain country if (1) both sources indicated that no investments took place in a certain technology and/or (2) one source covered a (limited) range of years and another source covered a different range of years (e.g. source one contained data for the period 2008-2012 and source two on the period 2013-2018). Through this approach, we limited the risk of double counting and large fluctuations. Meanwhile we still allowed the use of multiple sources to construct a dataset with fewer data gaps than existing datasets. It is clearly indicated in the Excel when we allowed the use of multiple sources. Where the use of multiple sources was not allowed, the source which reported the largest amounts of investment over the entire period (2008-2018) was preferred over the other sources (for reasons of data completeness as lower values were usually caused by data gaps).

Functioning of the Excel file and details of specific technologies

This section discusses the Excel file per sheet. We will first discuss the sheets at the end (right hand side) of the Excel file as these are considered the basis of the analysis.

Conversions and data validation (sheets in red)

The sheets *€_cap, Dat Val, Ad* contain conversion factors (e.g. exchange rates) which are used throughout the rest of the file. The *Ad* sheet is used throughout all tasks in this project to assure consistent use of conversion factors. *Dat Val* is a similar sheet as *Ad* but is tailored to this task. It also includes tables specifying e.g. the underlying sub technologies for various technologies (e.g. the exact types of production plants which qualify as *bio-power from biogas* within the PLATTS database). *€_cap* contains the monetisation values, as explained in section 0.

Raw data sheets (in yellow)

The sheets *PLATTS-rd, IRENA-rd, GIE-rd, H-rd, DH-rd, EV-rd, HP-rd* and *BF-rd* contain raw data on capacity additions. No major edits were made on most of these sheets.

The sheets *Rystad-rd, IEA-rd* and *Task 4-rd* contain raw data on investments. On the *Rystad-rd* sheet, we constructed investments in oil exploration by summing the CAPEX and Exploration CAPEX for both crude oil and condensate. Investments in gas exploration cover CAPEX and Exploration CAPEX for both gas and Natural Gas Liquids (NGL).

Cleaned data sheets (in blue)

The sheets *PLATTS, PLATTS IRENA SOLAR, IRENA, and OCD* (in light blue) contain cleaned data on capacity additions. Sheet *OCD* combines data from various raw data files. It includes capacity data on solar thermal heating, geothermal (direct use), biofuel production, heat distribution, underground gas storage, heat pumps and electric vehicles. Sheet *IRENA* contains the data from *IRENA-rd* which did not require manual edits. It includes capacity data on hydro power (total), pumped hydro, ocean energy, wind power (on and off shore), solar PV (total), concentrated solar power (CSP) and bio-power from biomass, bio-power from biogas and geothermal (electricity). Sheet *PLATTS* contains data from *PLATTS-rd* which did not require manual edits. It includes data on bio-power, coal/gas/oil fired power plants, geothermal (electricity), hydro (large scale), nuclear power plants, ocean energy, pumped hydro, solar PV (utility scale) and wind power (on and offshore).

Sheet *PLATTS IRENA SOLAR* combines data from PLATTS, IRENA and Solar Power Europe. It contains data on various technologies:

- Wind power onshore & offshore: data on wind power is extracted from both the *IRENA-rd* and *PLATTS-rd* sheets. Data from IRENA is preferred over PLATTS as it is considered more accurate and complete;
- Hydro power: data on hydro power (total) is extracted from the *IRENA-rd* sheet. Data on hydropower (large scale) is extracted from the *PLATTS-rd* sheet by summing all hydro projects with a capacity of at least 50 MW in certain countries and years. The data in PLATTS on small scale hydro plants was not considered sufficiently representative (i.e. was likely to contain many data gaps). As such, we opted to use IRENA as the main source of hydro power (total), PLATTS as the main source for hydro (large scale), and calculated hydro (small scale) by subtracting hydro (large scale) from hydro (total);
- Solar PV: data on Solar PV (total) is extracted from the *IRENA-rd* sheet. This data was then split into solar PV (utility scale) and solar PV (rooftop) based on country specific shares following Solar Power Europe[39]. The country specific shares are based on the shares of solar PV (rooftop) and solar PV (utility scale) in the respective total installed capacities in the year 2016. Country specific shares were not available for all countries. In case country specific shares were not available (or if the shares provided by country experts were considered more accurate), the shares provided by country experts were used. If country experts did not provide this split, a fifty-fifty split was assumed. For a few countries, the IEA or country experts provided investment data per category (utility scale and rooftop). For these countries, IEA or country experts estimates were used directly. The table below shows the final approach per country.

