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Final Report
Summary

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

Trinomics

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

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

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Abstracts

English

This summary report presents the key results from the study on 'Energy costs, taxes and the impact of government interventions on investments in the energy sector' which brings together the findings of detailed task reports addressing: (1) the cost of energy (LCOE); (2) network costs; (3) external costs of energy; (4) energy taxes; (5) energy subsidies; and, (6) energy investments.

This summary report also introduces three new synthesis analyses. The first analysis sums the results from (1)+(2)+(3) above to estimate a 'total cost of energy' per electricity technology. This shows that in the EU, wind energy, hydropower and nuclear power are the lowest cost technologies, whilst the fossil fuel technologies and biomass have the highest costs. The second analysis addresses energy taxes (4) and subsidies (5) and shows that subsidies to renewable energy are largely recovered through charges to consumers, and that tax revenues and their linked subsidies tend to move in tandem. The third analysis, compares the results of (3) and (4) to analyse the extent to which energy taxation compares to (internalises) the external costs identified in this work, it shows that for the EU27, consumption taxes for electricity are equivalent to around 50-60% of the external costs of electricity.

French

Ce résumé présente les résultats principaux de l'étude sur les "Coûts et taxes énergétiques, et l'impact des interventions gouvernementales sur les investissements dans le secteur de l'énergie", qui rassemble les conclusions détaillées de rapports de tâches sur : (1) le coût de l'énergie (LCOE) ; (2) les coûts de réseau ; (3) les coûts externes de l'énergie ; (4) les taxes énergétiques; (5) les subventions énergétiques; et (6) les investissements dans le secteur de l'énergie.

Ce résumé présente également trois nouvelles analyses de synthèse. La première analyse résume les résultats de (1)+(2)+(3) ci-dessus pour estimer un "coût total de l'énergie" par technologie de l'électricité. Il en ressort que dans l'UE, l'énergie éolienne, l'hydroélectricité et l'énergie nucléaire sont les technologies les moins coûteuses, tandis que les technologies des combustibles fossiles et de la biomasse ont les coûts les plus élevés. La deuxième analyse porte sur les taxes (4) et les subventions (5) énergétiques et montre que les subventions aux énergies renouvelables sont en grande partie récupérées par le biais des redevances imposées aux consommateurs, et que les recettes fiscales ainsi que les subventions qui y sont liées ont tendance à évoluer en tandem. La troisième analyse, qui compare les résultats de (3) et (4) pour analyser la mesure dans laquelle la taxation de l'énergie équivaut les coûts externes identifiés dans ce travail (c'est-à-dire, les internalise). Il en ressort que, pour l'UE27, les taxes sur la consommation d'électricité équivalent à environ 50-60% des coûts externes de l'électricité.

Executive Summary (EN)

This executive summary is atypical as it summarises the key findings of this report which is already a summary of 6 stand-alone reports tackling cost of energy (LCOE), network costs, external costs of energy, energy taxes, subsidies and investments.

The main objective of this study is to provide a '*consistent set of data on generation and system costs and the costs of externalities in the energy sector*'. The scope was the EU + the non-EU G20 countries. We cover the most important power generation technologies (from fossil fuels to renewable energies), heating and cooling technologies and electricity and gas transmission and distribution and electricity and gas storage. And we include the full energy value chain from primary production, to energy transformation, transmission, distribution, storage and consumption of energy.

All the necessary bottom up data has been gathered by 43 country experts for data between 2008 up to 2018/2019.

Levelised cost of energy (LCOE)

An interesting conclusion of the LCOE anaysis is that (for new projects in EU27) **most renewable energy sources (RES) have become cheaper than gas fired combined cycle gas turbines (CCGT)**. The main reason is that RES technologies are produced at increasingly large scales and CAPEX costs continued to decrease. This development in scale and the trend for CAPEX reductions has been driven by, amongst other factors, generous European RES support schemes.

Network costs

The section on network costs focuses on aggregated investments and scaled investment and O&M costs. **In the EU, but also in the non-G20 countries, investments are much higher in electricity than in gas networks.** A simple reason for the difference is that gas networks are less developed (in many countries there are nearly no gas networks). More interesting is that, **though overall electricity consumption in the EU has remained stable over the last 10 years, (distribution) network investment increased considerably**, due to market integration and security of energy supply. In the non-EU G20 countries, electricity network investments were mainly driven by CN, US, IN, SA, CA and BR.

Gas network investments stagnated. The stable investments for gas networks can be explained by renovation works, security of supply and market integration-driven projects (though gas consumption decreased by more than 10% over the last 10 years). In the non-EU G20 countries, total gas network investments increased by 57% since 2010 due to increased gas consumption in the non-EU G20 countries.

External costs

The external costs chapter provides disaggregated external costs data for the energy sector (such as the costs related to human health and ecosystems, etc.). This is based on a life-cycle impact assessment of the external costs of energy production (electricity and heat) technologies and the application of monetisation methodologies to the assessed impacts.

For electricity, fossil fuel technologies have the highest external costs of €68-€177/MWh for the EU27 average and these are even higher in the non-EU G20 countries (from €81-€305/MWh), reflecting weaker emissions abatement on fossil plants in these latter countries, especially China and India. **Nuclear and renewable energy technologies have external costs of €3-17/MWh** in the EU and G20 with wind and hydropower, reaching levels below €5/MWh. Domestic wood boilers have high associated external costs up to €170/MWh. The largest applicable policy measure (thus internalisation of the external costs), by far, is the EU-ETS (EU Emissions Trading System), this can be understood to offset 16%-19% of the total external costs for the fossil energy technologies in the EU27 (and UK).

The average external cost of electricity in the EU27 is €68/MWh (or €59/MWh after internalisations such as EU-ETS are included, both with large differences between the MS) **compared to €178/MWh for the G20 weighted average**. Together with the external costs of heat this leads overall to an external cost (across all 43 countries) of almost €4 100 billion per year (or 6.6% of the total annual GDP of these 43 countries considered). China (€1 900 billion) and the US (€600 billion) are the biggest 'polluters'.

Energy taxes

The energy taxes we looked at in this study are excise taxes on fuels, non-tax levies on fuel purchases, such as on natural gas and electricity bills and all other taxes, levies and fiscal measures that end consumers pay when they consume energy.

Taxes on energy consumption for the EU27 in 2018 totalled €263 billion, whilst taxes on energy production and infrastructure totalled each only around 2% of this amount, aprx. €5 bn. The tax rates on energy use increased by 29% between 2008 and 2018, in real terms. The total tax rates in the member states ranged from €9/MWh (Hungary) to €34/MWh in 2018 (Germany), with a median of €19/MWh. Total revenues from taxes on energy consumption increased 23% between 2008 and 2018. Three-quarters of revenues in the EU27 were from excise taxes in 2018, and 20% were for renewables support. Additional support for renewables accounted for about €40 billion.

Energy intensive industries (EIIs) and agriculture paid the least taxes relative to the amount of energy they consumed in 2018, whereas the road transport sectors paid the most. EIIs account for 18% of energy consumption in the EU27 and 2% of tax revenue (three times less than on non-EIIs), and agriculture accounts for 3% of energy use and 0.5% of tax revenue while road transport accounts for 29% of energy consumption and 60% of tax revenue. Tax rates on energy-intensive industries in Japan are twice that of the EU27.

Energy subsidies

By energy subsidies we do understand all forms of monetary transfers from public entities to private (direct transfers, tax expenditures) as well as regulatory economic mechanisms and schemes that results in cross-subsidies.

Total energy subsidies in the EU27 have increased by 65% from €95bn in 2008 to €159bn in 2018 in real terms (€$_{2018}$) driven by subsidies for energy production (+€48bn) that have risen by 130%.

Fossils fuel subsidies have slightly shrunk over the full 2008-2018 timeframe; however, they have rebounded in 2017 to **reach approx. €50bn in 2018**. The energy sector (€18bn), transport and industry

(€11bn each) received most of the fossil fuel subsidies in 2018. Tax expenditures for fossil fuels are extensively used by the MS and reached €27bn in 2018.

Financial support for **renewable energy sources** increased from €22bn in 2008 to **€73bn in 2018**. Solar PV captured the lions' share with €28bn in 2018 (+€24bn since 2008), followed by wind onshore (€16bn, +9.5bn), biomass (€15bn, +€9bn) and lately by wind offshore (€5bn, +4.5bn).

Subsidies for energy efficiency represented 10% of the total subsidy amount in 2018 at €15bn. They have increased by more than 114% since 2008, from €7bn.

Indirect subsidies or **total tax revenues forgone by the EU27 reached €57bn.** €35bn were revenue waivers from taxes on fossil fuels, including carbon taxes, and €9bn from taxes on electricity.

Energy Investments

Energy investments include both public and private sector investments and are defined as overnight investments in new energy related capacities or investments in refurbishments.

The total investment volume in energy assets across the EU27 and G20 countries went from approx. €1,000 billion in 2010 up to nearly €1,300 billion in 2014 and back down to €1,100 billion in 2018. **Fossil investments (extraction, refining, LNG terminals and fossil power plants) still accounted for close to 50% of the total investment volume in 2018 (thus EU27 and G20 together)**. Renewable power plants, fuel and heat production together accounted for roughly 20% of total investments in all years. Transmission & distribution investments accounted for 20 to 25% of total investments of which the majority went to electricity infrastructure.

The EU27 accounted for a relatively small share of the total investments with annual investment volumes declining from values around €140 billion (2010) to values around €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 in monetary terms, whereas renewable capacities increased significantly. EU27 investments are dominated by renewables and transmission & distribution investments, which together accounted for 70 to 75% of total investments.

The investments task also analyses the impact of subsidies on renewable investments and the take-up of low-carbon technologies with the aim to show how fossil fuel and renewable subsidies have an impact on the take-up of renewables. An analysis of the power sector is followed by three sector case studies on the impacts of subsidies on fossil fuel extraction, electric vehicle adoption and heat pump take-up . Overall, the modelling results suggests **that fossil fuel subsidies have a limited impact on hindering the installation of new renewable generation**. Another outcome is that **renewable subsidies have a substantial impact on supporting the investment in renewable capacity** (without renewable subsidies, renewable capacity would have been 40% lower in 2018).

Synthesis analysis

Further analysis was carried out to bring together the different task level findings.

Total cost of energy

Total costs of energy per technology range from €83/MWh for onshore wind to €258/MWh for Lignite. By combining the LCOE, network and external cost results, a total cost of energy was estimated. Overall, onshore and offshore wind, hydropower, geothermal power and nuclear energy have the lowest total costs of energy, combining relatively low LCOEs with low external costs. Solar PV and natural gas form a mid-level of total costs, the former with still relatively high LCOE but low externality costs, the latter with lower LCOE than solar PV but higher external costs. The coal technologies, biomass and solar CSP are the most expensive from the total cost perspective.

Energy taxes and energy subsidies

Energy taxes, charges, levies and subsidies are closely linked in many ways. Revenues from taxes on energy consumption and production, pollution and energy-related infrastructure are sometimes used by governments to finance programmes supporting certain groups of consumers or certain technologies. For example through policies such as feed-in tariffs or feed-in premiums which have often been financed by surcharges on the consumption of electricity by end consumers.

The additional annual €51 bn of renewable energy subsidies observed between 2008 and 2018 in the EU 27 were almost exclusively financed by surcharges. Therefore, the implementation of new FiT/FiP or their reliefs, as well as the change of rate, have generally impacted upon the energy bills of consumers in the short or long term, not on government budgets.

A strong relationship is established between taxes and tax reductions and exemptions (known technically as 'tax expenditures')[1]. EU tax expenditures amounted to €57 bn in 2018 representing more than a third of the €159 bn total subsidies paid in the EU27. Excise tax expenditures on fossil fuel and electricity reached €40 bn in the EU27 in 2018, which represents an 18% reduction in the tax revenues (€219 bn); r-atios vary from 45% and 43% in Sweden and Belgium to 12 Member States with ratios below 10%.

In many cases new energy taxes, charges and levies came with partial or full exemptions in order to protect some consumers from the new tax burden. Thus, when we study the joint evolution of excise tax revenues and excise tax expenditures in the EU27, we see that revenues have increased by 9% between 2008 and 2018, while excise tax expenditure increased by 11%.

Industry and agriculture receive significantly larger excise tax breaks than the taxes they pay. Whilst the ratio of excise tax expenditures to excise tax revenues for industry and agriculture has declined between 2008 and 2018 the tax expenditures still exceed revenues. The reverse is observed for the transport, services and households, which record respective ratios of 15%, 8% and 2%, meaning that their contribution to excise tax revenues is much larger than the excise tax expenditures they benefit from.

[1] Tax expenditures are a form of subsidy and can be partial exemptions (called "tax reductions" in the report, e.g. a reduced rate of 5% instead of a standard rate of 18%) or full tax exemption (called "tax exemptions", e.g. zero-rate instead of a standard rate of 18%). These exemptions can apply either to the tax rates or to the tax base. Tax reductions and exemption differ from tax credits that apply directly on the amount of due tax, not on the tax rate or on the tax base.

Energy taxes and external costs

In the EU27 taxes on energy consumption and production equate to around 40% of total energy production externalities. For energy production, if the energy consumption taxes and carbon taxes and measures are totalled, then these represent an internalisation of around 40% of the external costs.

Taxes on electricity consumption equate to around 63% of the external costs of electricity production in the EU27. Focusing only on consumption taxes on electricity consumption then total taxes of €77 billion can be identified. These taxes can be compared to the external cost of electricity of €123 billion after existing internalisation of EU-ETS and other climate measures are taken into account.

External costs of around €27/MWh for electricity in the EU27 can be estimated, with taxes internalising around 50-60% of the electricity production externalities. Taking the average electricity system external costs of €59/MWh and combining these with the energy consumption taxes on electricity of €32.1/MWh in 2018 (see Figure 11 in the tax task report) an estimate of external costs of €27/MWh can be calculated.

Executive Summary (FR)

Ce résumé est atypique car il résume les conclusions principales de ce rapport, qui est déjà un résumé de 6 rapports indépendants traitant du coût de l'énergie (LCOE), des coûts de réseau, des coûts externes de l'énergie, des taxes sur l'énergie, des subventions et des investissements.

L'objectif principal de cette étude est de fournir un *"ensemble cohérent de données sur les coûts de production et de réseau et sur les coûts des externalités dans le secteur de l'énergie"*. Le champ d'application était l'UE + les pays du G20 non membres de l'UE. Nous couvrons les principales technologies de production d'électricité (des combustibles fossiles aux énergies renouvelables), les technologies de chauffage et de refroidissement, ainsi que le transport et la distribution d'électricité et de gaz et le stockage d'électricité et de gaz. Et nous incluons toute la chaîne de valeur énergétique, de la production primaire à la transformation, la transmission, la distribution, le stockage et la consommation d'énergie.

Toutes les données nécessaires ont été recueillies par 43 experts nationaux pour les données de 2008 à 2018/2019.

Coût actualisé de l'énergie (LCOE)

Une conclusion intéressante de l'analyse LCOE est que (pour les nouveaux projets dans l'UE27) **la plupart des sources d'énergie renouvelables (RES) sont devenues moins chères que les turbines à gaz à cycle combiné (CCGT)**. La raison principale est que les technologies RES sont produites à des échelles de plus en plus grandes et que les coûts d'investissement continuent à diminuer. Cette évolution d'échelle et la tendance à la réduction des dépenses d'investissement sont dues, entre autres facteurs, aux généreux régimes européens de soutien aux RES.

Coûts de réseau

La section sur les coûts de réseau se focalise sur les investissements combinés et les investissements échelonnés, et les coûts d'exploitation et de maintenance. **Dans l'UE, mais aussi dans les pays ne faisant pas partie du G20, les investissements sont beaucoup plus élevés dans les réseaux d'électricité que dans les réseaux de gaz**. Cette différence s'explique simplement par le fait que les réseaux de gaz sont moins développés (dans de nombreux pays, il n'y a pratiquement pas de réseaux de gaz). Il est plus intéressant de noter que, **bien que la consommation globale d'électricité dans l'UE soit restée stable au cours des dix dernières années, les investissements dans les réseaux (de distribution) ont considérablement augmenté**, en raison de l'intégration des marchés et de la sécurité de l'approvisionnement énergétique. Dans les pays du G20 non membres de l'UE, les investissements dans les réseaux d'électricité ont principalement été réalisés par la Chine, les États-Unis, l'Inde, l'Afrique du Sud, l'Australie et le Brésil.

Les investissements dans les réseaux de gaz ont stagné. La stabilité des investissements dans les réseaux de gaz s'explique par les travaux de rénovation, la sécurité d'approvisionnement, et les projets axés sur l'intégration du marché (bien que la consommation de gaz ait diminué de plus de 10 % au cours des dix dernières années). Dans les pays du G20 hors UE, le total des investissements dans les réseaux de gaz a augmenté de 57 % depuis 2010 en raison de l'augmentation de la consommation de gaz dans les pays du G20 hors UE.

Coûts externes

Le chapitre sur les coûts externes fournit des données désagrégées sur les coûts externes pour le secteur de l'énergie (tels que les coûts liés à la santé humaine et aux écosystèmes, etc.). Ces données sont basées sur une évaluation de l'impact des coûts externes des technologies de production d'énergie (électricité et chaleur) sur l'ensemble du cycle de vie, et sur l'application de méthodes de monétisation aux impacts ayant ainsi été évalués.

Pour l'électricité, les technologies utilisant des combustibles fossiles ont les coûts externes les plus élevés, de 68 à 177 €/MWh pour la moyenne de l'UE27, et ceux-ci sont encore plus élevés dans les pays du G20 non membres de l'UE (de 81 à 305 €/MWh), ce qui reflète une réduction plus faible des émissions des centrales à combustibles fossiles dans ces derniers pays, en particulier en Chine et en Inde. **Les coûts externes des technologies nucléaires et des énergies renouvelables s'élèvent à 3-17 €/MWh** dans l'UE et au G20, avec l'énergie éolienne et l'hydroélectricité atteignant des niveaux inférieurs à 5 €/MWh. Les coûts externes associés aux chaudières à bois domestiques sont élevés, pouvant atteindre 170 €/MWh. La plus grande mesure politique applicable (correspondant donc à l'internalisation des coûts externes) est, de loin, le EU-ETS (Système d'échange de quotas d'émission de l'UE), que l'on peut considérer comme compensant 16 % à 19 % des coûts externes totaux des technologies d'énergie fossile dans l'UE27 (et au Royaume-Uni).

Le coût externe moyen de l'électricité dans l'UE27 est de 68 €/MWh (ou 59 €/MWh après la prise en compte des internalisations telles que l'EU-ETS, avec de grandes différences entre les États membres), **contre 178 €/MWh pour la moyenne pondérée du G20**. En prenant en compte les coûts externes de la chaleur, cela donne un coût externe global (pour l'ensemble des 43 pays) de près de 4 100 milliards d'euros par an (soit 6,6 % du PIB annuel total de ces 43 pays). La Chine (1 900 milliards d'euros) et les États-Unis (600 milliards d'euros) sont les plus grands "pollueurs".

Taxes sur l'énergie

Les taxes sur l'énergie que nous avons examinées dans cette étude sont les droits d'accises sur les combustibles, les prélèvements non fiscaux sur les achats de combustibles, tels que sur les factures de gaz naturel et d'électricité, et toutes les autres taxes, prélèvements et mesures fiscales que les consommateurs finaux paient lorsqu'ils consomment de l'énergie.

En 2018, les taxes sur la consommation d'énergie dans l'UE27 ont totalisé 263 milliards d'euros, tandis que les taxes sur la production d'énergie et les infrastructures n'ont représenté chacune qu'environ 2 % de ce montant, soit environ 5 milliards d'euros. Les taux d'imposition sur la consommation d'énergie ont augmenté de 29 % entre 2008 et 2018, en termes réels. Les taux d'imposition totaux dans les États membres varient entre 9 €/MWh (Hongrie) et 34 €/MWh en 2018 (Allemagne), avec une médiane de 19 €/MWh. Le total des recettes provenant des taxes sur la consommation d'énergie a augmenté de 23 % entre 2008 et 2018. Les trois quarts des recettes de l'UE27 provenaient des droits d'accises en 2018, et 20 % étaient destinés au soutien des énergies renouvelables. Le soutien supplémentaire aux énergies renouvelables a représenté environ 40 milliards d'euros.

Les industries à forte intensité énergétique (EIIs) et l'agriculture ont payé le moins de taxes par rapport à la quantité d'énergie qu'elles ont consommée en 2018, tandis que les secteurs du transport routier ont payé le plus. Les EII représentent 18 % de la consommation d'énergie dans l'UE27 et 2 % des recettes fiscales (soit trois fois moins que les industries non-EII), et l'agriculture représente 3 % de la consommation d'énergie et 0,5 % des recettes fiscales, tandis que le transport routier représente 29 % de la consommation d'énergie et 60 % des recettes fiscales. Les taux d'imposition des industries à forte intensité énergétique au Japon sont deux fois plus élevés que ceux de l'UE27.

Les subventions à l'énergie

Par subventions énergétiques, nous entendons toutes les formes de transferts monétaires des entités publiques vers le privé (transferts directs, dépenses fiscales) ainsi que les mécanismes et schémas économiques réglementaires qui aboutissent à des subventions croisées.

Le total des subventions énergétiques dans l'UE27 a augmenté de 65 %, passant de 95 milliards d'euros en 2008 à 159 milliards d'euros en 2018 en termes réels ($€_{2018}$), grâce aux subventions accordées à la production d'énergie (+48 milliards d'euros) qui ont augmenté de 130 %.