Table B-13 Final approach per country

C	Approach	C	Approach	C	Approach
AG	Country expert	FI	Country expert	NL	SPE, country specific
AT	SPE, country specific	FR	SPE, country specific	PL	Country expert
AU	IEA data	HR	SPE, average	PT	SPE, country specific
BE	Country expert	HU	SPE, average	RF	IEA data
BG	SPE, country specific	ID	IEA data	RO	Country expert
BR	IEA data	IE	SPE, average	SA	SPE, average
CA	IEA data	IN	IEA data	SE	SPE, average
CN	IEA data	IT	SPE, country specific	SI	SPE, average
CY	SPE, average	JP	IEA data	SK	SPE, country specific
CZ	SPE, country specific	KO	IEA data	TR	Country expert
DE	SPE, country specific	LT	Country expert	UK	SPE, country specific
DK	Country expert	LU	SPE, average	US	IEA data
EE	SPE, average	LV	Country expert	ZA	IEA data
EL	Country expert	ME	IEA data		
ES	SPE, country specific	MT	SPE, average		

C= Country, SPE = Solar Power Europe

Sheets *Task 4, Rystad, IEA* and *CE data* (in dark blue) contain cleaned data on investments. The first three sheets have an identical structure as the sheets discussed above (i.e. they all extract data from the corresponding raw data files). The sheet *CE data* contains the data from the country experts (and the correction for inflation and exchange rates).

[39] Solar Power Europe - Global market outlook 2016 – 2020

Key files – master, reality check and final dataset (sheets in green)

The sheets *MASTER*, *reality check* and *final dataset* are the key data sheets:

- MASTER: The *MASTER* sheet includes all the data from all relevant sources. Data is extracted from the sheets *CE data, IEA, Rystad, Task 4, PLATTS, IRENA, PLATTS IRENA SOLAR and OCD*. This is indicated in columns "Source Used" in columns C and D. This sheet contains seven groups of data:
    - Quantitative information core team:
        - Investments in various price levels (e.g. 2016 EUR and 2018 USD) – contains data on investments in price level from sheets *CE data*, *IEA*, *Rystad* and *Task 4*;
        - Investments in million EUR 2018 – converts investments into 2018 Euros;
        - Capacity additions – contains data on capacity additions from sheets *PLATTS, IRENA, PLATTS IRENA SOLAR* and *OCD*;
        - Investments based on capacity additions – calculates investments based on capacity additions (using the monetisation values from sheet *€ cap*).
    - Suggested changes – country experts:
        - Investments in million EUR 2018 – contains data on investments from country experts in 2018 Euros (data was converted on *CE data* sheet);
        - Capacity additions - contains data on capacity additions from country experts;
        - Investments based on capacity additions - calculates investments based on capacity additions (using the monetisation values from sheet *€ cap*).
- Reality check: This sheet includes the reality check (as explained in section 0). It includes data from all four final data groups (extracted from the *MASTER* sheet). Columns CB-CL indicate the years in which the highest value was more than 40% higher than the lowest value (for a certain technology and country). If this was the case, a manual assessment was performed (in column CM). If no manual assessment was performed, the standard data hierarchy remained valid. Columns CU-DI assess whether multiple sources were used for a single technology and country;
- Final dataset: This sheet shows the final data which was used in the analysis. Data was extracted from the *MASTER* sheet. Columns K-AB indicate from which final data group the data should be extracted (based on the data hierarchy, and the reality check and multiple sources check).

Analyses sheets (in red)

The sheets *Technology analysis* and *Country analysis* include the graphs based on the data from the *Final dataset* sheet to perform the analysis for this report. The country analysis sheet also includes a comparison between the IEA estimates for the EU28 and our estimates for the EU28 (by summing country specific data for all Member States). Based on this comparison, and being aware of data quality per technology and country, we chose to use the IEA estimates for five technologies (coal extraction, oil refining, LNG liquefaction and/or regasification, hydropower[40] and battery storage) in the analysis on the EU27. The data on coal extraction was corrected for coal extraction in the UK (and thus represents coal extraction in the EU27). Data on oil refining, LNG liquefaction and/or regasification and battery storage could not be corrected for the UK as no data was available for these technologies. The EU estimates for these technologies refer to the EU28, instead of EU27.

[40] The difference between our estimates for hydro power and the IEA estimates are most likely driven by scope differences. Our sources (IRENA and PLATTS) contain data on new capacities, whereas the IEA data includes new capacities and refurbishments.