Les subventions pour les combustibles fossiles ont légèrement diminué sur l'ensemble de la période 2008-2018, mais elles ont rebondi en 2017 et **ont atteint environ 50 milliards d'euros en 2018**. Le secteur de l'énergie (18 milliards d'euros), les transports et l'industrie (11 milliards d'euros chacun) ont reçu la plupart des subventions aux combustibles fossiles en 2018. Les dépenses fiscales pour les combustibles fossiles sont largement utilisées par les États membres et ont atteint 27 milliards d'euros en 2018.

Le soutien financier aux **sources d'énergie renouvelables** est passé de 22 milliards d'euros en 2008 à **73 milliards d'euros en 2018**. L'énergie solaire photovoltaïque a été la bénéficiaire principale, avec 28 milliards d'euros en 2018 (+24 milliards d'euros depuis 2008), suivie de l'énergie éolienne terrestre (16 milliards d'euros, +9,5 milliards), de la biomasse (15 milliards d'euros, +9 milliards) et plus récemment de l'énergie éolienne offshore (5 milliards d'euros, +4,5 milliards).

Les subventions pour l'efficacité énergétique ont représenté 10 % du montant total des subventions en 2018, soit 15 milliards d'euros. Elles ont augmenté de plus de 114 % depuis 2008, lorsqu'elles représentaient 7 milliards d'euros.

Les subventions indirectes ou **le total des recettes fiscales cédées par l'UE27 ont atteint 57 milliards d'euros**. Les exonérations de taxes sur les combustibles fossiles, y compris les taxes sur le carbone, se sont élevées à 35 milliards d'euros, et les exonérations des taxes sur l'électricité à 9 milliards d'euros.

Investissements dans le secteur de l'énergie

Les investissements dans le domaine de l'énergie comprennent les investissements du secteur public et du secteur privé et sont définis comme des investissements dans de nouvelles capacités liées à l'énergie ou dans des investissements pour des rénovations.

Le volume total des investissements dans les actifs énergétiques dans l'UE-27 et les pays du G20 est passé d'environ 1 000 milliards d'euros en 2010 à près de 1 300 milliards d'euros en 2014, pour redescendre à 1 100 milliards d'euros en 2018. **Les investissements dans les énergies fossiles (extraction, raffinage, terminaux GNL et centrales électriques à combustibles fossiles) représentaient encore près de 50 % du volume total des investissements en 2018 (soit l'UE-27 et le G20 réunis)**. Les centrales à électricité renouvelable et la production de combustibles et de chaleur ont représenté ensemble environ 20 % des investissements totaux pour toutes les années. Les investissements dans le transport et la distribution ont représenté de 20 à 25 % du total des investissements, dont la majorité a été consacrée aux infrastructures électriques.

L'UE27 a représenté une part relativement faible du total des investissements, le volume annuel des investissements étant passé d'une valeur d'environ 140 milliards d'euros (2010) à une valeur d'environ 100 milliards d'euros en 2014 et 2018. La diminution des investissements dans l'UE27 entre 2010 et 2014 a été principalement due à une baisse des investissements dans les centrales électriques à énergie renouvelable en termes monétaires, alors que les capacités d'énergie renouvelable ont augmenté de manière significative. Les investissements dans l'UE27 sont dominés par les énergies renouvelables et les investissements dans le transport et la distribution, qui représentent ensemble 70 à 75% du total des investissements.

La tâche sur les investissements analyse également l'impact des subventions sur les investissements dans les énergies renouvelables et l'adoption de technologies à faible intensité de carbone, dans le but de démontrer comment les subventions aux combustibles fossiles et aux énergies renouvelables impactent l'adoption des énergies renouvelables. Une analyse du secteur de l'électricité est suivie de trois études de cas sectorielles sur l'impact des subventions sur l'extraction des combustibles fossiles, l'adoption des véhicules électriques et l'adoption des pompes à chaleur. Dans l'ensemble, les résultats de la modélisation suggèrent que **les subventions aux combustibles fossiles ont un impact limité en ce qui concerne l'entrave à l'installation de nouvelles énergies renouvelables**. Un autre résultat est que **les subventions aux énergies renouvelables ont un impact substantiel en terme du soutien qu'elles apportent aux investissements dans les capacités renouvelables** (sans les subventions aux énergies renouvelables, les capacités renouvelables auraient été inférieures de 40 % en 2018).

Analyse de synthèse

Une analyse plus approfondie a été effectuée pour rassembler les résultats des différentes tâches.

Coût total de l'énergie

Le coût total de l'énergie, par technologie, va de 83 €/MWh pour l'éolien terrestre à 258 €/MWh pour le lignite. En combinant les résultats du LCOE, du réseau et des coûts externes, un coût total de l'énergie a été estimé. Dans l'ensemble, les énergies éolienne, hydroélectrique, géothermique et nucléaire, sur terre et en mer, ont les coûts totaux de l'énergie les plus bas, combinant des LCOEs relativement faibles avec des coûts externes peu élevés. L'énergie solaire photovoltaïque et le gaz naturel forment un niveau intermédiaire des coûts totaux, la première ayant un LCOE relativement élevé mais des coûts externes faibles, la seconde ayant un LCOE inférieur à celui de l'énergie solaire photovoltaïque mais des coûts externes plus élevés. Les technologies du charbon, de la biomasse et du CSP solaire sont les plus coûteuses du point de vue des coûts totaux.

Taxes sur l'énergie et subventions à l'énergie

Les taxes, redevances, prélèvements et subventions sur l'énergie sont étroitement liés à beaucoup d'égards. Les recettes des taxes sur la consommation et la production d'énergie, la pollution et les infrastructures liées à l'énergie sont parfois utilisées par les gouvernements pour financer des programmes de soutien à certains groupes de consommateurs ou à certaines technologies. Par exemple, cela se produit parfois par le biais de politiques telles que les tarifs de rachat ou les primes de rachat, qui ont souvent été financées par des surtaxes sur la consommation d'électricité des consommateurs finaux.

Les 51 milliards d'euros de subventions annuelles supplémentaires en faveur des énergies renouvelables observés entre 2008 et 2018 dans l'UE27 ont été presque exclusivement financés par des surtaxes. Par conséquent, la mise en œuvre des nouveaux FiT/FiP ou de leurs allégements, ainsi que le changement de tarif, ont généralement eu un impact sur la facture énergétique des consommateurs à court ou à long terme, et non sur les budgets des gouvernements.

Une relation étroite est établie entre les taxes et les réductions et exonérations fiscales (appelées techniquement "dépenses fiscales"). Les dépenses fiscales de l'UE se sont élevées à 57 milliards d'euros en 2018, ce qui représente plus d'un tiers des 159 milliards d'euros de subventions totales versées dans l'UE27. Les dépenses liées aux droits d'accises sur les combustibles fossiles et l'électricité ont atteint 40 milliards d'euros dans l'UE27 en 2018, ce qui représente une réduction de 18 % des recettes fiscales (219 milliards d'euros) ; les ratios varient de 45 % et 43 % en Suède et en Belgique à 12 États membres dont les ratios sont inférieurs à 10 %.

Dans de nombreux cas, les nouvelles taxes, redevances et prélèvements sur l'énergie ont été assortis d'exonérations partielles ou totales afin de protéger certains consommateurs de la nouvelle charge fiscale. Ainsi, lorsque l'on étudie l'évolution conjointe des recettes et des dépenses liées aux droits d'accises dans l'UE27, on constate que les recettes ont augmenté de 9 % entre 2008 et 2018, tandis que les dépenses liées aux droits d'accises ont augmenté de 11 %.

L'industrie et l'agriculture bénéficient d'allégements des droits d'accises nettement plus importants que les taxes qu'elles paient. Bien que le ratio entre les dépenses en matière de droits d'accises et les recettes des droits d'accises pour l'industrie et l'agriculture ait diminué entre 2008 et 2018, les dépenses fiscales restent supérieures aux recettes. L'inverse est observé pour les transports, les services et les ménages, qui enregistrent des ratios respectifs de 15 %, 8 % et 2 %, ce qui signifie que leur contribution aux recettes des droits d'accises est beaucoup plus importante que les dépenses de droits d'accises dont ils bénéficient.

Taxes sur l'énergie et coûts externes

Dans l'UE27, les taxes sur la consommation et la production d'énergie représentent environ 40 % du total des externalités de la production d'énergie. Pour la production d'énergie, si l'on additionne les taxes sur la consommation d'énergie et les taxes et mesures sur le carbone, cela représente une internalisation d'environ 40 % des coûts externes.

Les taxes sur la consommation d'électricité représentent environ 63 % des coûts externes de la production d'électricité dans l'UE27. Si l'on se concentre uniquement sur les taxes sur la consommation d'électricité, on obtient un total de 77 milliards d'euros. Ces taxes peuvent être comparées au coût externe de l'électricité de 123 milliards d'euros après prise en compte de l'internalisation existante de l'EU-ETS et d'autres mesures climatiques.

Les coûts externes de l'électricité dans l'UE-27 peuvent être estimés à environ 27 €/MWh, les taxes internalisant environ 50 à 60 % des externalités de la production d'électricité. En prenant les coûts externes moyens du système électrique de 59 €/MWh et en les combinant avec les taxes sur la consommation d'énergie de l'électricité de 32,1 €/MWh en 2018 (voir la figure 11 dans le rapport sur la tâche fiscale), on peut estimer les coûts externes à 27 €/MWh.

1 Introduction

This summary final report presents the highlights from each of the 6 task reports produced as part of this study on ‘Energy costs, taxes and the impact of government interventions on investments’ produced on behalf of DG Energy (the European Commission). This work represents an addition to the regular Energy costs studies commissioned by DG ENER which continues elements introduced in prior studies but also adds new thematic elements and/or geographic coverage to deepen and keep up-to-date knowledge of key aspects of the energy system.

For the interested reader, we recommend the detailed task reports published alongside this summary report.

1.1 The objectives of the study

The general objective of this study is ‘*to provide the European Commission with a complete and consistent set of data on energy (electricity and heating) generation costs, system costs and the costs of externalities in the energy sector.’*

This includes an inventory of taxes, levies, government interventions and subsidies in the energy sector and main sectors consuming energy, as well as of investments in the whole energy value chain, for each Member State, for the EU as a whole and for the G20 countries. The study also analyses the impact of subsidies on investments in the energy sector, especially looking at the impacts of fossil fuel subsidies on low-carbon investments.

The outcomes of this study are important in the context of EU international obligations[2] since phasing out inefficient fossil fuel subsidies requires the monitoring of subsidies, both at EU and MS level. This study will provide a comprehensive database on all aspects of the energy sector (generation and external costs, government interventions, taxes and investments) within the EU and for G20 countries.

Moreover, this study is relevant in the context of EU regulation and governance requirements, such as the Green Deal and Energy Union Governance. The range of topics covered provide important system-wide insights for policy makers into the state-of-play and trends within the energy system, to help understand how this can be made cleaner and more integrated. It is particularly relevant, as it will provide an objective framework for the MS to develop their own reporting methodologies for energy subsidies, supporting efforts for the phasing out fossil fuel subsidies. Finally, the results of the study can also contribute to the publications under the Energy Union initiative: the next edition of the State of the Energy Union Report and the next report on Energy prices and costs in the EU.

[2] For example, the EU has committed under G7 and G20 processes to phase out ‘inefficient fossil fuel subsidies’ by 2025. Other similar commitments are covered in Free Trade Agreements, and UN processes (SDG’s, Paris Agreement).

The specific objectives of this study were to:

- Elaborate a methodology and framework for the creation of an energy costs dataset, comprising costs in energy production, energy system and consumption, as well as direct, indirect, financial, regulatory and external costs and taxation & subsidies;
- Collect existing estimates of the costs of electricity and heat for different energy products available in international databases, and compare the different estimates between them and with the energy costs collected in the study;
- Provide energy costs data for electricity and heat generating technologies, including renewable sources, nuclear and fossil fuel based technologies. The energy cost data to cover capital and operating costs from each technology and external costs (whether or not these are internalised). Energy network costs from transmission, distribution and storage, and system costs - the impact of one element of the production on other elements of the production – is also included;
- Inventory existing forms of subsidies and other support measures on the production, system and consumption side of energy products and carriers, with special attention to measures that directly impact energy costs and wholesale energy market prices;
- Identify and measure the external costs in the energy sector;
- Provide an inventory of taxes, levies, and other fiscal measures applied in the energy sector related to energy production and energy consumption;
- Quantify the investments in the whole energy supply chain and provide a detailed analysis on how regulatory measures and subsidies impact investments in the energy sector. This includes a focus on how fossil fuel subsidies impact investments in low carbon energy technologies.

These objectives are addressed through six task reports provided alongside this summary report which address:

- **The cost of energy (LCOE)**, namely of electricity and heat generation;
- **Network costs** for electricity and gas infrastructures, which comprises system costs, especially for the integration of renewable energy sources**;**
- **The external costs** in the whole life cycle of energy production and use, and indicative estimates for energy consumption;
- **Governmental taxation** of energy production and use, including in the forms of custom duty, excise duty, VAT, carbon tax, and other taxes and levies;
- **Government interventions** in the energy and other sectors consuming energy products, including subsidies in the form of tax expenditures, direct transfers, indirect transfers and RD&D support;
- **Investments in the energy sector** covering the whole supply chain (production, transmission, distribution and consumption) and the influence of energy subsidies on these investments.

This report provides a summary of the main findings from each of these task reports.

1.2 Methodological notes

Each task adopted an approach relevant to the data and analysis required; the specifics of this are discussed briefly in the summary chapters in this report, and in more detail in the task reports. Two key elements in our approach cut across all tasks, namely:

- **Data gathering by country experts** – experts in each of the 43 countries within scope were provided with data templates per task to fill;
- **Stakeholder workshops** – the approach to each task was presented to stakeholders in a workshop held on 5 July 2019. A 2nd (online) workshop was held on 4th June 2020 to present the draft final results presented in this report and the task reports.

In addition to these, the tasks also draw upon:

- **Stakeholder consultation** including direct contact and review processes;
- **Top-down data collection** from transversal literature on energy data;
- **Data control** through comparison with external sources, development of aggregate indicators, input from sectoral experts and verification with national organizations;
- **Life cycle assessment and monetarisation** of negative externalities of the production and use of energy;
- **Macroeconomic modelling and econometric analysis** of energy investments and subsidies.

Furthermore, there are a handful of definitional and scoping issues that cut across multiple or all tasks, we present short notes on these below.

Geographic scope

This study comprises three geographic dimensions:

- The national dimension of the 27 EU Member States;
- The regional dimension of the European Union;
- The international dimension of the non-EU G20 countries (the UK is included in this group).

Temporal scope

This study updates the temporal scope compared to previous work for the EC on energy costs by covering the period from 2008 until the most recent year with available data for each task. Thus the target temporal scope of this study is the 2008-2020 period, although in some cases the latest available year is 2018.

Units and deflators

This study uses:

- MWh as the base energy unit. Standardised conversion factors (IEA) were used as necessary to convert between different units;
- Euros (€ / €) as the base currency and using ECB annual average exchange rates to convert between currencies;
- Conversions to constant 2018 prices using the World Bank GDP deflators[3].

Energy value chain coverage and technological classification

We have covered the following sectors/technologies (see Tables 2-1 and 2-2), aligning with the earlier energy costs studies, but also considering additional technologies as relevant. It has not always been possible to cover all technologies in full for all elements of the work. For example, oil power, ocean energy and floating wind technologies, have only limited data or only a handful of active examples and

[3] The World Bank dataset: (NY.GDP.DEFL.KD.ZG.AD) Inflation, GDP deflator: linked series (annual %) – is used to calculate constant prices. The indicator is used to derive a price index per country relative to the base (constant) year, which is used to adjust past prices, which are then converted to € using the annual average exchange rate for the base year (2018).

were not able to be addressed in all elements. It was also not always possible to separate out CHP and non-CHP, condensing/ non-condensing, or onshore and offshore, versions of the technologies and these are therefore treated together. Variations in scope are discussed and presented in the individual chapters of this report.

Table 1-1 Energy technologies covered

Electricity	Heating and cooling	Network and storage
• Coal, Hard coal or lignite (advanced pulverised coal, IGCC) • Natural Gas (CCGT, OCGT) • Oil* • Nuclear • Biomass (dedicated) • Solar PV • Solar - CSP • Wind – onshore • Wind – offshore • Ocean energy* • Hydropower – large (>10 MW) • Hydropower – small (up to 10MW) • Geothermal • CHP (gas, biomass, coal, solid municipal waste)	• Domestic gas boiler (condensing) • Domestic oil boiler • Domestic wood pellet boiler • Domestic heat pump • Domestic solar thermal • CHP (gas, biomass, coal, solid municipal waste)	• Electricity transmission and distribution • Gas transmission and distribution • Gas storage (underground gas storage) • Electricity storage (pumped hydro, batteries, thermal)

** Data may be limited for this power generation type*

The work has addressed the **full energy value chain** from primary production, to energy transformation (generation), transmission, distribution, storage and consumption of energy. As part of this we have covered the following sectors to the extent possible: energy industry, households, services, public sector, industry (manufacturing and specific sub-divisions), agriculture and transport. Task specific variations are explained in the specific task reports. The technologies from Table 1-1 were mapped to the value chain segments in Table 1-2 below.

Table 1-2 Energy value chain and sector coverage

Value chain segment	Technology / process covered
Extraction	Coal supply / Gas / Oil
Production	Bio-power / Coal-fired power plants / gas power plants / oil-fired power plants / geothermal direct use / hydro power (large) / LNG liquefaction / modern bio-heat / nuclear power plants / oil refining / other renewable power / solar (PV) power / solar thermal heating / wind power
Transmission and distribution	Distribution – electricity / distribution – gas / distribution heat / transmission - electricity / transmission - gas
Storage	Battery storage / pumped hydro / underground gas storage
Energy efficiency	Building: heat pumps / other energy efficiency investments Industry: energy intensive industries / non-energy intensive industries Transport: road / aviation / rail / waterborne transport

2 Levelised cost of energy (LCOE)

2.1 Objectives

This report estimates the costs of producing electricity and heat from different technologies using the methodology of levelised cost of electricity and heat (LCOE & LCOH). The scope of this report includes all EU27 and non-EU G20 countries (including the UK). The timespan covered is: 2008, 2010, 2013, 2016, and 2018 for renewable energy sources and domestic[4] energy systems; and 2008, 2013, and 2018 for non-domestic thermal energy sources and nuclear. For results reporting, we present graphs using a discount rate of 3% for domestic systems and of 7% for all other technologies (large scale renewables, nuclear and thermal). Furthermore, all values (unless otherwise indicated) are in € of 2018 (real values). Investment costs used for LCOE estimates were overnight capital costs that already take into consideration costs related to the construction period of the power plants. Furthermore, LCOE results represent costs from the power plant's commissioning date and costs related to its operational lifetime (operational and fuel costs, when pertinent for the technology).

2.2 Methodology

The database built is composed of almost two thousand observations[5], 22% is for wind onshore, 25% for solar PV and 8% for solid biomass. As expected, data for fossil fuel fired technologies (coal and gas) is less abundant due to a low number of projects in the period analysed (most projects, especially in EU27 countries, are older than 2008). Most data for LCOE calculation were provided by different data sources (experts submissions, IRENA, and Enerdata's Power Plant Tracker), but in some cases, estimations were needed. All methodology notes are detailed in the main task report.

2.3 LCOE results

LCOE results for new projects in EU27 show that most renewable energy sources (RES) have become cheaper than gas fired combined cycle gas turbines (CCGT) and supercritical coal power plants. In 2018 onshore wind LCOE were around €60/MWh, offshore wind around €85/MWh and utility-scale solar PV around €87/MWh. Meanwhile, despite the reduction of gas prices, LCOE of CCGT power plants have been around €95/MWh (20% higher than 2008 costs) while coal-fired power plants have costs around €90/MWh (12% higher than 2008 costs)[6]. Multiple aspects explain this: as the EU has established carbon prices, thermal generation costs increased. On the other hand, RES technology advancements and production in large scale drove capital expenditure (CAPEX) costs down significantly since 2008. As support schemes in most European countries have boosted the development of renewables, the large-scale production of solar PV panels/modules provided the "heated market" with cheap components, while the use of larger wind turbines (without significant increases in CAPEX) enabled power plants to access much higher capacity factors over time leading to lower LCOEs.

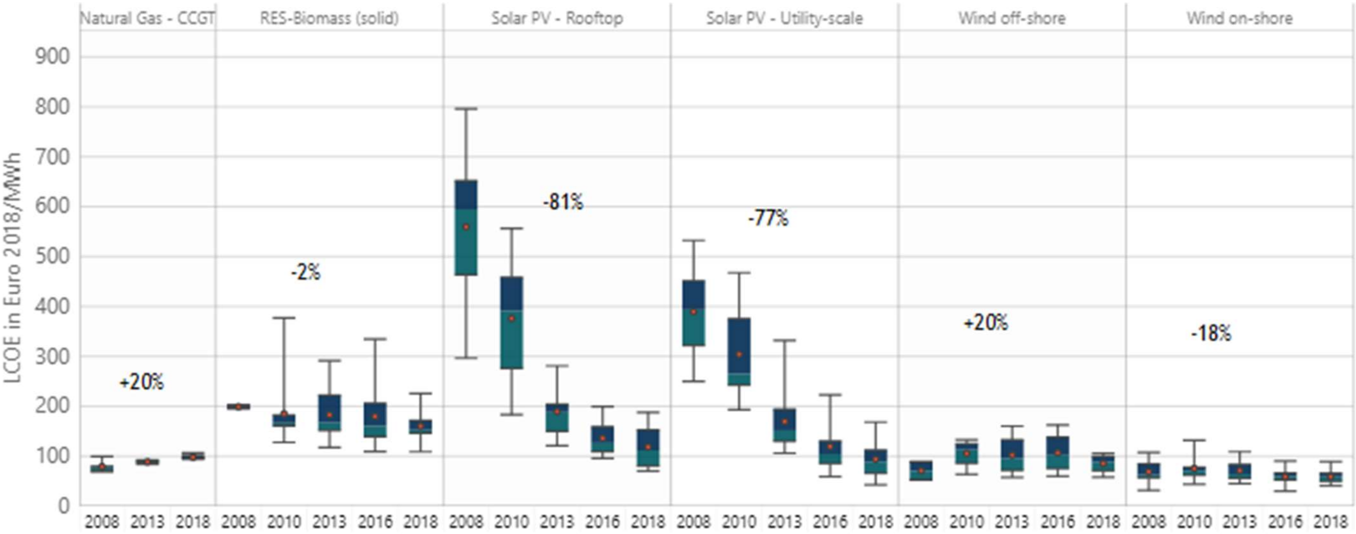
[4] Domestic systems are energy systems installed at residential scale. The size of such systems is provided in detail within the database provided with this report.

[5] Each observation is the LCOE calculated using data provided by the sources (experts submissions, IRENA and Enerdata's PPT). The sources provide a mix of project specific information and national averages. Details are provided in the database provided with this report.

[6] It is important to mention that our sample for coal-fired power technologies is small due to the scarcity of new projects during the 2008-2018 period in the EU27.

Nuclear power is not included in the EU27 summary results as no new plants have been commissioned in the EU27 since 2008. However, new plants in China, South Korea and the United States provide some basis for comparison with LCOEs ranging from €67/MWh in China to €82/MWh in the US in 2018.

Figure 2-1 LCOE results for EU27 – main technologies' comparison

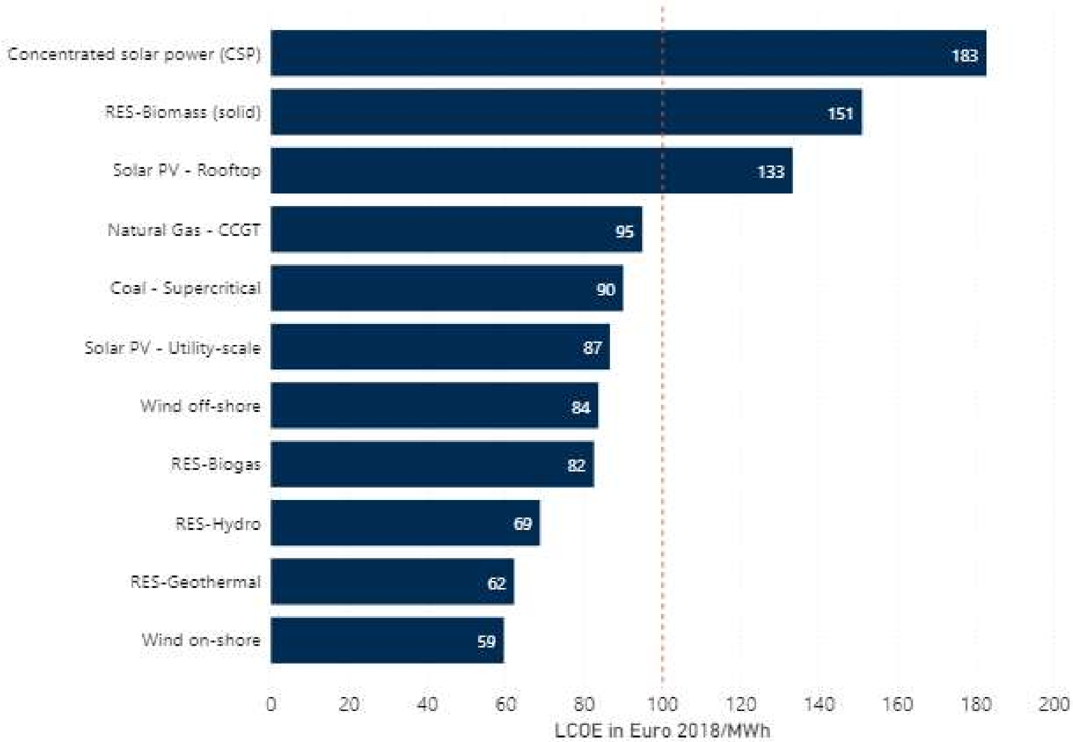


Number of observations per year

Country group	2008	2010	2013	2016	2018	Total
EU27	92	117	171	141	147	668

Source: Authors' elaboration.
Orange dot is the dataset's mean, lower whisker is the minimum while higher whisker is the maximum value observed. Boxes represent the second and third quartiles.

Figure 2-2 LCOE results for EU27 - in 2018



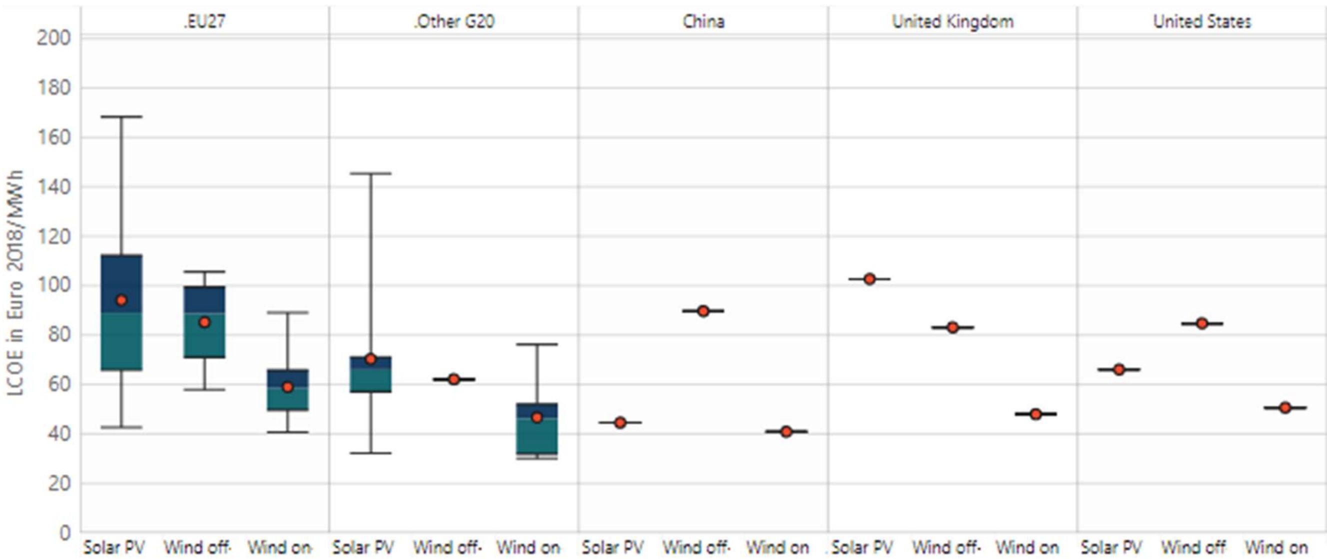
Source: Authors' elaboration.

2018 CAPEX levels for **onshore wind** in the US and the EU27 were €1,400/kW and €1,600/kW respectively, and average annual capacity factors were at 37% and 32%. These advantages in the American market are offset by higher O&M costs (at €40/kW/year whilst €30/kW/year in the EU27). With much lower soft costs (balance of plant, labour costs, etc.), the Chinese market presents a rather low LCOE for wind. In China, CAPEX for the technology were around €1,000/kW in 2018, while capacity factors remained around 30% and OPEX levels around €24/kW/year. Taking all these variables into account, LCOE in China is the lowest at €40/MWh in 2018, followed by the US at €50/MWh and Europe at €60/MWh.

With relatively low capacity additions of **offshore wind** being registered over the 2008-2018 timeframe, and due to projects' specificities (location, distance from shore, depth of installations, etc.), LCOE for this technology show significant volatility in all countries. China presents the lowest CAPEX levels in 2018, around €2,200/kW, which is offset by relatively low recorded average annual capacity factors (around 30% in 2018). Meanwhile, the US and the European countries present more comparable CAPEX levels at €3,000/kW and €3,300/kW, respectively, and capacity factors between 45-50%.

For utility-scale **Solar PV** differences in LCOE results are explained by two aspects: national average annual capacity factors (based on the country's solar irradiation) and the level of "soft costs"[7] and installation within the CAPEX costs (IRENA 2019). In the US, those costs correspond to over 70% (€945/kW) of CAPEX levels which were around 1,350/kW in 2018 and are compensated by high capacity factors (at 22-25% in 2018) leading to LCOEs of €65/MWh. In the EU27 countries, soft costs are lower, leading to CAPEX levels of €940/kW in 2018, offset by lower capacity factors (from 9% to 20% in a few areas). China has the lowest CAPEX levels at €750/kW and a national average annual capacity factor recorded at 17%.

Figure 2-3 2018 LCOE results for EU27 vs. China, US, UK and other G20 – Wind & Solar



Number of observations per year

Technology	.EU27	.Other G20	China	United Kingdom	United States	Total
Solar PV - Utility-scale	31	17	1	4	8	**61**
Wind off-shore	10	1	1	4	1	**17**
Wind on-shore	37	20	1	3	7	**68**

Source: Authors' elaboration.

[7] Soft costs are the so-called national cost components of the CAPEX (costs in balance of plant, engineering, labour and others)

3 Network Costs

3.1 Objectives

This report analyses electricity and gas network cost data (investments, operation & maintenance - O&M, and system service costs) for the EU27 Member States and non-EU G20 countries, for 2010, 2014 and 2018. It also provides a high-level analysis regarding the regulatory frameworks used for setting the allowed revenues of system operators for 2018 and discusses possible structural under- or over-recovery of network costs. Network cost allocation parameters to network users are assessed for the EU27 Member States for the three years of focus, and some specific cost allocation practices applied in non-EU27 countries are presented.

3.2 Methodology

To conduct the analysis, country-level data was collected for network costs, cost allocation parameters and network characteristics, focusing on electricity and gas transmission and distribution networks. Network costs covered are investments, operations and maintenance (O&M) and system service costs. Data is neither collected nor analysed for the depreciation of assets or capital remuneration, and monetary volumes for the cost of service are not presented.

The analysis of network costs and cost allocation followed the following steps:

- Cross-country data collection by the core team from transversal sources;
- National data collection by country experts;
- Validation by the core team;
- Validation by national regulatory authorities (for EU Member States).

The main data sources for the exercise were:

- Transversal sources for all countries: IEA electricity and natural gas statistics;
- Transversal sources for EU27 Member States:[8] Reports from ACER, CEER, European Commission services, ENTSO-E and ENTSOG;
- National data: Reports by and direct communication with national regulators and (associations of) network operators, as well as financial statements of network operators.

The project core team received final validated data from the NRAs of the following Member States: AT, BE, BG, CY, DE, EE, ES, FI, FR, HR, HU, IE, LT, LV, NL, PL, RO, SI, SK. Country experts had additional contacts with EU NRAs during the data collection phase. This report contains data submitted by country experts and NRAs until June 2020.

3.3 Network costs in the EU27 and in non-EU G20 countries

This section presents electricity and gas networks absolute aggregated investments, scaled investment and scaled O&M costs. The main report presents also scaled system service costs data for available countries, not shown here due to more limited data coverage.

[8] Most EU transversal sources included data for the UK. The EU27 is used for the analysis throughout this chapter, and the UK is classified under the non-EU G20 countries.

Total electricity and gas network investments

Table 3-1 provides the aggregated electricity and gas investment costs for EU27 countries and non-EU G20 countries in the three years of analysis.[9]

Table 3-1 Total electricity and gas network investments for the EU27 and non-EU G20 countries (billion €$_{2018}$)

		Electricity				Gas			
Category	Year	Trans.	Distr.	Both	Total	Trans.	Distr.	Both	Total
EU27	2010	6.6	15.6	1.4	23.6	3.8	2.7	2.6	9.1
	2014	8.7	16.4	1.4	26.5	3.4	3.7	1.0	8.1
	2018	9.5	22.5		32.0	4.1	5.4	0.4	9.9
non-EU G20	2010	36.1	48.1	57.2	141.4	19.9	10.8	5.8	36.5
	2014	59.7	59.3	55.5	174.4	16.5	17.9	6.3	40.7
	2018	59.0	64.4	69.3	192.6	22.5	23.7	9.6	55.9

In both country groups, investments in electricity networks are much higher than in gas networks. This is explained by the specific network investment costs, which are higher for electricity than for gas, as well as by specific drivers in the EU and non-EU G20 countries, detailed next.

In the case of the EU as a whole, the total investments in electricity networks have increased from €23.6 billion in 2010 to €32 billion in 2018. Investments in transmission increased by almost €3 billion from 2010 to 2018. In the case of distribution investments, from 2010 to 2014 the increase was €0.8 billion and from 2014 to 2018 €6.1 billion to reach a total investment of €22.5 billion in 2018.

While overall electricity consumption in the EU has remained stable in the period, a number of factors explain the increase in electricity network investments in the EU. Aspects related to market integration and security of energy supply help explain why in the EU27 investments in electricity networks have increased over time, whereas they have stagnated in the case of gas networks. Also, the increase has been driven especially by investments in electricity distribution, which usually form the larger share of total electricity investments in any case. The rapid increase in investments in electricity distribution networks could moreover be correlated to the increase of the share of distributed electricity generation (especially from renewable energy sources) in the period and electrification in general. Also, strict quality standards for electricity (and gas) in the EU trigger investments (and O&M).

For non-EU G20 countries, the change in total electricity network investments was from €141.4 billion in 2010 to €192.6 billion in 2018. In 2010, more than €36 billion were spent on transmission network investments and more than €48 billion on distribution. By 2014, investments in transmission networks increased by more than €23 billion and those in distribution by more than €11 billion. Finally, between 2014 and 2018 there was an increase in distribution investments of €5 billion and a slight decrease in network transmission investments. In the case of G20 countries, electricity network investments are

[9] It is important to note that, due to data availability, the coverage between years and network-levels might slightly differ. Nonetheless, the table does allow to identify general trends in electricity network investments over time. Also, the threshold between transmission and distribution voltages can vary significantly per country and be a determining factor in the ratio between transmission and distribution costs. However, many countries do not have a clear threshold, with overlaps between voltages operated by TSOs and DSOs.
The data presented refers to, when specific data is available, to overnight investments. Hence some investment peaks may be caused by the commissioning of strategic, large projects, especially in smaller systems. This is discussed in the text where appropriate.

driven by a handful of countries, mainly CN, US, IN, SA, CA and BR (see Figure 3-2). The investment trends in electricity networks corroborate the ongoing electrification trends in G20 countries. Between 2010 and 2018 electricity consumption increased by 25% in the G20 countries, compared to stable consumption in the EU27.

Total gas investments in the EU27 have not changed much between 2010 and 2018. During this time period, the investments in gas networks in the EU27 increased by only 9%, to €9.9 billion in 2018,and with a dip in 2014. The stable investments are explained by contrasting drivers. On the one hand, gas consumption in the EU27 decreased by 11% during the 2010-2018 period. On the other hand, some drivers helped to maintain the investment level, including: renovation works, security of supply and market integration-driven projects (some gas investments for reverse flows, integration of isolated Member States), investment in some MSs with underdeveloped gas networks (e.g. LT), and biomethane development.

For non-EU G20 countries, total gas network investments increased from €36.3 billion in 2010 to €55.9 billion in 2018. This change represents a 57% increase in investments during the eight-year time period. The observed trend in gas network investments is related to changes in gas consumption for the two groups of countries. Whereas in the G20 countries gas consumption increased by around 24% between 2010 and 2018, in the EU27 gas consumption decreased by 11% as noted. Also, as can be observed in the full report, G20 gas network investments in terms of overall investment volumes are mainly driven by a few countries, notably CN, RU and the US.

Investments in electricity and gas networks scaled to domestic energy consumption

Table 3-2 provides the summary of the weighted average scaled network investments in $€_{2018}$/MWh for both electricity and gas networks at transmission, distribution and aggregated levels for all three years of analysis for the EU27 and non-EU G20.

Some interesting trends can be observed. Based on the data below, in 2018, EU countries invested on average more in both electricity and gas networks than non-EU G20 countries. In the case of scaled electricity network investment, 2018 is the only year where the total scaled investments in the EU exceeded those in non-EU G20 countries. These results contrast the pattern of Table 3-1, where absolute investments by the non-EU G20 group largely surpasses that of the EU27 for all years and carriers. With the exception of the non-EU G20 2014 gas investments, in all other cases investments in distribution networks are higher than in transmission, or slightly below it. The figures with scaled network investments support the previous analysis based on the absolute investments, where investments in electricity networks are greater than in gas networks in both groups of countries.

Table 3-2 Weighted average scaled network investments for the EU27 and G20 ($€_{2018}$/MWh)

		Electricity				Gas			
Category	Year	Trans.	Distr.	Both	Total	Trans.	Distr.	Both	Total
EU27	2010	2.3	6.4	11.8	8.8	1.0	1.1	2.8	2.1
	2014	3.2	6.2	12.0	9.5	1.0	1.4	2.7	2.4
	2018	3.3	7.8		11.2	1.1	1.5	1.1	2.5
non-EU G20	2010	3.5	4.8	12.1	9.6	1.2	0.6	1.9	1.8
	2014	5.1	5.1	9.7	10.0	0.9	1.0	1.6	1.8
	2018	4.8	5.2	9.9	10.0	1.1	1.2	1.8	2.2

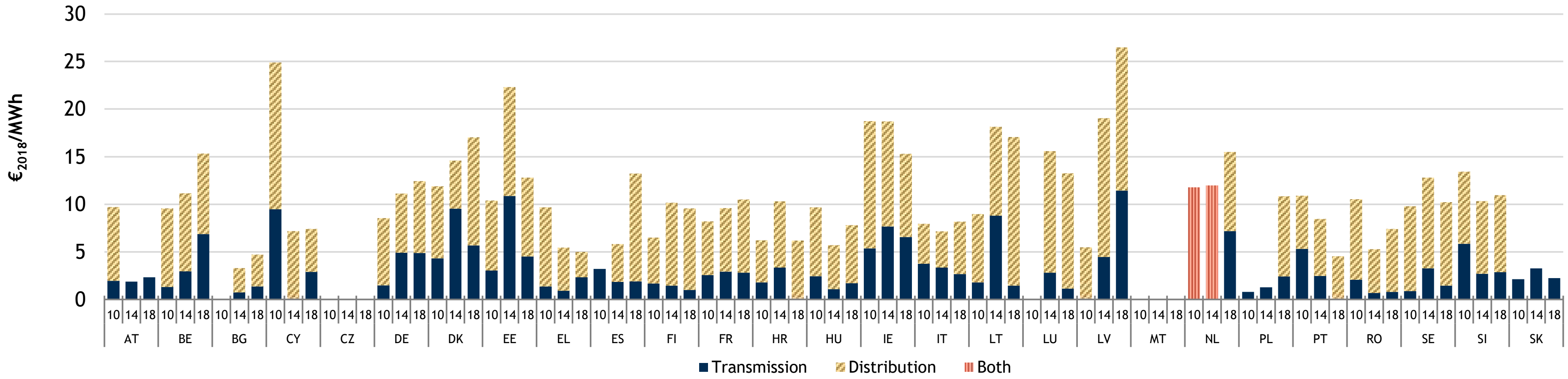
Figure 3-1 shows the electricity network investments in individual EU MSs per domestic energy consumption for transmission and distribution in 2010, 2014 and 2018.[10] Total investments per energy consumption range from below ~ 3 €/MWh to more than 25 €/MWh across countries and years. Large ranges are also observed for gas network investments in individual EU MSs (Figure 3-3).

Figure 3-2 shows that the total investments in electricity networks per domestic energy consumption for the non-EU G20 ranged between around 3 €/MWh to 25 €/MWh across countries and years, similar to EU member states. The average spending across G20 countries in 2018 was of 10 €/MWh. In comparison, the investments in gas networks per domestic energy consumption ranged from 0.25 €/MWh to slightly less than 7 €/MWh across countries and years (Figure 3-4). The weighted average spending in gas networks was 2.2 €/MW.

No meaningful comparison can be made between trends on transmission versus distribution spending in specific countries of both groups as the variation within each set is too great. Interestingly, in the EU electricity distribution network costs generally make up the larger part of the total network costs, in the case of ID, IN, MX and SA transmission investments are higher.

[10] Only public data is indicated. Table 3-1 aggregated investments include also confidential investment data, not shown in the graphs.