Annex C - Additional results

Table C-1 Fossil Fuel Extraction case study - Additional OLS models

VARIABLES	ln(Investment)								
ln(Subsidies)	0.357***	0.290***	0.425***	0.368***	0.291***	0.426***	0.389**	0.147	0.347**
	(0.0413)	(0.0495)	(0.0403)	(0.0388)	(0.0510)	(0.0411)	(0.181)	(0.122)	(0.138)
ln(GDP)	-0.353***	1.075***	0.672***	-0.426***	1.085***	0.669***	-0.244	1.072***	0.730***
	(0.117)	(0.100)	(0.114)	(0.111)	(0.104)	(0.116)	(0.171)	(0.120)	(0.136)
2009				0.282	-0.187	-0.0260			
				(0.420)	(0.515)	(0.560)			
2010				-0.0962	-0.437	-0.262			
				(0.421)	(0.500)	(0.550)			
2011				-0.262	-0.244	-0.0664			
				(0.421)	(0.489)	(0.541)			
2012				-0.139	-0.255	-0.00615			
				(0.421)	(0.489)	(0.541)			
2013				-0.404	-0.166	-0.00866			
				(0.449)	(0.488)	(0.550)			
2014				-0.268	0.0247	0.195			
				(0.449)	(0.478)	(0.541)			
2015				-0.156	-0.397	-0.0110			
				(0.449)	(0.470)	(0.534)			
2016				-0.756*	-0.579	-0.111			
				(0.410)	(0.470)	(0.519)			
2017				-0.743*	-0.754	-0.360			
				(0.393)	(0.470)	(0.513)			
2018				-1.301***	-0.689	-0.555			
				(0.393)	(0.470)	(0.513)			
ln(Gas price)	1.896	1.060	0.660						
	(1.349)	(1.329)	(1.515)						
ln(Coal price)	-0.941	-0.525	-0.721						
	(0.567)	(0.559)	(0.636)						
ln(Oil price)	-0.668	-0.0128	0.00454						
	(1.186)	(1.147)	(1.317)						
ln(Subsidies) (-1)							0.248	0.147	0.145
							(0.226)	(0.146)	(0.174)
ln(Subsidies) (-2)							-0.209	0.126	0.0600
							(0.192)	(0.0934)	(0.115)
Constant	13.10***	-7.615***	-1.732	11.26***	-7.703***	-3.391**	7.991***	-8.791***	-5.210***
	(2.893)	(2.740)	(3.086)	(1.533)	(1.570)	(1.639)	(2.330)	(1.792)	(1.886)
Observations	57	114	171	57	114	171	41	88	129
R-squared	0.673	0.572	0.568	0.756	0.579	0.571	0.689	0.600	0.621
Sample	EU27	Non-EU G20	Full	EU27	Non-EU G20	Full	EU27	Non-EU G20	Full
Type	OLS	OLS	OLS	OLS	OLS	OLS	OLS	OLS	OLS
Country effects	no	no	no	no	no	no	no	no	no
Year effects	no	no	no	yes	yes	yes	yes	yes	yes
Lags	no	no	no	no	no	no	yes	yes	yes

Standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Source: Own calculation