Figure 3-1 Electricity network investments in the EU27 per domestic energy consumption for transmission and distribution, 2010-2018 (€2018/MWh)



Not shown (confidential): AT (2014, 2018 D), CZ (2010-2018 T&D), HR (2018 T), LV (2010 T), PL (2010-2014 D), SK (2018 D)

Figure 3-2 Electricity network investments in the non-EU G20 per domestic energy consumption for transmission and distribution, 2010-2018 (€2018/MWh)

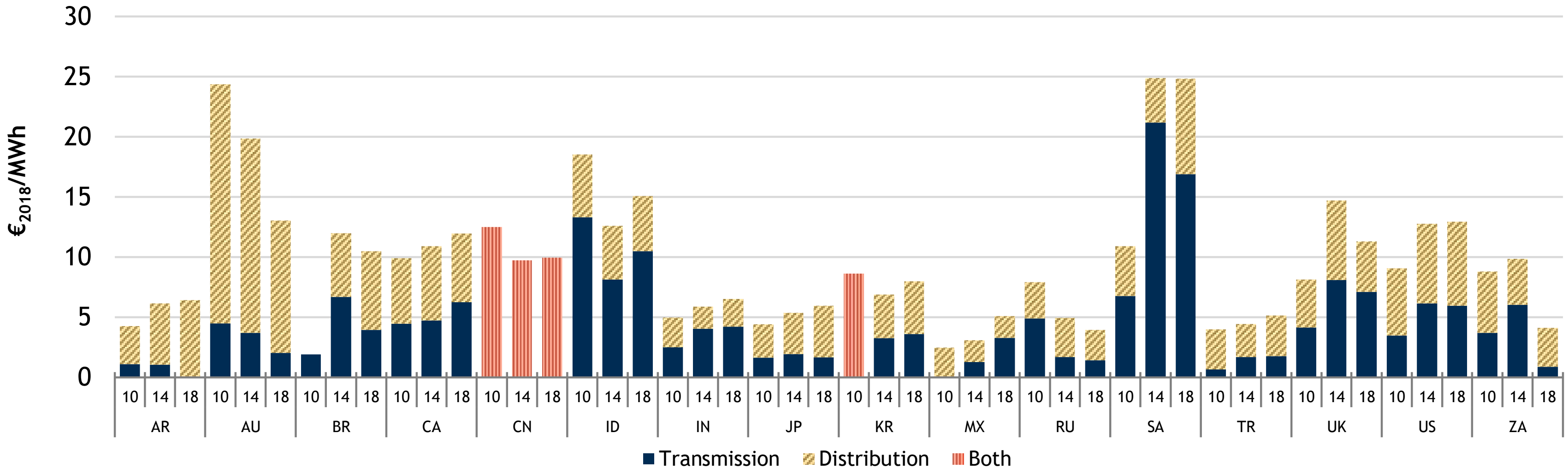
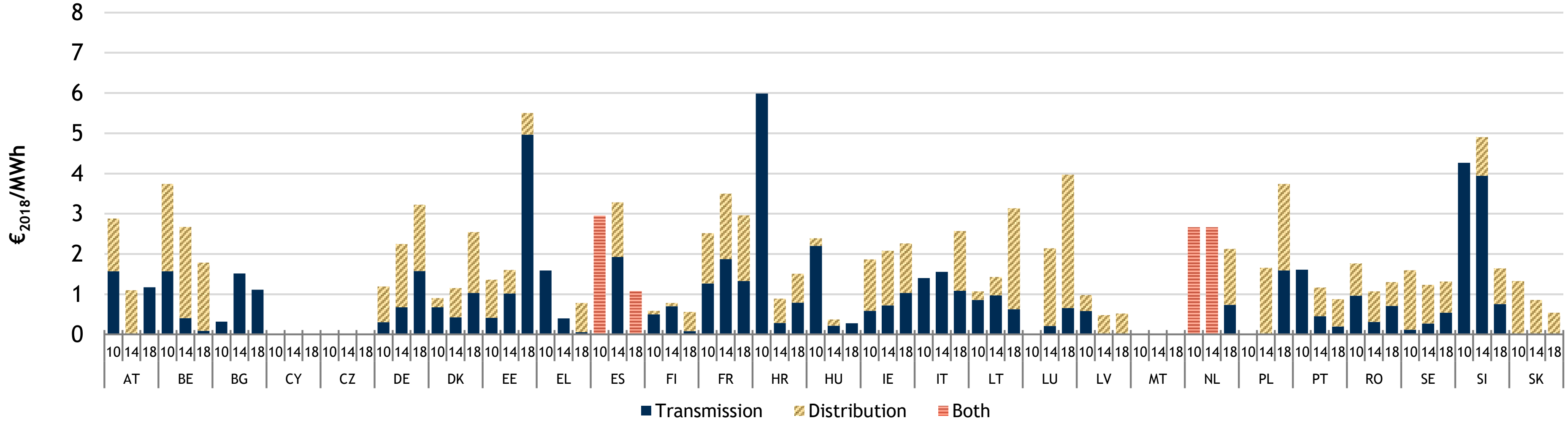
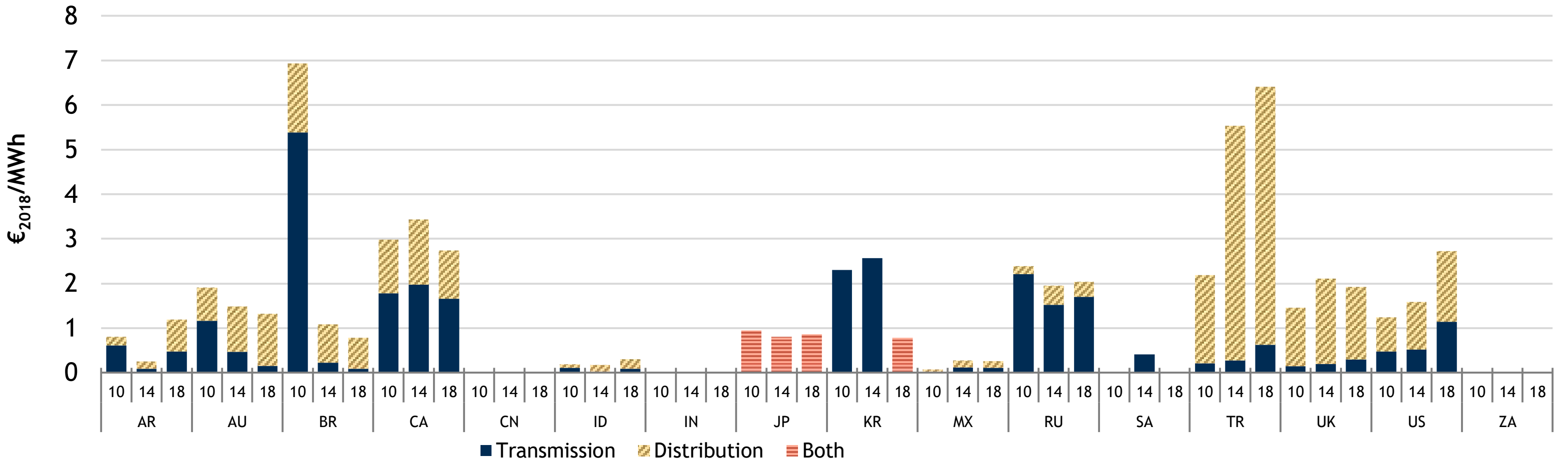


Figure 3-3 Gas network investments in the EU27 per domestic energy consumption for transmission and distribution, 2010-2018 (€2018/MWh)



Not shown (confidential): AT (2014 T), CZ (2010-2018 T&D), PL (2010, 2014 T), SK (2014, 2018 T)

Figure 3-4 Gas network investments in the non-EU G20 per domestic energy consumption for transmission and distribution, 2010-2018 (€2018/MWh)



Not shown (confidential): CN (2010-2018 T&D), IN (2010-2018 T&D

Electricity and gas networks O&M scaled to domestic energy consumption

Table 3-3 provides the summary of the weighted average network O&M costs for both electricity and gas networks at transmission, distribution and aggregated levels for all three years of analysis for the EU27 and non-EU G20. In the EU27, the overall weighted average spending on both electricity and gas O&M has decreased between 2010 and 2018, although in the case of gas where was stable between 2010 and 2014. In the EU27, most of the weighted average spending on O&M is directed towards electricity distribution networks. In the G20 countries, the weighted average spending on electricity networks O&M remained stable around 6.4 €/MWh. The average spending on gas network O&M decreased, from 1.5 €/MWh in 2010 to 1.2 €/MWh in 2018. Hence, average spending on energy networks O&M per MWh in the non-EU G20 countries is between 40% and 60% of that in the EU27. Multiple factors could contribute to that, including labour and material cost differences and higher service quality levels in the EU.

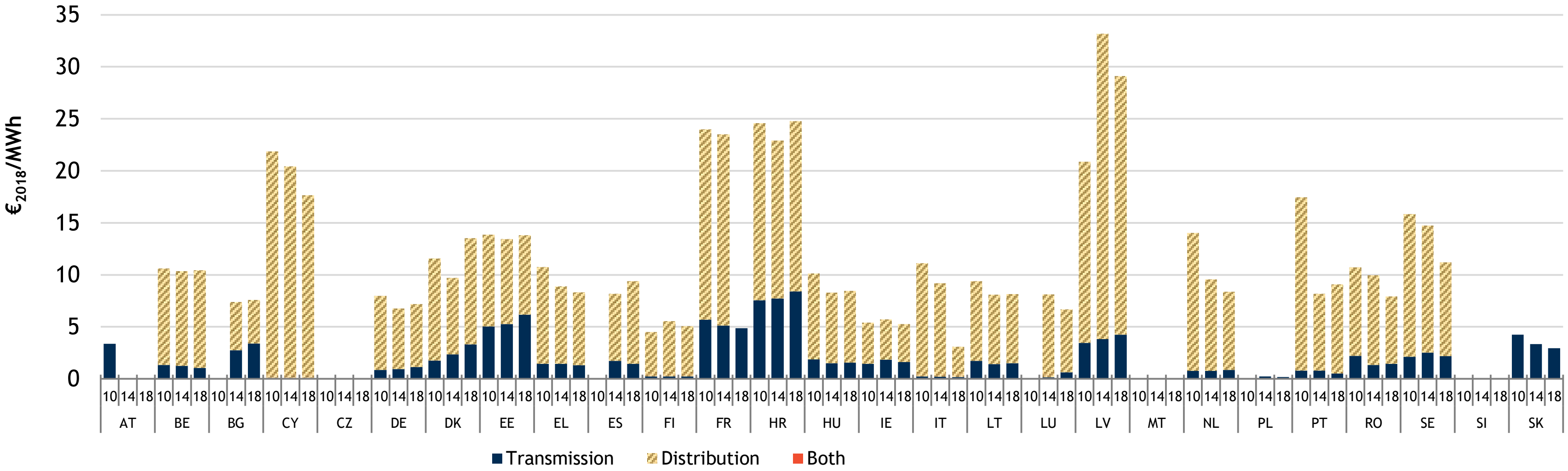
Table 3-3 Weighted average scaled network O&M for the EU27 and G20 (€$_{2018}$/MWh)

		Electricity				Gas			
Category	**Year**	**Trans.**	**Distr.**	**Both**	**Total**	**Trans.**	**Distr.**	**Both**	**Total**
EU27	2010	2.3	11.6		12.6	0.9	1.7		2.6
	2014	2.2	10.3		11.2	1.1	2.0		2.7
	2018	2.3	7.5		10.2	0.8	1.6		2.3
non-EU G20	2010	2.3	4.1	4.9	6.3	0.6	0.8	0.5	1.5
	2014	2.4	4.2	5.8	6.5	0.6	0.6	0.4	1.2
	2018	2.6	3.9	4.9	6.4	0.5	0.8	0.5	1.2

Figure 3-5 and Figure 3-6 present the electricity and gas network O&M in the EU27 Member States per domestic energy consumption. In the case of EU27 countries, the cost of O&M of electricity networks across countries and time was in the range of below 4 and 33 €/MWh. In contrast, the money spent on O&M of gas networks across EU27 countries varied between more than 1 and 8 €/MWh. In the case of non-EU G20 countries the variation in spending on electricity O&M across countries and across time was between less than 3 to more than 15 €/MWh.[11] None of the countries analysed from either EU27 or non-EU G20 spent more on gas network O&M than on electricity network O&M. The technical characteristics of gas and electricity make it less expensive to transport energy through molecules than electrons per MWh, as indicated in the start of the section, leading to higher specific investment and O&M costs for electricity networks.

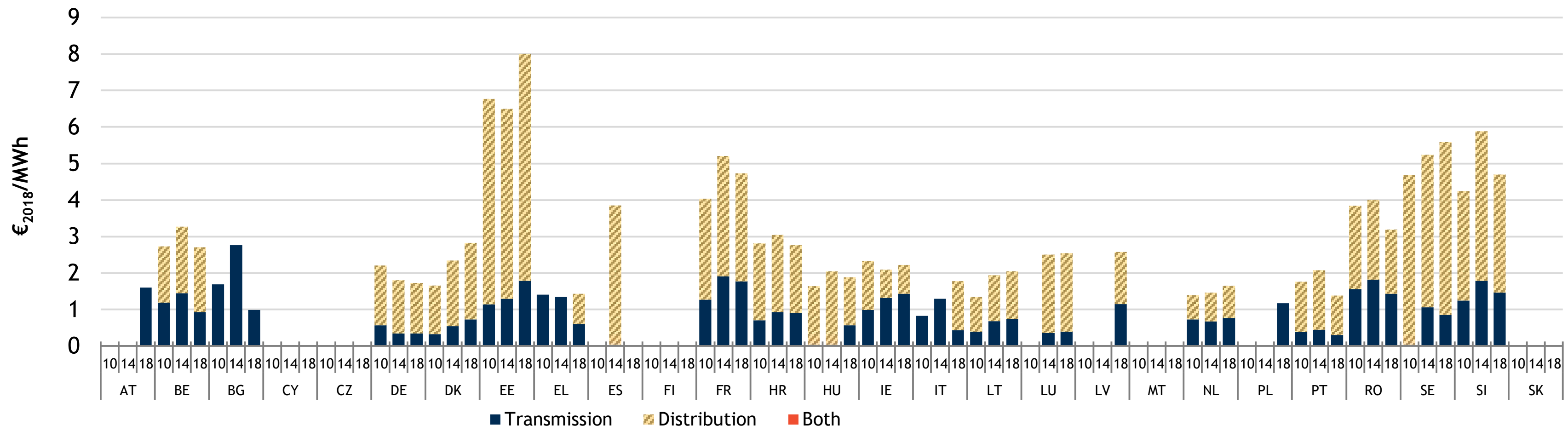
[11] O&M costs of non-EU G20 countries shown only in the full report for brevity.

Figure 3-5 Electricity network O&M in the EU27 per domestic energy consumption for transmission and distribution, 2010-2018 (€2018/MWh)



Not shown (confidential): AT (2014, 2018 T&D), CY (2010-2018 T), PL (2010 T, 2010-2018 T&D), SI (2010-2018 T&D), SK (2018 D)

Figure 3-6 Gas network O&M in the EU27 per domestic energy consumption for transmission and distribution, 2010-2018 (€2018/MWh)



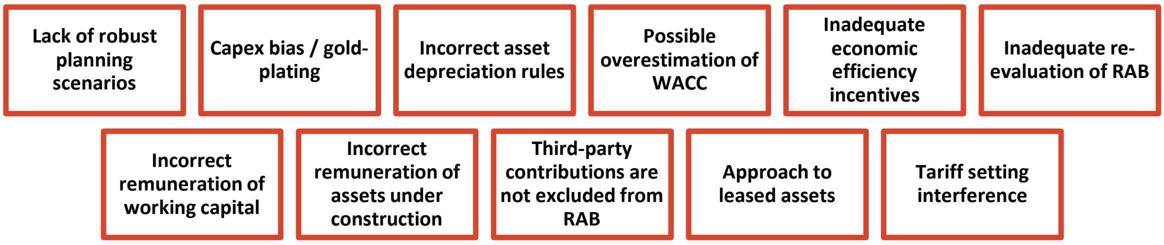
Not shown (confidential): CZ (2010-2018 T&D), SK (2010-2018 T&D)

3.4 Network national regulatory frameworks and the cost of service in EU Member States

This section provides an overview of the national regulatory frameworks regarding the revenue-setting elements for network operators and discusses the potential structural under- or over-recovery of network costs.

The main report first briefly analyses the data in CEER reports.[12] The report then qualitatively identifies main risks for over- or under-recovery of the network cost of services, detailing the risks listed in Figure 3-7. Finally, an overview of net (after taxes) profits or losses of electricity and gas TSOs in the EU for 2017 and 2018 indicates that nearly all TSOs had a net profit in the considered years.

Figure 3-7 Main risks for over- or under-recovery of the network cost of service covered in the main report



3.5 Network cost allocation

The main report presents relevant aspects for the allocation of electricity and gas network costs in EU Member States and discusses their compatibility with regards to the EU network tariff principles, focusing especially on cost-reflectiveness, recovery, non-discrimination and simplicity. The cost allocation aspects covered are:

- Network connection charges;
- Cost recovery shares from tariff capacity/commodity/fixed/other components;
- Cost recovery shares from charges to energy injection and withdrawal;
- Tariff discounts for network users;
- Cost allocation of electricity balancing services;
- Locational and time-related network tariff signals;
- Electricity distribution net metering.

In general, the data collected confirms the challenge in reconciling certain desired network tariffication principles especially as regards cost-reflectiveness and non-discrimination versus simplicity. The data obtained shows that the approaches to network cost allocation vary significantly across Member States. For example, in the case of electricity transmission connection charges, certain MS choose a deep approach to provide a locational signal and increase cost reflectiveness, while others have opted for a shallow method to favour simplicity. Similarly, location and time-related signals require balancing principles such as cost-reflectivity and non-discrimination against the simplicity of tariff structures. For example, as of 2018, the majority of Member States have not yet introduced locational or time-related signals in the majority of their electricity transmission network tariffs. Nonetheless, in the case of certain aspects, a convergence can be observed, due to increased cooperation and diffusion of best practices as exemplified in recommendations provided by CEER and

[12] Mainly CEER (2019) Report on Regulatory Frameworks for European Energy Networks. C18-IRB-38-03; CEER (2020) Report on Regulatory Frameworks for European Energy Networks 2019. C19-IRB-48-03c.

ACER, to the roll-out of smart meters or to specific regulation such as the network code on harmonised transmission tariff structures for gas. An example of the later is the increased use of capacity-based transmission tariffs for gas networks.

To complement the overview of cost allocation aspects in the EU27, alternative selected network cost allocation practices in non-EU G20 countries are detailed. The objective is to identify alternative practices which could be considered in some or several EU Member States, for example in order to facilitate the integration of renewable energy sources and to increase the cost-reflectiveness of network tariffs. The final selected practices comprise:

- Alternative electricity RES connection cost allocation in the US (New York State);
- Use of system-coincident peak electricity transmission capacity charges in the US (Texas);
- Distribution dynamic and time-of-use pricing in the US and Canada;
- Critical Time of Use (ToU) and peak pricing of network tariffs in Brazil;
- Differentiation of electricity tariff structures according to different purposes of transmission facilities in the US;
- Introduction of electricity capacity-based transmission charges to generators in Japan.

4 External Costs

4.1 Objectives

The objective of this work was to provide a full range of disaggregated external costs data for the energy sector and energy use in the EU27 and non-EU G20 countries. This was based on two main strands of work, the first an assessment of the external costs of energy production (electricity and heat) technologies and the second an indicative assessment of the externalities of energy consumption.

An **externality** is a cost (or benefit) of an activity to those that are not directly participating in the activity itself. In the case of energy and this work, we use the definition that the **total cost of energy** includes both the **'private costs'** of energy, e.g. those directly related to the activity such as the price paid for a power plant, any fuel costs, plus any taxes or other charges; and the **'external costs'** to society such as the impacts of emissions from the power plant on health, ecosystems, agriculture, buildings and the climate.

4.2 Methodology

Our approach focuses on the environmental externalities of energy and uses **Life Cycle Assessment (LCA)** to define the specific impacts and emissions we quantify and monetise. The use of a life cycle approach means that we assess costs from all steps of the energy supply process, from (1) the initial extraction of fuels and materials; to (2) their transport, processing and distribution; to (3) the combustion or power/heat generation step; and, to (4) decommissioning and waste management.

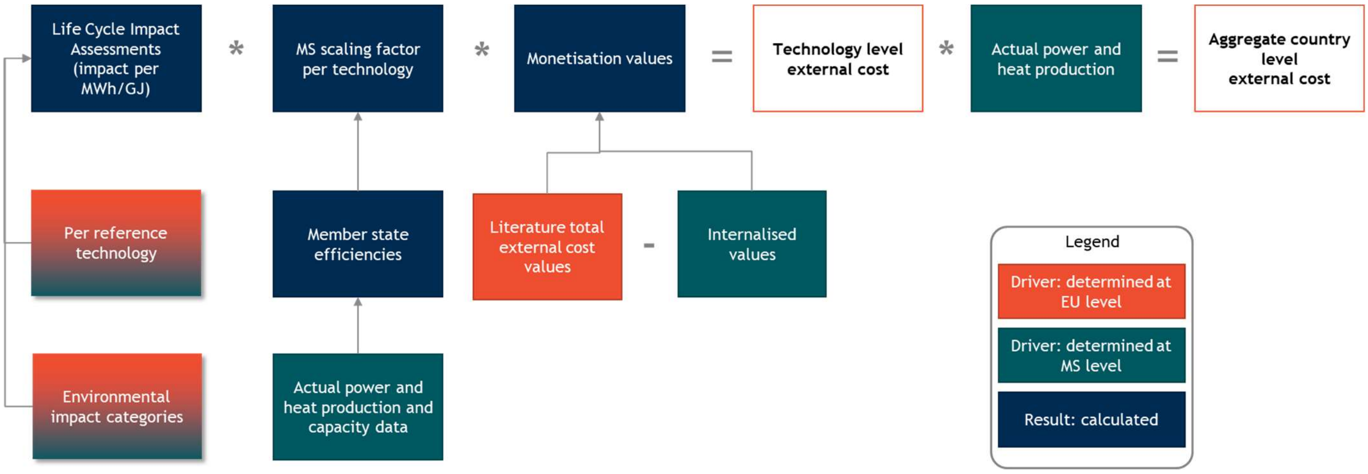
As shown below in Figure 4-1, life cycle impacts multiplied by monetisation factors (identical for all countries), and in some cases scaling factors, to estimate technology level external costs, and further again by power and heat generation data at country level to assess aggregate country level costs. Internalisation of external costs, i.e. when a tax or levy directly targets an environmental externality, to fully or partially 'internalise' the externality in the prices was also carried out, primarily focused on climate measures. A higher level analysis based on the tax data gathered as part of this study was also carried out.

The LCA underpinning our approach is based on two key methodological choices:

1. The use of the **Product Environmental Footprint (PEF)** Life Cycle Impact Analysis (LCIA) framework with its Environmental Footprint (EF) method 2.0, as developed by the Joint Research Centre (JRC) of the European Commission, whose indicators and factors are also used for the monetisation of costs; and
2. The use of **Environmental Footprint (EF-compliant)** datasets for the LCIA analysis, and only whenever such datasets were not available for a specific technology, Ecoinvent 3.5[13] datasets were used.

[13] https://www.ecoinvent.org/database/database.html

Figure 4-1 Summary of calculation approach to external costs



Our approach applied the following monetisation values to quantify the environmental impacts in 2018 Euros[14]. The impact categories are those of the EF framework[15]. The values were derived from a handful of key sources, including the Handbook on the External Cost of Transport and its annexes[16], the Environmental Prices Handbook – EU28[17], a report on Monetisation of the MMG (Environmental Performance of Building Elements) method[18], and through advice from the JRC. Detailed information on the selection of the external cost values is provided in Annex B of the External costs task report. Unless otherwise stated, i.e. in the sensitivity analyses, the central values are used in all following sections, although values for the human health and ecosystem impacts have been income adjusted.

Table 4-1 Monetisation values for the impact categories[19]

Environmental category	Unit	Monetisation value (€$_{2018}$/impact unit)		
		Low	Central	High
Climate Change	kg CO_2 eq	0.0615	**0.1025**	0.1936
Ozone depletion	kg CFC-11 eq	22.8	**31.4**	127.2
Ionising radiation, Human health	kBq U235 eq	0.0008	**0.0012**	0.0461
Photochemical ozone formation, human health	kg NMVOC eq	0.87	**1.19**	1.90
Particulate matter	Disease incidence	661 974	**784 126**	1 204 600
Human toxicity, non-cancer	CTUh	30 211	**163 447**	755 270
Human toxicity, cancer	CTUh	174 324	**902 616**	2 789 181
Acidification	mol H+ eq	0.176	**0.344**	1.617
Eutrophication, freshwater	kg P eq	0.26	**1.92**	2.18
Eutrophication, marine	kg N eq	3.21	**3.21**	3.21
Ecotoxicity, freshwater	CTUe	2.39E-24	**3.82E-05**	1.88E-04
Land use (Soil quality index)	dimensionless (pt)	0.000087	**0.000175**	0.000349
Water use	m3 water eq	0.00419	**0.00499**	0.2359
Resource use, fossils	MJ	0	**0.0013**	0.0068
Resource use, minerals and metals	kg Sb eq	0	**1.64**	6.53

[14] Values are presented in 2018 Euros for consistency with the rest of the work. This was implemented through the use of the ECB Eurozone currency deflators [MNA.A.N.I8.W2.S1.S1.B.B1GQ._Z._Z._Z.IX.D.N] to convert values, for example converting from 2012 Euros to 2018 Euros involves a multiplier of 1.071.
[15] The EF framework also includes an indicator on Eutrophication Terrestrial, but no satisfactory monetization approach is yet available and therefore this indicator was not included.
[16] For EC DG MOVE: CE Delft (2019): Handbook on the external costs of transport
[17] CE Delft (2018) Environmental Prices Handbook: EU 28 version
[18] VITO for OVAM (2017) Annex: Monetisation of the MMG method [update 2017]
[19] Full explanations of the impact categories and which damages are included can be found in Annex B of the main External costs task report.

Actual power and heat production data, and energy consumption by fuel data, was collected for the latest available year, typically 2016-2018, for each country and technology. This data was mainly sourced from Eurostat (mainly for EU27 and UK), IEA and IRENA statistical publications.

For the external costs of energy consumption analysis, a number of simplifying assumptions were required to enable such an analysis, particularly the assumption of single processes to represent energy consumption by a sector. Whilst necessary given the time and resources available, this has an important impact on the robustness of the results, particularly for industry as for example, the many thousands of different industrial energy consuming processes are represented only by a single LCIA dataset per fuel.

Full and detailed explanations of the methodological approach are provided in the main report.

4.3 External costs - Electricity technologies

Total external costs

Figure 4-2 presents a production weighted (by electricity generation) average[20] of the external costs of electricity generation technologies in the EU27.

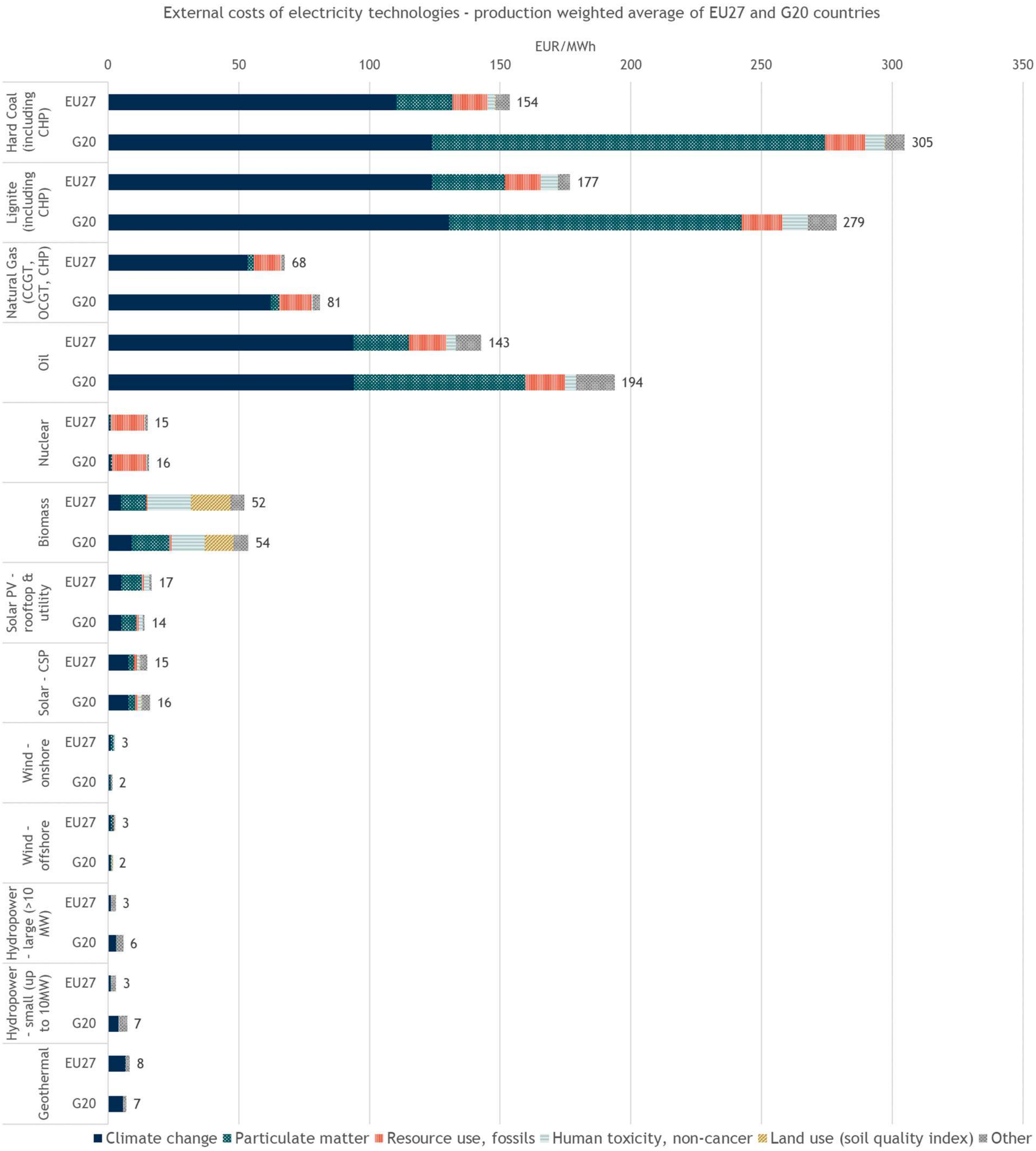
Fossil fuels have the highest external costs of €68-€177/MWh for the EU27 average. Figure 4-2 shows the highest total external cost per MWh impacts for the fossil fuel power technologies, hard coal, lignite, natural gas and oil, ranging from around €68/MWh - €177/MWh. The costs for Biomass (€52/MWh) are less than those for natural gas, but higher than for nuclear (€15/MWh). **For the non-EU G20 countries the costs are higher, from €81-€305/MWh,** reflecting weaker emissions abatement on fossil plants in these countries, especially China and India.

Nuclear and Renewable energy technologies have external costs of €3-17/MWh in the EU and G20, these technologies include solar PV, solar CSP, and geothermal generation, but exclude biomass. The technologies with external costs significantly lower than all the others are wind and hydropower, reaching levels below €5/MWh.

Climate change and particulate matter are by far the two highest externalities, especially for fossil power. Amongst the impacts, the largest impact on average is from climate change impacts, which is largest for coal, lignite, oil and natural gas. This represents at least half of the external costs of the fossil technologies. The second largest share of external costs is associated with particulate matter which represent disease damages to human health from emissions to air - and is highest for the combustion-based power sources (fossil fuels and biomass, with the exception of natural gas) and almost zero for the renewable and nuclear power technologies. The third largest share of external costs is associated with resource use, fossils and is significant for all of the fossil fuels, and also nuclear energy. These three cost categories are followed by the impacts of Human toxicity, non-cancer (significant especially for power generation from biomass, and also coal, lignite and oil) and Land use (biomass). A few other impacts are valued as only very minor impacts overall but are important for a few technologies e.g. water use (hydropower and geothermal) and resource use, metals and minerals (solar PV).

[20] Use of production weighted average gives a more realistic picture of average external costs compared to a simple average by reducing the influence of impact data from countries which may only have very low production.

Figure 4-2 EU27 average (production weighted) external cost of electricity per technology in €2018/MWh



Sensitivity analysis

The range of external costs is high, but the ranking of technologies does not change considerably under different monetisation assumptions. Analysis of external costs includes a number of uncertainties, not least in the monetisation methodologies. Sensitivity checks were carried out using the low and high monetisation values shown in Table 4-1. When considering the low monetisation values, total external costs reduced by between 24% (hydropower – small) and 90% (nuclear), and an average of 45%, across the technologies. The relative distribution of costs across the technologies remained broadly the same as in the central scenario, although nuclear power, with the reduction in the resource use, fossils impact to zero, sees its external cost reduced to around €1/MWh, similar to wind and hydro power, the other technologies with the lowest external costs. Using the high monetization values, total external costs increase by around 120% (lignite) to around 3 000% (small hydro), across the technologies. The hydro (+2 800% large hydro & +3 000% small hydro) and geothermal (+950%) technologies, which have very low costs using the central values, see very high percentage increases, driven almost entirely by a higher valuation of water use impacts. The other technologies see increases averaging 153% overall.

Internalisation of external costs

Few internalisation measures (taxes) on energy producers, taxation is focused on consumption. Following review of the tax data we noted that there are very few instruments outside the area of climate change that can be considered as internalisations of the external cost impacts we assess. The main reason is that by far the largest share of energy taxes and measures are taxes on consumption, not production. Consumption externalities and their internalisation are addressed in section 4.7.

The largest applicable measure by far is the EU-ETS (EU Emissions Trading System), whereby the climate change impact for the electricity technologies in the EU27 is reduced by €24.72 per tCO_2e, this value representing the average price of 1 tCO_2 in the EU-ETS in 2019. As almost all major (fossil) power plants in the EU27 (and UK) are subject to the EU-ETS they would face this cost[21], and therefore this can be considered a partial internalisation of the climate change externality, reducing the external cost from €102 tCO_2e to €77 tCO2e, a change of -24%. This is applied to all fossil power technologies. Other carbon taxes and climate measures in some EU27 countries and the G20 were also applied. In the US an SO_2 trading mechanism is active which internalises part of the acidification impact, is also included in our calculations.

Significant declines of 16%-19% for the EU27 average total external costs for the fossil energy technologies were observed when the identified internalisations were applied to the results previously presented in Figure 4-2, although the costs of the fossil technologies remain highest of all technologies overall. The effect is much less pronounced (-0.4 to –1.2%) in the G20 due to the lack of carbon policies, or the low effective rate of any policies that are in place.

4.4 External costs - Heat technologies

Total external costs

The results for the external costs of heat technologies for the EU27 are presented in Figure 4-3[22].

Domestic wood boilers have high associated external costs. The highest total external cost per MWh is estimated for domestic wood boilers, reaching more than €170/MWh. The main share (almost 70%) of this cost is caused by external costs associated with particulate matter, pointing to the incomplete /dirty combustion of the fuel in installations lacking filters or other emissions controls, i.e. in contrast to the larger Biomass CHP technology. The corresponding average value for the G20 countries is much lower (€80/MWh) but this stems largely from the income adjustment of the dominant human health

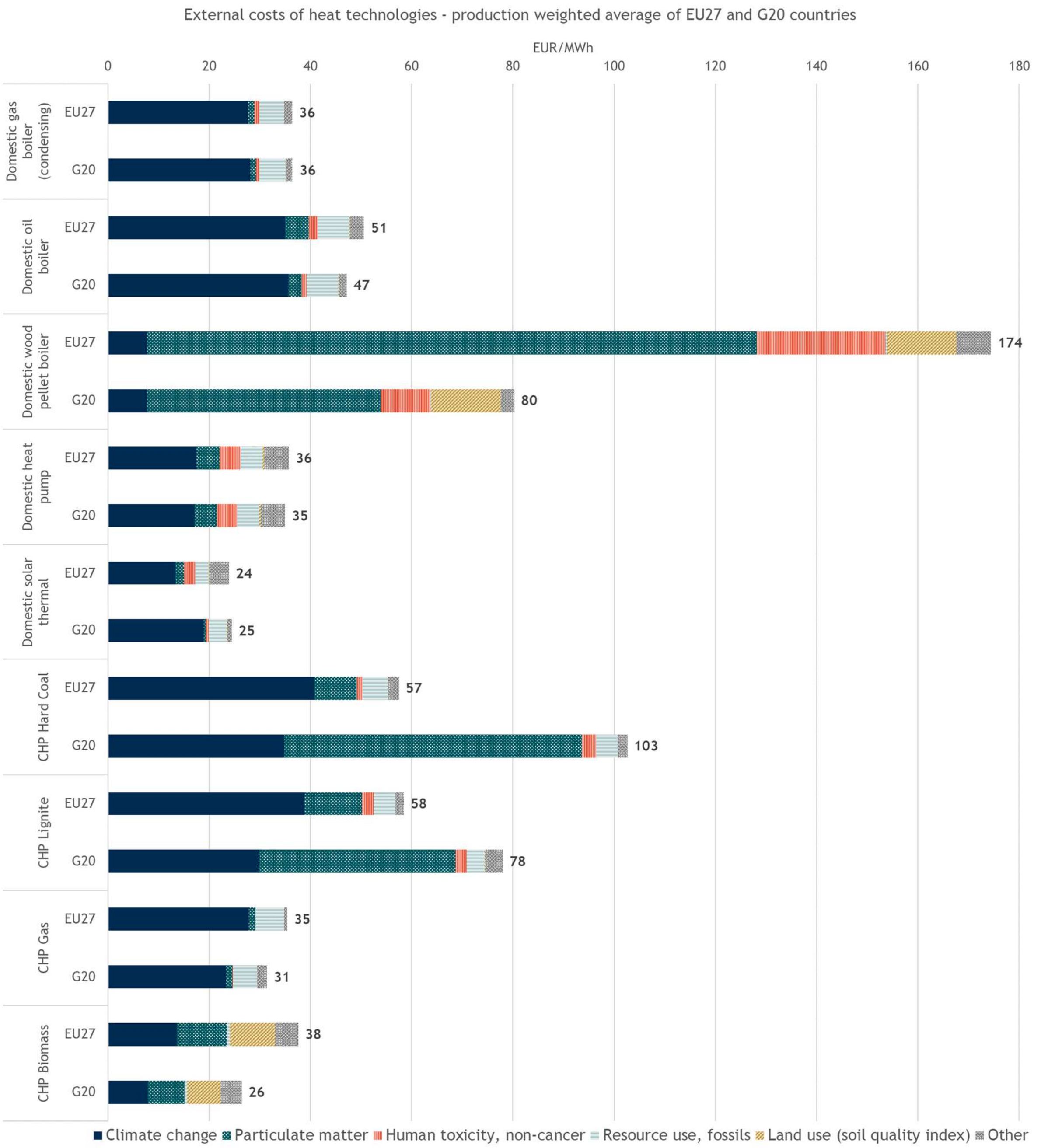
[21] We have applied the EU-ETS internalization to all EU-ETS MS, although it should be noted that transitional arrangements were used by 8 countries (BG, CY, CZ, EE, HU, LT, PL, RO) to provide (a decreasing number of) free allowances to existing power plants up until 2019, in return they committed to spend an equivalent amount on investments in cleaner energy. From 2020 only 3 countries (BG, HU, RO) are taking advantage of this derogation. More information is available here: https://ec.europa.eu/clima/policies/ets/allowances/electricity_en

[22] Note: the LCIA datasets underpinning the analysis, particularly for domestic heating technologies, whilst valid are not considered as robust as those used for the electricity technologies.

impacts, as the countries that dominate the G20 weighting for this technology are India, China and Indonesia, all with considerably lower incomes than the EU average. Domestic heat pumps (€36/MWh), have the same total external costs as domestic gas boilers, although we expect over time that the impacts of heat pumps will reduce as the electricity mix, which drives their main energy use and impact, becomes cleaner.

Climate change and particulate matter are the highest impacts and important for all technologies. Particulate matter is particularly relevant for domestic wood boilers and hard coal, lignite and biomass CHP. The human toxicity, non-cancer, resource use, energy carriers and land use make up the rest of the top five drivers of external costs. For the latter impact, the biomass-based technologies have relatively high costs.

Figure 4-3 EU27 average (production weighted) external cost of heat per technology in €2018/MWh



Sensitivity analysis

Sensitivity checks were also carried for the heat technologies using the low and high monetisation values shown in Table 4-1. In the Low monetisation scenario, total external costs are between -30% (domestic wood boiler and CHP Coal) and -54% (domestic solar thermal), and an average of -43%, lower across the technologies. Using the High monetisation values, total external costs are between 88% (CHP Biomass) and 213% (Domestic heat pump), and an average of 138%, higher across the technologies. The relative distribution of the costs among the technologies remains the same for both the EU27 and G20 with the exception of domestic heat pumps, which in a high value scenario would become more costly than domestic gas boilers.

Internalisation of external costs

As for electricity, the only policies that can be directly identified as internalisations are climate change policies such as carbon taxes, which in the case of heating applies to the fuels used. The policies that are internalised include the EU-ETS which affects the large-scale CHP heat technologies, and a number of country specific carbon taxes which affect residential heating use of natural gas and oil.

When the identified internalisations are applied to the results previously presented in Figure 4-3, they result in significant declines of 16%-19% for the EU27 average total external costs for the large scale fossil heat CHP technologies. It also results in declines of 5-7% in the external costs of domestic natural gas and oil boilers as part of their climate change impact is internalised. The effect is much less pronounced (-0.3 – 0.5%) in the G20 due to the lack of carbon policies, and/or low effective rates of any policies that are in place.