Table C-2 Fossil Fuel Extraction case study - Additional Random Effects models

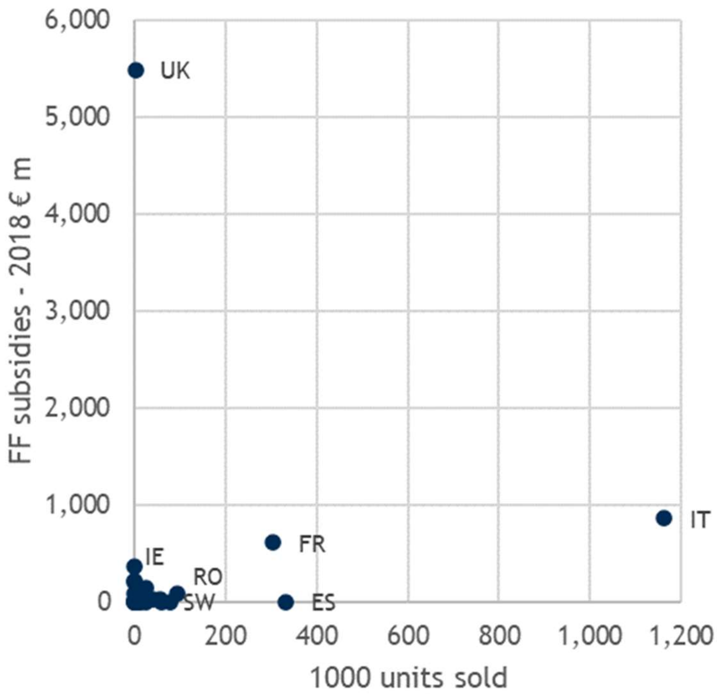
VARIABLES	ln(Investment					
ln(Subsidies)	0.259***	0.00246	0.0334	0.270***	0.0102	0.0351
	(0.0885)	(0.0257)	(0.0285)	(0.0794)	(0.0223)	(0.0256)
ln(GDP)	-0.107	0.700***	0.737***	-0.182	0.564***	0.916***
	(0.296)	(0.150)	(0.170)	(0.249)	(0.180)	(0.188)
2009				0.307	-0.0694	0.0949
				(0.355)	(0.147)	(0.148)
2010				-0.00501	0.0508	0.0305
				(0.360)	(0.148)	(0.147)
2011				-0.141	0.221	0.0685
				(0.359)	(0.147)	(0.146)
2012				-0.0622	0.287*	0.130
				(0.359)	(0.154)	(0.149)
2013				-0.158	0.340**	0.131
				(0.359)	(0.153)	(0.151)
2014				-0.0226	0.497***	0.282*
				(0.358)	(0.150)	(0.149)
2015				0.0870	0.226	0.0741
				(0.358)	(0.156)	(0.152)
2016				-0.452	-0.0321	-0.251*
				(0.334)	(0.154)	(0.148)
2017				-0.417	-0.0935	-0.323**
				(0.334)	(0.160)	(0.149)
2018				-1.009***	-0.0379	-0.493***
				(0.333)	(0.155)	(0.148)
Constant	6.641*	-0.680	-2.292	7.932**	1.089	-4.896*
	(3.810)	(2.171)	(2.383)	(3.226)	(2.563)	(2.617)
Observations	57	114	171	57	114	171
Countries	7	12	19	7	12	19
Sample	EU27	Non-EU G20	Full	EU27	Non-EU G20	Full
Type	RE	RE	RE	RE	RE	RE
Country effects	yes	yes	yes	yes	yes	yes
Year effects	no	no	no	yes	yes	yes
Years F-test	-	-	-	0.015	0	0
Hausman	0.015	0.005	0.001	0.015	0.005	0.001

Standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

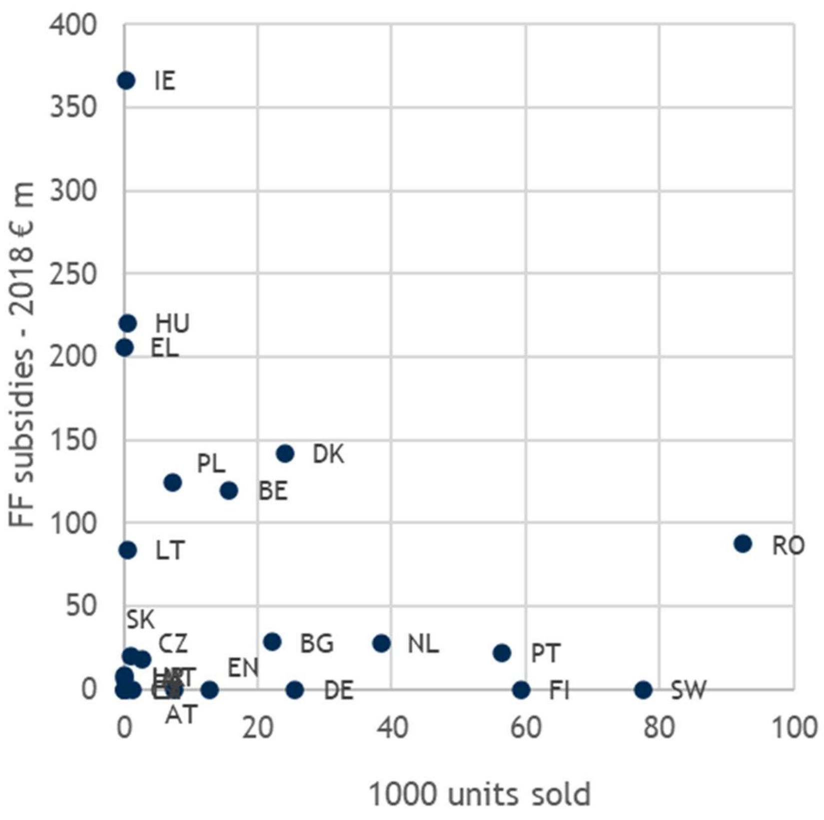
Source: Own calculation

Figure C-1 Average fossil fuel building heating subsidies and heat pump sales



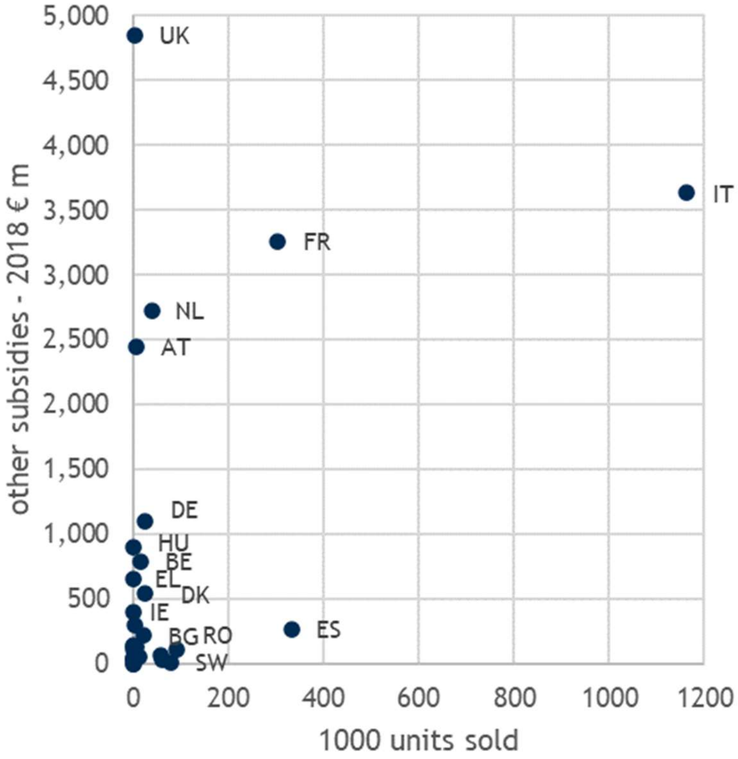
Source: Own calculation based on the subsidies and investment data sets

Figure C-2 Average fossil fuel building heating subsidies and heat pump sales – small subsidies and sales



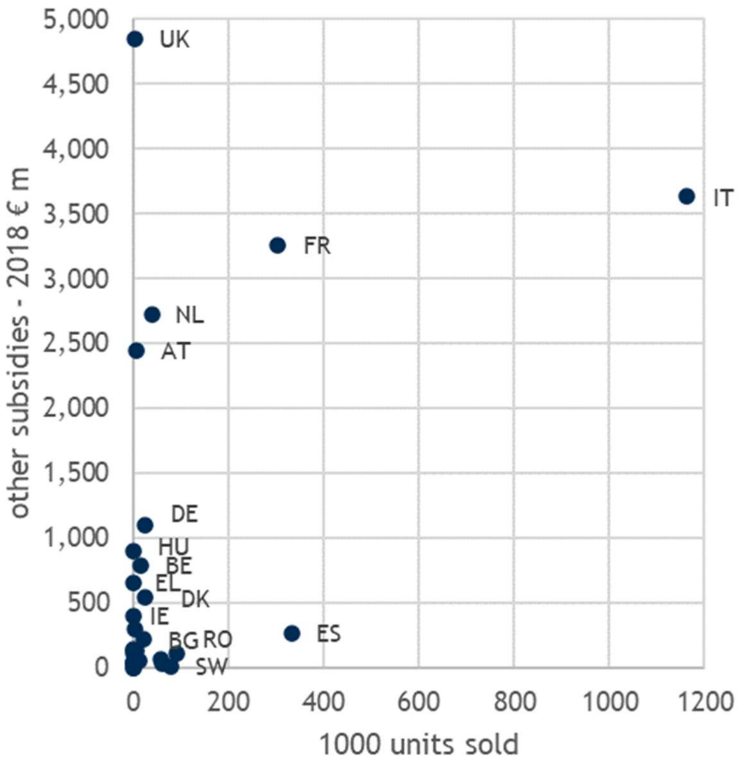
Source: Own calculation based on the subsidies and investment data sets

Figure C-3 Average non-fossil fuel building heating subsidies and heat pump sales



Source: Own calculation based on the subsidies and investment data sets

Figure C-4 Average non-fossil fuel building heating subsidies and heat pump sales - small sales and subsidies



Source: Own calculation based on the subsidies and investment data sets

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