4.5 External costs - Normalised (per MWh) external costs per country

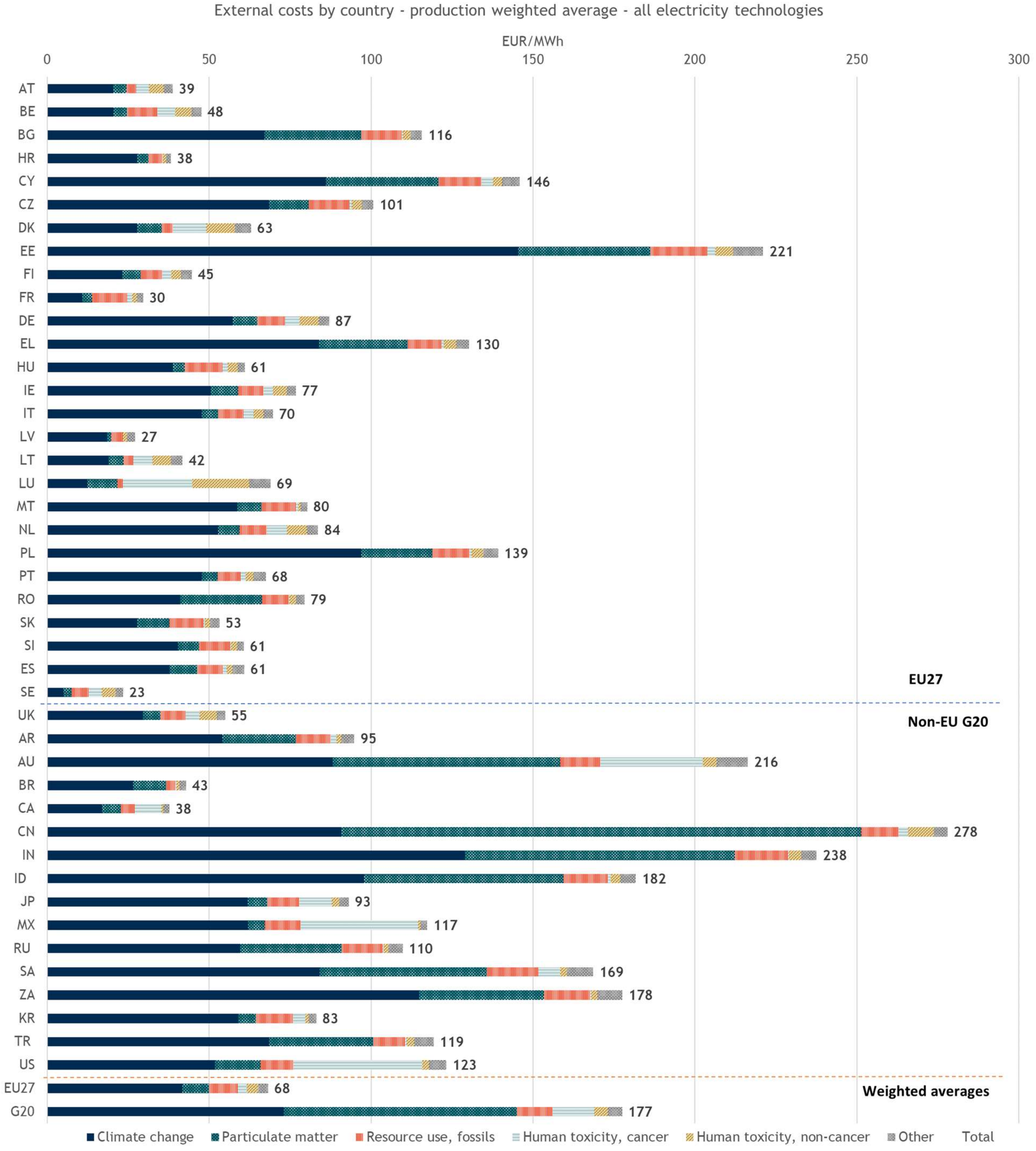
4.5.1 Electricity

By summing the multiplications of generation per technology and external cost impacts per technology and then dividing by the total electricity generation, a per MWh external cost of electricity can be estimated per country as shown in Figure 4-4.

The average external costs in the EU27 are €68/MWh. This shows the influence of the actual energy mix in a country on the average external costs of generation. The lowest values are found in Sweden (€24/MWh) Latvia (€27/MWh) and France (€30/MWh), Sweden with a high share (60%) of hydropower paired with natural gas, Latvia with high shares (40% each) of nuclear and hydropower, and France with a high share (70%) of nuclear. The countries with highest average external costs in the EU27 of €120-220/MWh are unsurprisingly those still heavily dependent on power production from fossil fuels, mainly from lignite and/or hard coal (Bulgaria, Poland, Greece) or from oil (Estonia -power from shale oil -, Cyprus).

The EU27 average is significantly lower than the G20 weighted average of €178/MWh. As can be seen on the figure there is significant variation in the G20 values. Whilst the other most developed countries in the G20 (for example the UK, Canada, South Korea, or Japan), record similar values to the EU average the resulting G20 average value is heavily influenced by the high values of China (€278/MWh) and India (€238/MWh) that have very large weightings in the average. Australia is notable as a highly developed country but with a relatively high external cost of €216/MWh, due to high shares of coal in its electricity production. Indonesia (€182/MWh) and South Africa (€178/MWh) also stand out for their high external costs, both driven by high shares of coal in their electricity mix. For Australia, their power plants may be somewhat cleaner than China and India, but relatively high income levels mean that the human health impacts are attributed higher external costs. The US has relatively high external costs of €123/MWh compared to the EU average, similarly to Australia, relatively high income levels (+34% compared to the EU average) drive higher costs of human health impacts.

Figure 4-4 Average (production weighted) external cost of electricity per country in €2018/MWh

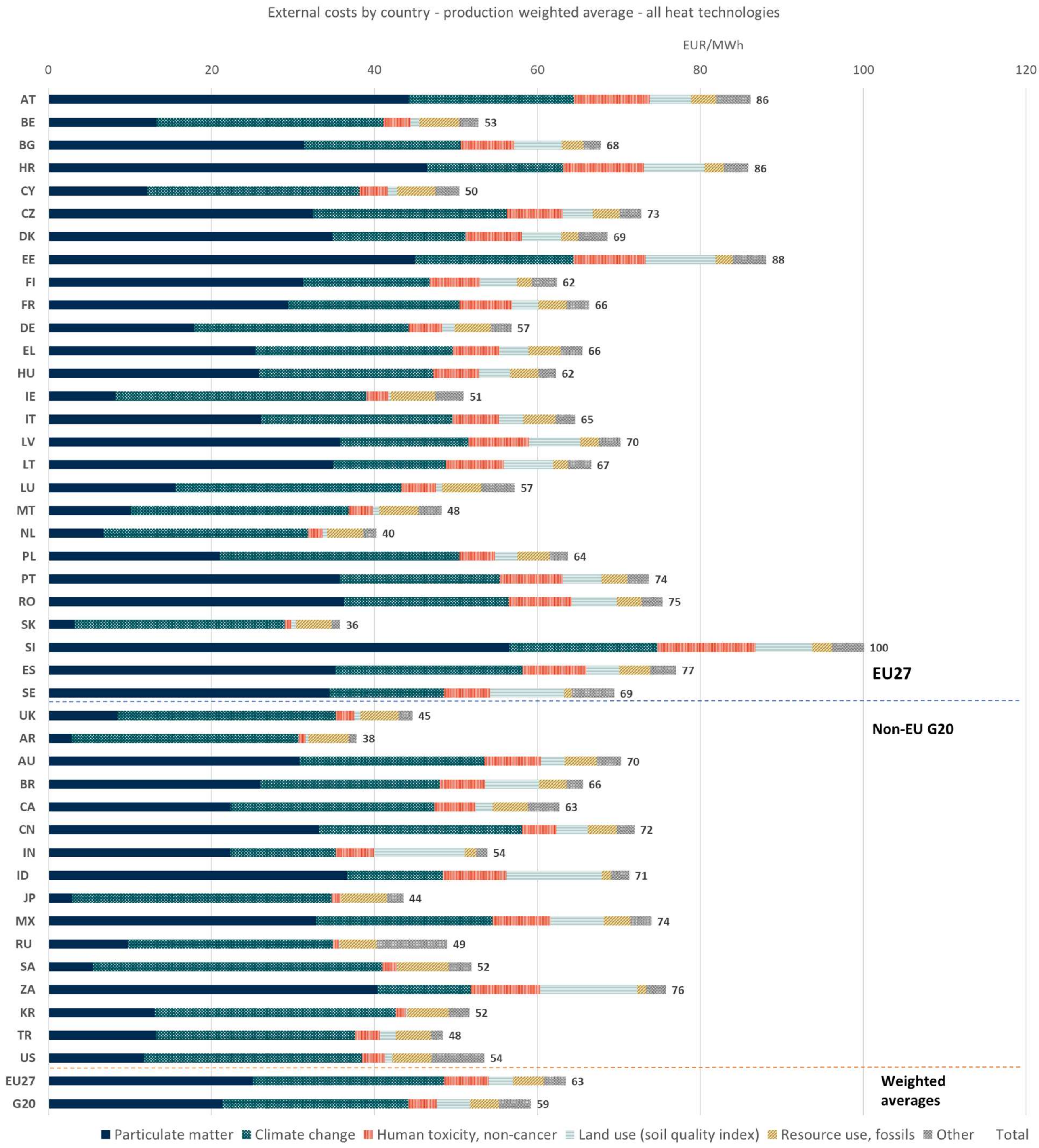


4.5.2 Heat

The analysis of external costs of heating per country (see Figure 4-5) shows a more varied picture than in the case of electricity between the EU and G20.

There is no clear trend across the countries although the average external costs for the G20 are a little lower than those of the EU. The countries with lowest total external costs in the EU are Slovakia (€36/MWh) and the Netherlands (€40/MWh), driven by high shares of gas (domestic and CHP). Amongst the G20 Argentina (€38/MWh), Japan (€44/MWh) and the UK (€45/MWh) have the lowest costs. The EU27 countries with largest external impacts are Slovenia (€100/MWh) and Estonia (€88/MWh), driven by high shares of domestic wood boilers. Amongst the G20 countries, those with largest costs are South Africa (€76/MWh) and Mexico (€74/MWh), the former driven by very high shares of domestic wood boilers, the latter by high use of both wood and oil boilers.

Figure 4-5 Average (production weighted) external cost of heat per country in €2018/MWh



4.6 Total external costs per country

The total external costs across all 43 countries are almost €4 100 billion per year (see Table 4-2). This is clearly a huge number, representing about 6.6% of the total annual GDP of the 43 countries considered. China (€1 900 billion) and the US (€600 billion) have the highest impacts. The only other countries surpassing the €100 billion threshold are India, Russia and Japan – notably amongst the most populous countries of the G20. Brazil and Indonesia, which have populations of 210 and 270 million, respectively, are exceptions, Brazil with relatively low costs – mostly due to the large role of hydropower (60% of electricity) in its energy mix; Indonesia more closely linked to low income levels and therefore lower valuation of human health impacts. From the EU27 countries, the largest sums of external costs are also linked closely to population and economy size, and therefore Germany, France, Italy, Poland and Spain have the highest costs.

External costs of electricity can be as high as 14% of GDP. Focusing on just the EU27 and electricity, for which the numbers are most robust, the external costs of €179 billion represent around 1.3% of annual GDP. For countries with relatively high costs per MWh and relatively low GDP this value increases, e.g. to 5% for Poland and then 10% for Bulgaria and 12% for Estonia. These types of values are also achieved in many G20 countries, with ratios of 14% external costs of electricity to GDP in China, India and South Africa.

Table 4-2 Total external costs per country, latest year (2016-2018), €$_{2018}$ billion

EU27 Country	External Cost Total (€ bn)			G20 Country	External Cost Total (€ bn)		
	Electricity	Heat	Total		Electricity	Heat	Total
Austria	2.0	6.6	8.5	United Kingdom	14.3	16.1	30.4
Belgium	2.8	4.6	7.4	Argentina	13.0	4.2	17.3
Bulgaria	5.3	1.4	6.7	Australia	57.5	4.4	61.9
Croatia	0.5	2.0	2.5	Brazil	23.2	10.3	33.5
Cyprus	0.7	0.1	0.8	Canada	24.2	14.1	38.4
Czech Republic	8.6	6.1	14.7	China	1 642.6	234.3	1 876.9
Denmark	1.0	4.1	5.1	India	329.5	91.8	421.3
Estonia	3.0	1.0	4.0	Indonesia	46.6	46.6	93.2
Finland	2.6	4.6	7.2	Japan	90.3	11.5	101.8
France	14.2	23.6	37.8	Mexico	36.5	10.8	47.4
Germany	47.5	35.0	82.5	Russia	117.6	100.9	218.5
Greece	7.2	2.1	9.2	Saudi Arabia	58.1	1.1	59.2
Hungary	1.8	4.4	6.3	South Africa	43.8	4.1	47.9
Ireland	2.3	1.0	3.3	South Korea	45.9	10.4	56.3
Italy	17.5	24.4	42.0	Turkey	35.3	9.2	44.5
Latvia	0.2	1.1	1.3	United States	508.8	85.9	594.6
Lithuania	0.1	1.2	1.2	**Non-EU G20 Total**	**3 087.3**	**655.8**	**3 743.1**
Luxembourg	0.0	0.4	0.4				
Malta	0.1	0.0	0.1	**Global Total**	**3266.4**	**817.3**	**4083.7**
Netherlands	8.0	5.0	13.0				
Poland	23.7	10.5	34.3				
Portugal	3.7	1.9	5.6				
Romania	5.3	6.7	12.1				
Slovakia	1.5	0.9	2.3				
Slovenia	1.0	1.1	2.1				
Spain	16.4	7.7	24.1				
Sweden	1.9	4.1	6.0				
EU27 Total	**179.0**	**161.5**	**340.6**				

In terms of impact categories, at the global level climate change is the no.1 impact, with costs of €1 700 billion, or around 42% of the total. Impacts of 13.6 $GtCO_2e$ are accounted for in the analysis, equivalent to around 1/3 of global annual GHG emissions. **Particulate matter, with costs of €1 575 billion (39%) is a close second**; indeed in 9 countries, including China, particulate matter is the larger impact. This similarity in cost between the climate and particulate impacts is broadly consistent with other estimates of the cost of air pollution, with some studies noting that these could be higher than climate impacts[23]. These two key impacts are followed by resource use, fossils (€270 billion), and then human toxicity, cancer (€253 billion) and non-cancer (€127 billion) human health effects. The other 10 impact categories total €154 billion together.

Sensitivity checks

When the low and high monetisation values are applied, a range of external costs between €196 - €854 billion is estimated for the EU27 (or -42% and +151% compared to the total using the central values), whilst for the G20 between €2 300 billion and €9 000 billion costs are estimated (or -38% and +140% compared to the total using the central values). In the high value scenario all impacts increase, but especially water use, resource use fossils and the human toxicity impacts all increase significantly their proportions in the total.

Internalisation of external costs

Approximately €34.5 billion of the external costs are internalised in the EU. For the EU the reduction of €34.5 billion from total external costs of €340 billion, represents a 10% internalisation of the external costs. For electricity the €28.1 billion represents a 16% internalisation of the €179 billion costs. For heat the €6.4 billion internalisation represents 4% of the €162 billion external costs. The EU-ETS is responsible for by far the largest share of this internalisation.

But only €18.1 billion is internalised in the G20, which is much lower proportionally when considering the comparative size of the external costs (G20 has more than x10 the base external costs than the EU). For the G20 the reduction of €18.1 billion from total external costs of €3 750 billion, represents a 0.5% internalisation of the external costs. The internalisations occurring mostly through measures in the UK (including the EU ETS), China (Pilot ETS), Canada, India and the US. These apply almost entirely to electricity, with minimal internalisation of heat externalities.

Box 4-1 External costs of transport

A key source study on the external costs of transport was published by DG MOVE in 2019, the Handbook on the External Costs of Transport (Version 2019).

Key results

The study summarises total external costs of transport (road, rail, inland waterways, aviation and maritime) within the EU28 of €987 billion in 2016, or 6.6% of GDP. Road transport accounted for 83% of these total costs, of which the split was 76:24 between passenger transport and road freight. Maritime (10%) and aviation (5%) were the other major contributors. The largest external cost impact category was accidents, accounting for 29% or €286 billion, whilst congestion costs accounted for 27% or €271 billion. However, part of these delay costs are internalised and hence they are only partly external. Climate change and air pollution, both contributed approximately 14% or €140 billion, whilst well-to-tank emissions accounted for around 5% or €53 billion of the total costs.

[23] Such as those highlighted in OECD/NEA (2018) The costs of electricity provision

Comparing results
The total external costs of transport in the EU of €987 billion cannot be compared to total EU external costs in this work of €341 billion, as transport external costs include significant costs such as congestion and accidents that are not relevant for this study. On measures that are consistent across the studies, such as climate change, the total cost of €140 billion per year for transport compares to a cost of €143 billion per year in this study (for electricity + heat) for the climate change impact, very similar totals. For air pollution the €138 billion in the transport study, can be taken as corresponding to the aggregate of the photochemical oxidant formation and particulate matter categories in this work, and the total impact of €91 billion. However, it is important to note that these comparisons are not highly robust, given the methodological differences highlighted below. Similarly, comparisons could be made with the sector values derived in chapter 4 of this work, but we would caution against giving much weight to these given the associated uncertainties.

4.7 Indicative analysis of the external costs of energy consumption

In this section we summarise the results of an indicative analysis of external costs from an **energy consumption** perspective for the industrial, agricultural, residential and commercial and public sectors. This is in contrast to the **energy production** perspective presented in the previous chapters. By using a life-cycle approach there can be significant overlap of results between both consumption and production sectors.

Therefore, significant care is needed when comparing sectors or aggregating the results, as substantial double counting may occur. We recommend therefore to only consider the results at the sector level, and not to aggregate them.

Average external cost of energy consumption

In Figure 4-6 we present the results for external costs at sector level when consumption is weighted per fuel and provide comparison between the EU27 and G20.

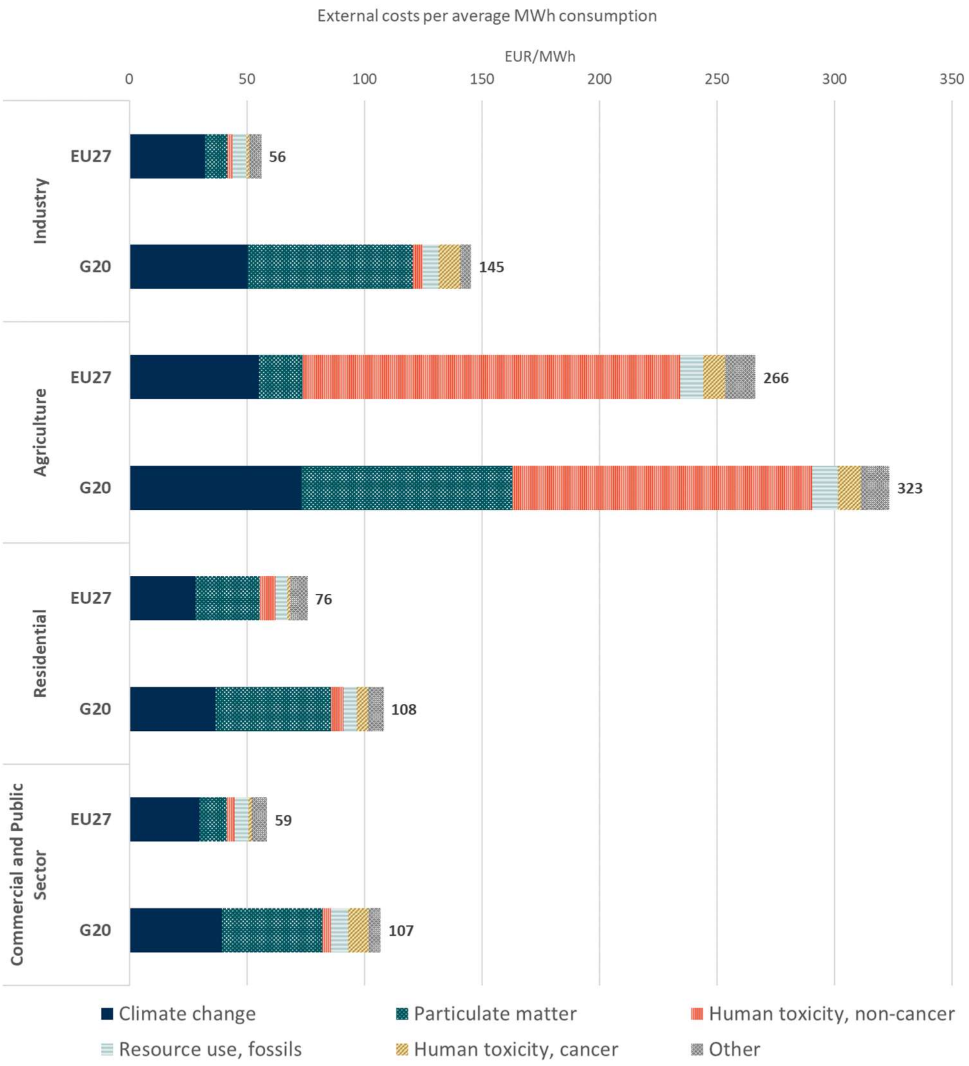
Industry energy consumption in the EU averages external costs of €56/MWh, significantly lower than the €145/MWh average cost calculated for the G20. This is consistent with high natural gas use by EU industry and also high electricity consumption with a much lower average external cost than the central value of €118/MWh presented above. For the G20 the latter factor, significantly higher coal use and electricity with significantly higher external costs are the major factors in the relatively high costs.

Agricultural energy consumption sees a less marked difference between the EU27 and G20, although the EU has the lower costs. The relatively high values for both highlight the importance of oil products consumption in the total sector energy use, primarily diesel consumption in farm vehicles and machinery, which are relatively inefficient uses with weak emissions controls, leading to the relatively high human toxicity health impacts.

Residential energy consumption shows average external costs of €76/MWh in the EU and €108/MWh in the G20.

Commercial and public sector energy consumption shows a lower external cost than residential energy consumption of €59/MWh in the EU, but a very similar cost value for the G20 of €107/MWh. For the EU the difference derives from a relatively much higher share of electricity which has lower average costs, and a lower share of biomass/waste which has high external costs.

Figure 4-6 Average external costs of energy consumption, consumption weighted per sector, EU27 and G20 in €2018/MWh



Total external costs of energy consumption

The total external costs of energy consumption are presented below in Table 4-3. As noted previously, these figures are indicative given both the uncertainties and lack of specificity in the datasets used and should not be aggregated as there are likely significant overlaps in costs across consumption sectors and the calculated externalities of energy production presented in chapters 2 and 3.

Industry energy consumption is calculated to have an external cost of €157 billion in the EU and €3 560 billion in the G20. Within the EU Germany has more than double the costs of the 2nd country with total costs of €41.5 billion, or around 26% of the total. In the G20 China is even more dominant than Germany is within the EU, with external costs of €2 365 billion almost 10 times higher than the next highest country, the US at €290 billion, and representing 66% of the total.

Agricultural energy consumption is calculated to have external costs of €71 billion in the EU and €485 billion in the G20. Within the EU France has the highest costs of €16 billion. Within the G20 India has the highest external costs for energy consumption of €130 billion, China (€107 billion) and United States (€95 billion) also have high costs.

Residential energy consumption is calculated to result in annual external costs of €217 billion in the EU and €1 500 billion in the G20. The external costs are highly linked to population and climate. In the EU Germany, France and Italy have the highest total costs. Whilst in the G20 China, India and the United States have the highest costs.

Commercial and Public sector energy consumption is calculated to result in annual external costs of €90 billion in the EU and €660 billion in the G20. As before this is closely linked to population and climate, and also to a greater extent in this case, income. In the EU Germany and France have the highest associated external costs. Whilst in the G20 China and United States have the highest costs.

Table 4-3 Total external costs per country, latest year (2016-2018), €2018 billion

EU27 Country	External Cost Total (€ bn)				G20 country	External Cost Total (€ bn)			
	Industry	Agriculture	Residential	Commercial and public services		Industry	Agriculture	Residential	Commercial and public services
Austria	3.6	1.0	6.4	1.3	United Kingdom	13.2	2.7	21.5	8.6
Belgium	6.2	2.1	5.2	2.1	Argentina	12.2	13.1	9.3	4.3
Bulgaria	2.3	0.4	3.2	1.5	Australia	26.9	13.6	16.2	14.2
Croatia	0.6	0.7	2.3	0.4	Brazil	34.4	15.0	18.2	8.1
Cyprus	0.2	0.1	0.3	0.3	Canada	31.6	29.1	19.9	28.0
Czech Republic	5.6	1.7	8.2	2.7	China	2 364.8	106.5	655.7	195.4
Denmark	1.3	2.7	4.7	1.4	India	354.3	130.0	249.9	66.0
Estonia	0.7	0.5	1.5	0.8	Indonesia	43.0	6.0	74.6	17.4
Finland	5.2	2.1	5.3	1.8	Japan	79.8	22.6	37.1	37.4
France	17.2	16.0	32.7	13.4	Mexico	39.5	11.8	19.8	3.7
Germany	41.5	*	44.6	24.3	Russia	124.7	16.3	79.7	35.3
Greece	2.8	0.5	4.8	2.8	Saudi Arabia	33.2	*	24.0	15.8
Hungary	2.7	1.6	5.3	1.2	South Africa	39.8	4.4	19.7	8.1
Ireland	1.6	1.4	2.2	0.8	South Korea	44.0	6.7	14.3	18.5
Italy	15.7	11.0	27.1	9.6	Turkey	31.2	12.1	18.4	12.9
Latvia	0.3	0.5	1.3	0.4	United States	288.2	95.1	224.6	186.4
Lithuania	0.6	0.2	1.5	0.4	**Non-EU G20 Total**	**3 560.9**	**485.1**	**1 502.9**	**660.1**
Luxembourg	0.3	0.2	0.4	0.2					
Malta	0.0	0.0	0.1	0.1	**EU27 + G20 total**	**3718.1**	**555.8**	**1720.3**	**749.8**
Netherlands	8.9	5.0	5.9	4.7					
Poland	15.3	9.1	23.2	9.3					
Portugal	2.3	1.6	2.5	1.3					
Romania	4.3	1.2	7.9	*					
Slovakia	2.3	0.3	1.1	0.8					
Slovenia	0.8	0.3	1.3	0.3					
Spain	10.5	9.7	12.6	5.9					
Sweden	4.4	0.5	5.5	1.9					
EU27 Total	**157.2**	**70.8**	**217.4**	**89.7**					

** = no energy consumption for this sector is recorded in IEA data, therefore no total cost is estimated*

Internalisations of energy consumption externalities

Using the tax database prepared for the energy taxes work in this study we were able for the EU27 and UK to make a comparison between the external costs of energy consumption and taxes[24]. It is important to note that the share of taxes on energy production were identified in the parallel report on energy taxes as very low, only 2% of total energy taxes, and concentrated in the handful of primary energy producers in the EU. Furthermore, of the taxes on energy consumption, more than 60% of the total energy tax revenues come from taxes on transport fuels. These are not considered below, as externalities in the transport sector was already presented in a separate text box.

The analysis identified approximately €104 billion of energy consumption taxes relevant to the consumption sectors, or around 40% of the €263 billion taxes identified in the tax work. Specifically:

- **For industry** the calculated external costs of €157 billion can be compared against around €26 billion energy consumption taxes on industry, representing around 16% of the external cost. Amongst EU member states the highest ratios between taxes and external costs can be found in Denmark (43%), Italy (40%) and Germany (29%). Rates are below 5% in many countries, including BE, BG, HR, CZ, EE, IE, LV, LT, LU, MT, PL, PT and RO;
- **For agriculture** the calculated external costs of €71 billion can be compared against around €4.4 billion energy consumption taxes, representing only around 6% of the external cost. This is the lowest ratio of any of the consumption sectors and could point to a relatively privileged position for the agricultural sector and its energy use. Amongst EU member states the highest ratios between taxes and external costs can be found in Sweden (47%), Slovakia (13%) and Austria (12%). Rates are below 5% in many countries, including BE, BG, HR, CY, DK, EE, IE, IT, LV, LT, LU, MT, PL, RO and ES;
- **For residential** energy consumption the calculated external costs of €217 billion can be compared against around €40 billion energy consumption taxes, representing around 18% of the external cost. Amongst EU member states the highest ratios between taxes and external costs can be found in the Netherlands (86%), Germany (37%) and Denmark (35%). Rates are below 5% in many countries, including BE, BG, HR, CY, CZ, EE, HU, LV, LT, LU, MT, PL, PT, RO and SI.
- **For commercial and public sector** energy consumption the calculated external costs of €90 billion can be compared against around €33.7 billion energy consumption taxes, representing around 38% of the external cost. This is the highest ratio for any of the sectors. Amongst EU member states the highest ratios between taxes and external costs can be found in Italy (79%), Germany (62%) and Sweden (56%). Rates are below 5% in many countries, including BE, BG, HR, CY, CZ, EE, LV, LT, LU, MT, PL and PT.

[24] It should be noted that the energy taxes considered here are not usually, apart from some climate measures, targeted at reducing a specific externality. Rather they are general energy taxes with a variety of purposes including both environmental protection and revenue raising amongst others.

5 Energy Taxes

The taxes report focuses on energy consumption in the EU27. Including:

- Excise taxes on fuels;
- Non-tax levies on fuel purchases, such as on natural gas and electricity bills, used to finance renewable energy (e.g., the Renewable Energy Sources Act ('EEG') in Germany), or energy efficiency (e.g., Italy's White Certificate scheme);
- All other taxes, levies and fiscal measures that end consumers pay when they consume energy.

Taxes on energy production and infrastructure in the EU27 and the United Kingdom[25] are also covered, although in less detail than taxes on energy consumption. Finally, taxes on energy in 11 G20 countries are reported and compared to tax rates and levels in the EU27.

Environmental charges such as carbon taxes are included in the total taxes, with the exception of the EU Emissions Trading Scheme ('ETS') which is not considered a tax and is therefore covered under external costs and subsidies. Value added taxes ('VAT') are not covered in this report due to data and methodological difficulties.

5.1 Summary of approach

This task included three steps: data collection, data analysis and reporting.

The approach to data collection for taxes on energy consumption was to develop a detailed data collection template, pre-populate it for each EU27 and G20 country with data from transversal sources, including Enerdata Global Energy and CO2 Data and Enerdata EnerDemand online databases, Eurostat, etc., send the templates to country experts for updating with data from national sources, and conduct data quality control.

Data from MS and UK national reports was used to estimate taxes on energy production, and Eurostat data was used to estimate taxes on energy infrastructure.

Note that in the analysis 'taxes' comprises all of those types of taxes listed at the top of this page (thus including excise taxes on fuels, non-tax levies on fuel purchases and all other taxes, levies and fiscal measures that end consumers pay when they consume energy.

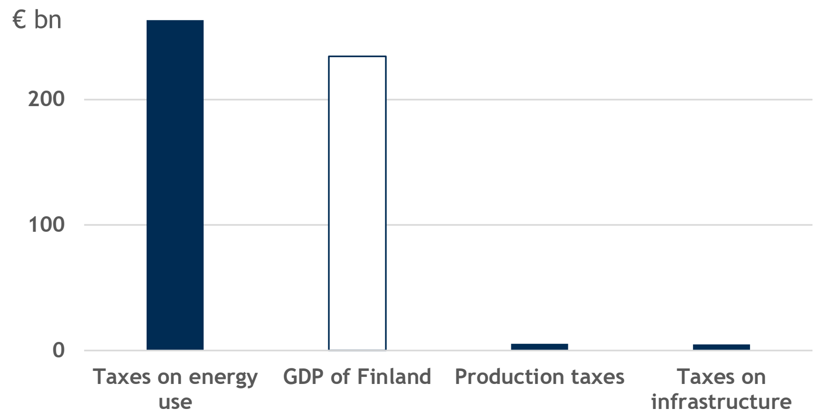
5.2 Key takeaways

All taxes analysed

- Revenues from taxes on energy consumption in the EU27 totalled €263 bn in 2018, more than the GDP of Finland, or around 18% of all consumption taxes[26]. However, taxes on energy production and infrastructure each totalled only around €5 bn or around 2% of the value of taxes on consumption.

[25] The UK in considered a non-EU G20 country in this analysis.
[26] Calculated from Table 39 of EC (2019) Taxation trends in the European Union 2019 edition (2017 values)

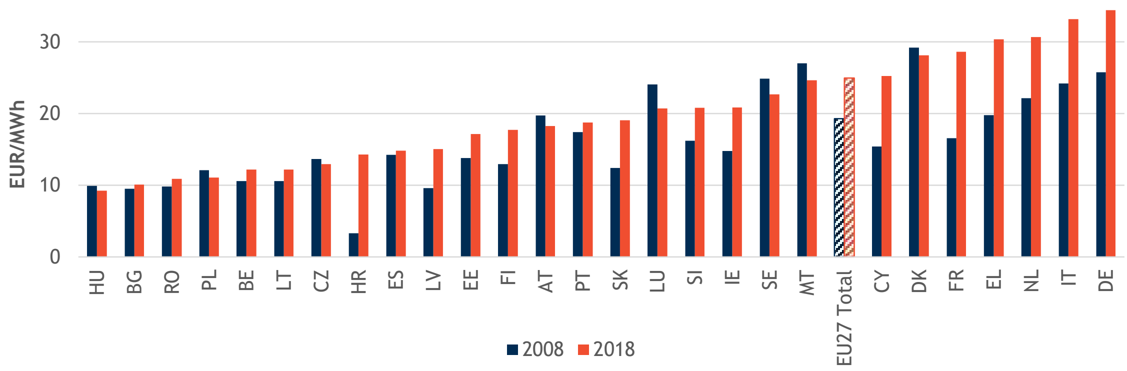
Figure 5-1 Total revenues from taxes on energy use, production and infrastructure in the EU27 in 2018



Reported tax rates on energy consumption in the EU27

- **Tax rates on energy use increased by 29% between 2008 and 2018, in real terms.** The total reported tax rate on energy consumption in the EU27 was €25/MWh in 2018[27]. Member states total tax rates ranged from €9/MWh (Hungary) to €34/MWh in 2018 (Germany), with a median of €19/MWh.

Figure 5-2 Reported total tax rates on energy consumption in the EU27 in 2008 and 2018



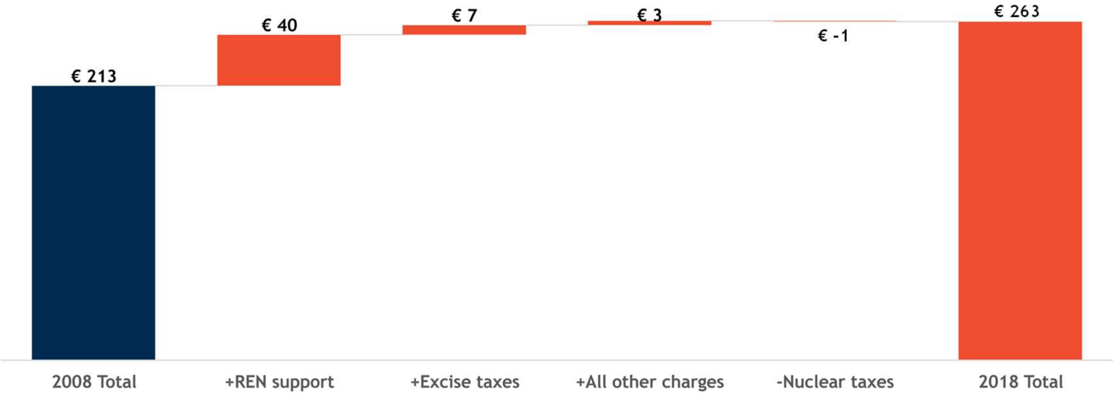
- **There is now more differential tax treatment by sector than there was in 2008**. Rates increased the most, in absolute terms, in the non-energy-intensive industry ('non-EII'), services and construction sectors, while rate changes in the passenger road and water transport sectors were small;
- **Tax rates on EIIs are three times less than on non-EIIs**. And the median tax rate on EIIs is half that of non-EIIs;
- **Tax rates on liquid fuels used for road transport are the highest and rates on petroleum coke and coal are the lowest**. The median tax rate levied by EU MS on gasoline is €60/MWh and €37/MWh on diesel, while the median tax rate on solid fossil fuels (i.e. coal) is €1/MWh, €2/MWh on natural gas, and €4/MWh on electricity.

[27] Calculated as the sum of consumption tax revenues across the EU27 divided by the sum of energy volumes taxed across the EU27.

Estimated tax revenues from taxes on energy consumption in the EU27

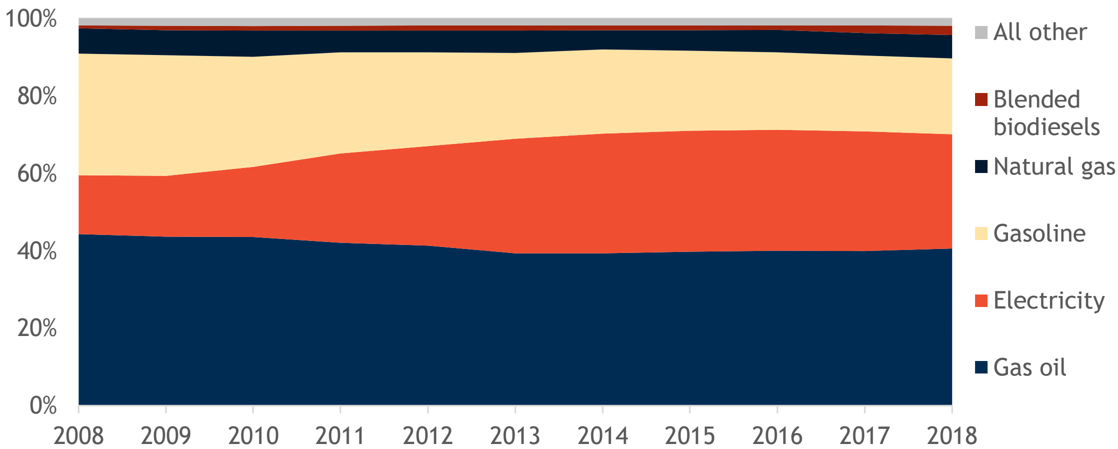
- **Total revenues from taxes on energy consumption increased 23% between 2008 and 2018** (from €219 billion in 2008 to €263 billion in 2018). 47% of the revenue in 2018 was accounted for by Germany and France, and another 28% by Italy, Spain and the Netherlands. Road transport accounts for 60% of tax revenue, followed by residential (15%), then services (12%);
- **Three-quarters of revenues in the EU27 were from excise taxes in 2018, and 20% were for renewables support.** Additional support for renewables accounted for €40 billion, or 80% of the €50 billion in additional revenue in 2018 relative to 2008.

Figure 5-3 Decomposition of additional revenues from taxes on energy use in 2018 v. 2008 (€ billion)



- **Energy intensive industries and agriculture paid the least taxes relative to the amount of energy they consumed in 2018, whereas the road transport sectors paid the most**. EIIs account for 18% of energy consumption and 2% of tax revenue, and agriculture accounts for 3% of energy use and 0.5% of tax revenue while road transport accounts for 29% of energy consumption and 60% of tax revenue;
- **Revenues from taxes on electricity rose while those on gasoline fell.** Taxes on diesel account for the largest share of tax revenues in 2018 (41%), as they did in 2008. Electricity accounted for 30% of tax revenues in 2018, up 15 percentage points from 2008, while the gasoline share decreased from 30% to 20%, corresponding to a drop of a fifth in gasoline consumption between 2008 and 2018.

Figure 5-4 Share of tax revenues by fuel in the EU27, 2008-2018



Taxes on production and infrastructure in the EU27

- Revenues from taxes on energy production fell from €21 billion in 2008 to €5 billion in 2018, while taxes on infrastructure doubled to €5 billion.

Taxes on energy consumption in G20 countries

- **Total tax rates on passenger road transport within 11 G20 countries (including the United Kingdom, but excluding Germany, France and Italy) are, on average, half that in the EU27.** The US tax rate is 40% that of the lowest EU MS tax rate (Bulgaria) and a quarter of the total EU27 rate. The rate in Japan is 20% lower than the EU27 total and equivalent to the rates in Austria, Romania, and Latvia;
- **Tax rates on energy-intensive industries in Japan are twice that of the EU27 (€12/MWh versus €6/MWh), but tax rates on non-energy-intensive industries are a third lower (€12/MWh versus €18/MWh).**

6 Energy Subsidies

The aims of this task were to provide an analysis of the evolution of the energy subsidies in the EU27 since 2008 and a comparison with non-EU G20 countries. We have also provided a detailed inventory that can be used for methodological support to the EC in future reporting on energy subsidy accounting and Member States' policy measures addressing the phasing-out of inefficient fossil fuel subsidies.

6.1 Methodology

Subsidy data collected covers all energy sources, products and carriers, as well as all economic sectors from 2008 to the latest available year, 2018. The study covers subsidy data comprising various forms of monetary transfers from public entities to private (direct transfers, tax expenditures) as well as regulatory economic mechanisms and schemes that results in cross-subsidies.

The process implemented during the study to collect, control and harmonise subsidy data and to assemble these in a single database (later called "*inventory*") comprised six steps: (1) developing a detailed data collection template; (2) pre-populating it for each country with data from the former inventory and transversal sources; (3) sending the templates to country experts for updating with data from national sources; (4) conducting data quality controls; (5) developing dashboards to ensure cross-country validation; and, (6) complementing the inventory by inserting subsidy data estimated by the core team.

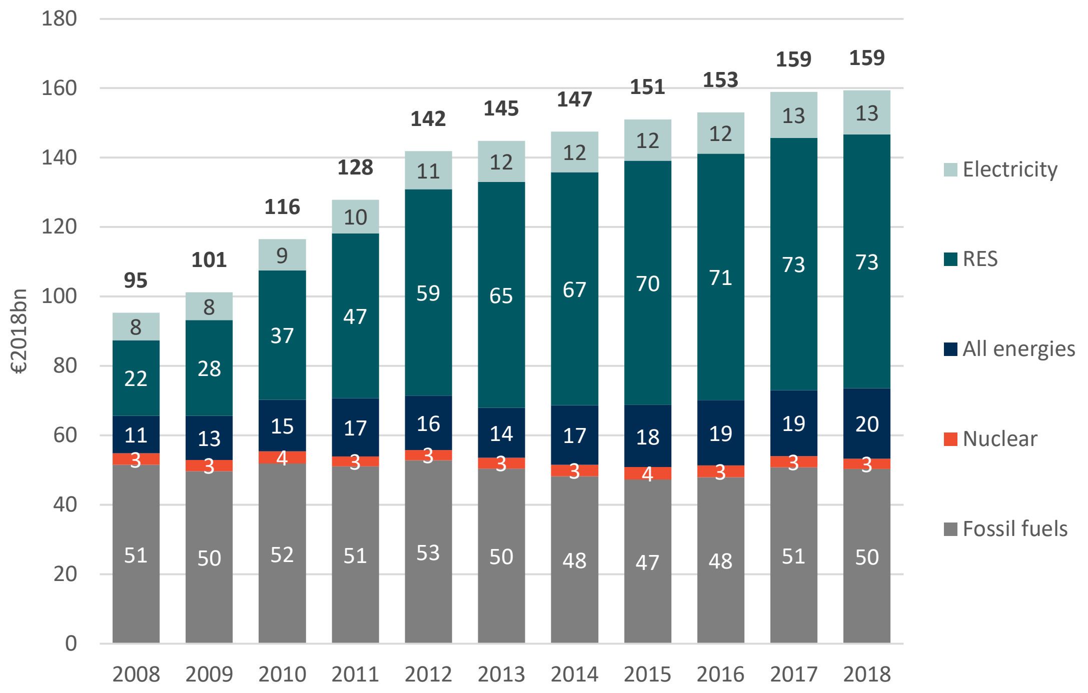
Subsidy amounts have been converted to 2018 Euros to allow comparison across years. Data have been arranged in the following categories to facilitate analysis:

- **Purpose**: support to energy demand, support to energy efficiency, support to industry restructuring, support to infrastructure, support to energy production, support to R&D;
- **Subsidy_category**: direct transfers, tax expenditures, under-pricing of goods/services, and Income or price supports;
- **Subsidy instruments;**
- **Energy sources, products and carriers;**
- **Economic sectors;**
- **Source of financing.**

6.2 Energy subsidies - Trends since 2008

Total energy subsidies in the EU27 have increased by 67% from €95 bn in 2008 to €159 bn in 2018 in real terms (€$_{2018}$) driven by subsidies for energy production (+€48 bn) that have increased by 130%. Most of this amount has been directed to the production of electricity, especially for renewables through feed-in tariff and feed-in premium schemes have benefited the most.

Figure 6-1 Subsidies by main energy carrier in the EU27 (€2018bn, 2008-2018)



Although **fossils fuel subsidies** have slightly shrunk over the full 2008-2018 timeframe, they have rebounded since a low of €47 bn in 2015 to **reach €50 bn in 2018**. The energy sector (€18 bn), transport and industry (€11 bn each) received most of the fossil fuel subsidies in 2018. Tax expenditures for fossil fuels are extensively used by the MS and reached €35 bn in 2018, whilst €8.5 bn of support were provided in the form of feed-in tariffs, feed-in premiums, renewable obligations and producer price support schemes for producing electricity from CHP burning fossil fuels.

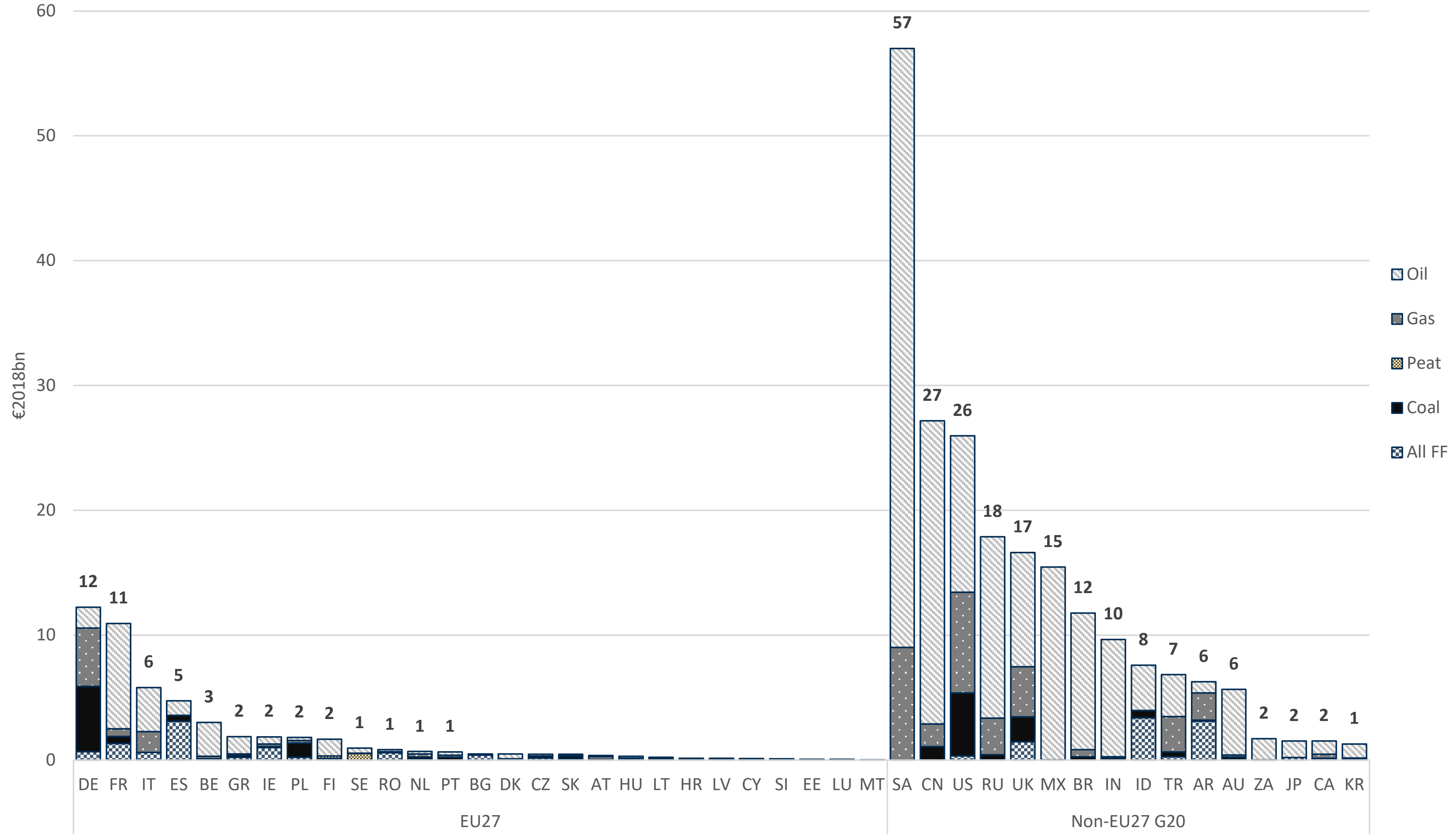
6.3 Fossil fuels subsidies

Although Germany was still the largest provider of fossil fuel subsidies (€12 bn) in 2018, this amount reduced by €2.7 bn since 2008. Fossil subsidies were also lower in Italy (3rd highest with €6 bn in 2018) which also recorded a €2.6 bn reduction since 2008. Conversely, fossil fuel subsidies have grown in France by €4 bn to €11 bn since 2008 driven by new and growing excise tax expenditures and the growing cost of its equalisation system[28], and in Poland, up €1.3 bn since 2008 to €1.8 bn in total, mainly due to support to its coal industry.

Beyond the EU border, large fossil fuel subsidies have been granted by some G20 countries with Saudi Arabia ranking first with an estimated €57 bn of fossil fuel subsidies in 2018, followed by China (€27 bn) and the US (€26 bn) (Figure 6-2). Oil is by far the most supported fuel in the G20 countries mainly due to two types of policies: a) policies aimed at subsidising fuel prices for end-users (road transport) in some countries like China, India, Indonesia, Mexico, Saudi Arabia and South Africa; b) policies supporting oil and gas extraction activities through tax expenditures (Brazil, Russia, the UK).

[28] According to the principle of equalisation at national level, consumers pay identical electricity tariffs everywhere in France, even in the Outermost territories where the production costs are higher than in mainland France. To ensure national tariff equalisation, compensation of cost overruns is necessary. This is calculated by the Energy Regulation Commission (CRE) and forms part of the State budget.

Figure 6-2 Fossil fuel subsidies per country in EU27 and G20 in 2018 (€2018)



6.4 Renewable energy sources

In line with the EU target of 20% **renewable energy sources** in final energy consumption by 2020, Member States have implemented policies boosting these technologies resulting in a surge in financial support from €22 bn in 2008 to **€73 bn in 2018**. Solar PV captured the lions' share with €28 bn in 2018 (+€24 bn since 2008), followed by wind onshore (€16 bn, +€9.5 bn), biomass (€15 bn, +€9 bn) and lately by wind offshore (€5 bn, +4.5 bn).

Meanwhile, several MSs have implemented schemes to secure electricity supplies to cope with the increasing penetration of intermittent renewables in the electricity markets. Payments under the **capacity mechanisms** (reserve) reached €2.2bn in 2018, while **interruptible load schemes** received €0.7bn.

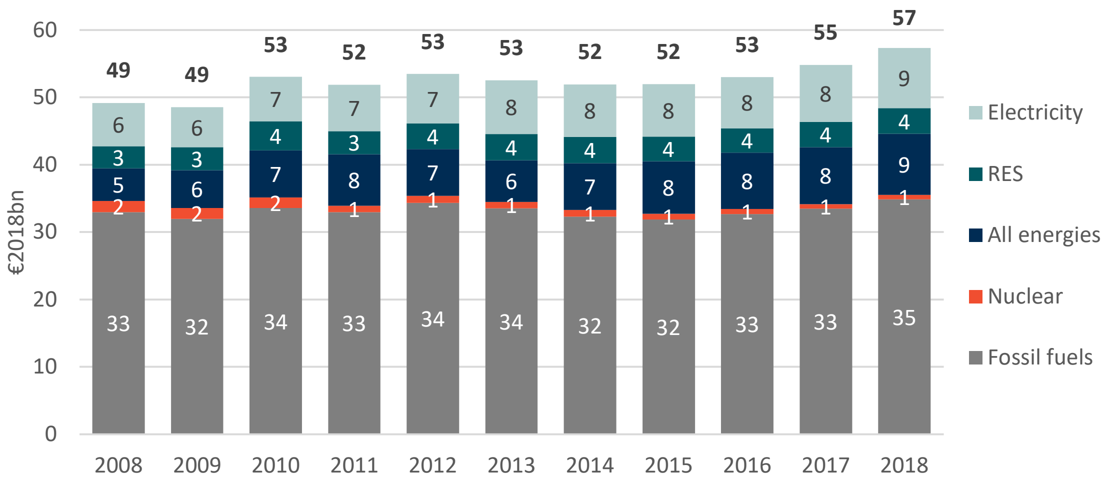
6.5 Subsidies for energy efficiency

Subsidies for energy efficiency represented 9% of the total subsidy amount in 2018 at €15 bn. They have increased by 114% since 2008, from €7 bn. MSs' strategies to support energy efficiency vary across countries: while most MS support energy efficiency by providing grants, Italy and France have favoured tax expenditures and energy efficiency obligation schemes, whilst in Germany there is greater subsidy in the form of soft loans.

6.6 Tax expenditures

In 2018, the **total tax expenditures** (or the indirect subsidies to taxpayers) **by the EU27 reached €57 bn**[29]. €35 bn were revenue waivers from taxes on fossil fuels, including carbon taxes[30], and €9 bn from taxes on electricity (Figure 6-3). **Marked gasoil** (also called coloured gasoil), which is consumed for off-road uses in agriculture, industry, rail transport, public administration and for heating purposes in residential and services, accounted for **€9.8 bn** in 2018 alone, up from €5.8 bn in 2008.

Figure 6-3 Tax expenditure in the EU27 by type of tax and levy (€2018bn, 2008-2018)*



[29] This amount disregarded behavioral responses, i.e. consumer price elasticity.
[30] Most of the MS having implemented a carbon tax report the amounts corresponding to this tax included in the excise tax revenue. Only a few MS report the amounts collected for their carbon tax separately. Therefore, for harmonisation purposes, it has not been possible to isolate the revenues from carbon taxes, and therefore they are included in the excise tax.

Of the €57bn tax expenditures, **revenue foregone on excise taxes reached €40 bn**, corresponding to 18% of excise tax revenues in the EU27 in 2018 (stable since 2008 around 18%) or the total 2018 government revenues of Hungary (€41 bn) or Romania (€42 bn). Between 2008 and 2018, the EU27 (as a whole) share of excise tax expenditures[31] compared to their revenues (18%) and the EU27 reliance on excise taxes to finance state budgets (around 8%) have remained stable. However, Figure 6-4 highlights the heterogeneity of fiscal strategies implemented by the MSs. Ireland is moving toward the group of MSs with high level of excise tax expenditures, namely Sweden and Belgium, while Greece has taken the opposite path getting closer to the EU average. During the period, Austria, Czechia, Germany and Sweden have reduced their dependence on excise tax revenues while reducing its share of excise tax expenditures. Countries like Cyprus, France, The Netherlands, Poland and Romania have taken the opposite path increasing both their budget exposure to revenues from excise taxes and the subsidies provided.

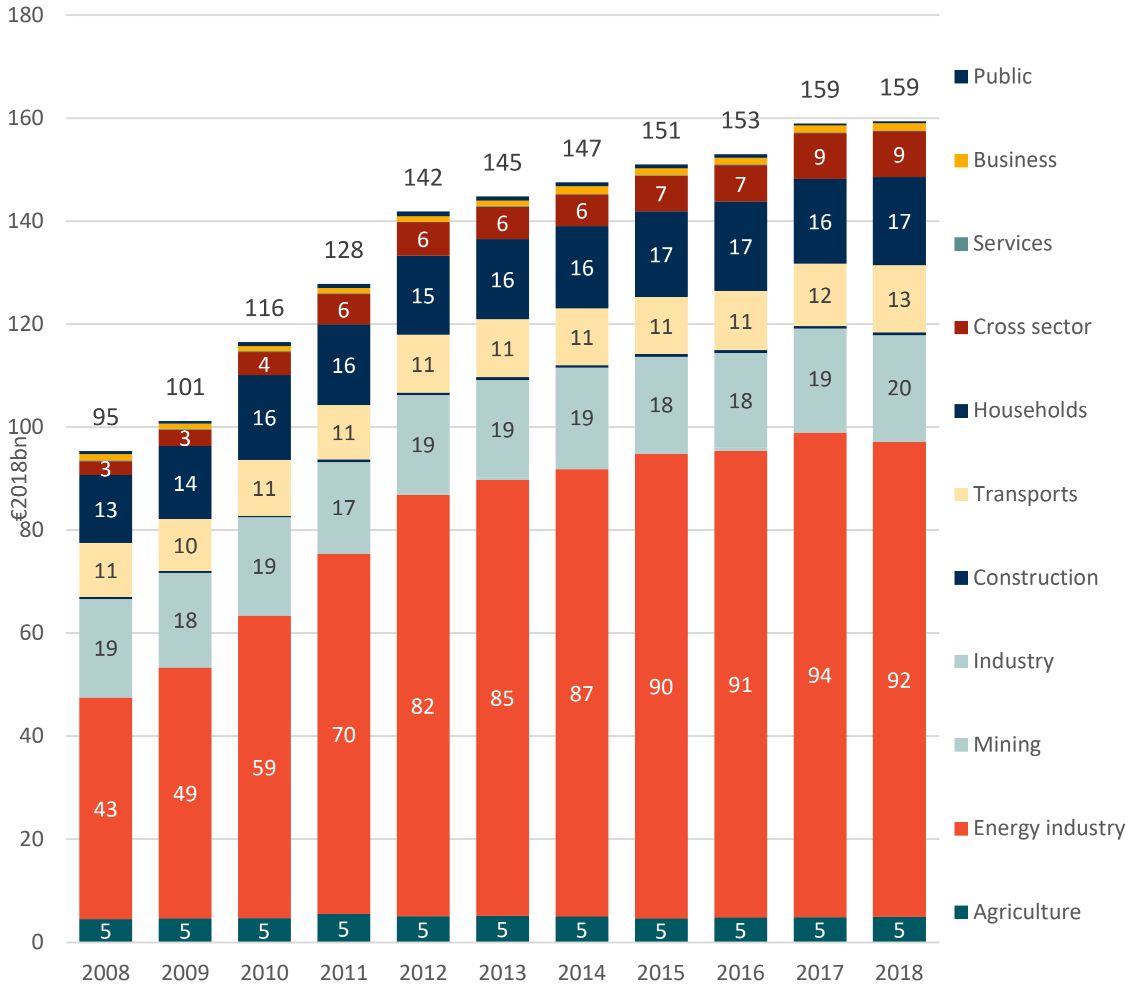
Figure 6-4 Excise tax expenditures vs excise tax revenues and total government revenues in 2018

6.7 Subsidies by economic sectors

The energy sector has received the lions' share of the total energy subsidies, with €92 bn or 58% of the total subsidies in 2018, this is followed by industry (€20 bn, 13%), households (€17 bn, 11%), transport (€13 bn, 8%), and agriculture (€5 bn, 3%).

[31] Reductions in excise taxes (subsidies) are considered excise tax expenditures

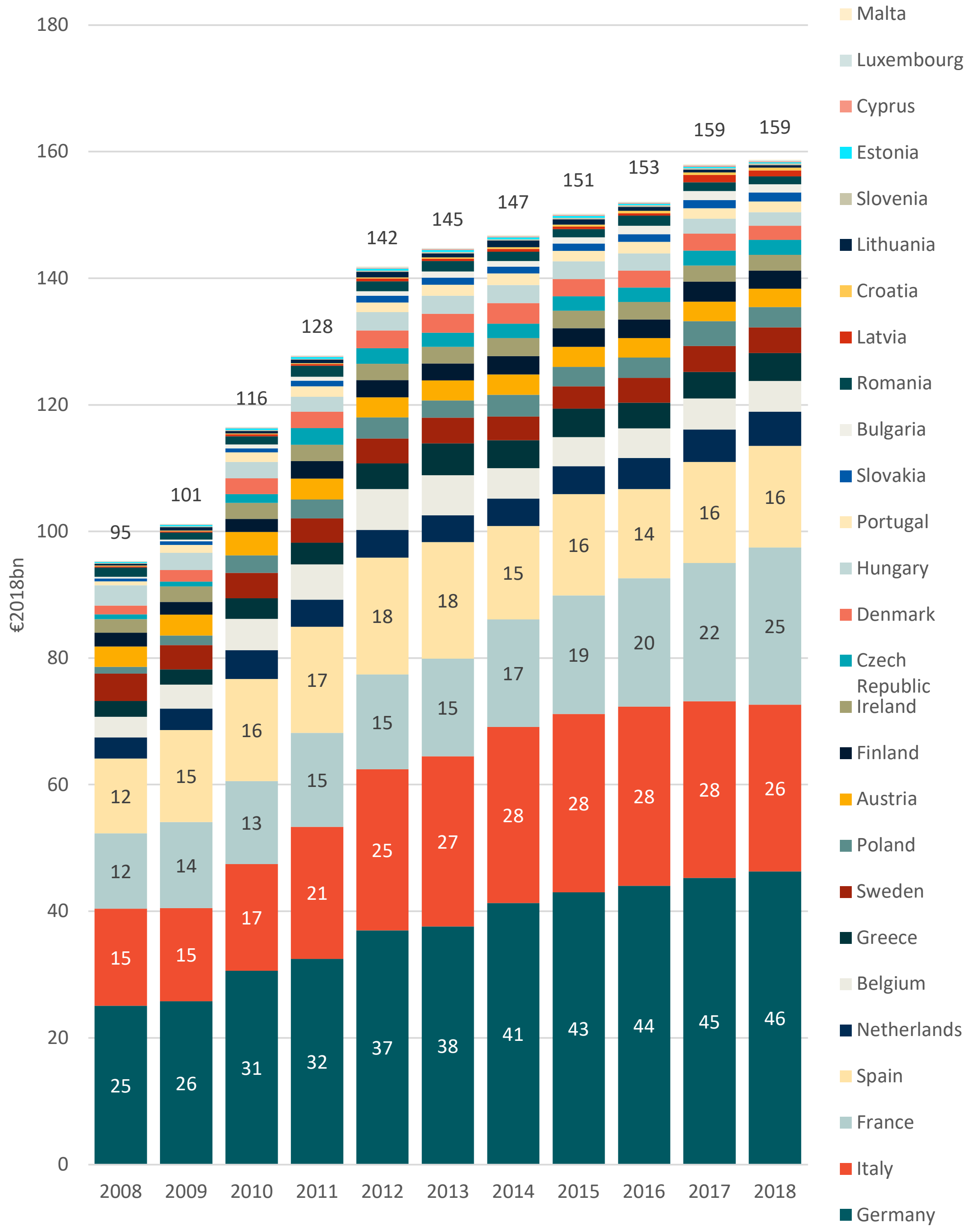
Figure 6-5 Subsidies in the EU27 by economic sector (€2018bn, 2008-2018)



6.8 Energy subsidies trends by MS

Of the additional €64 bn of energy subsidies provided by the EU27 since 2008, Germany added €21 bn of support to a total of €46 bn in 2018, followed by Italy (+€11 bn at €26 bn), France (+€13 bn at €25 bn) and Spain (stable around €16 bn since 2010). The other 23 countries provided an additional €14 bn over the 2008-2018 period, with upward trends in The Netherlands (+63%, +€2.1 bn), Poland (+200%, +€2.1 bn), Greece (+75%, +€1.9 bn), Czechia (+213%, +€1.6 bn) and Belgium (+50%, +€1.6 bn), and downward trends in Romania (-15%, -€0.2 bn), Sweden (-5%, -€0.2 bn), Austria (-10%, -€0.3 bn) and Hungary (-33%, -€1.1 bn).

Figure 6-6 Energy subsidies in the EU27 by country (€2018bn, 2008-2018)



7 Energy Investments

7.1 Objectives

The overarching objective of this report is to analyse the impact of subsidies on investments in the energy sector for the period 2008-2018. This includes investments in the extraction and refining of fuels, the production of electricity and heat, transmission & distribution infrastructure, storage and electrification.

The main deliverables of this task are a comprehensive database of energy investments for the countries in scope, a high-level analysis on the trends and developments in investments and an analysis on the impact of subsidies on investment levels.

7.2 Methodology

Investments include both public and private sector investments, are measured in 2018 Euros, and are defined as overnight investments in new capacities or investments in refurbishments[32].

Data collection and validation was carried out in a three-staged approach that aimed to deliver monetary estimates of investments per investment category[33], country and year:

- Step 1: Data collection from transversal sources such as the IEA, Rystad Energy, S&P (Platts), and IRENA. This data included data in monetary terms (e.g. € or USD) and in capacity additions terms (e.g. MW) and was used to pre-populate the dataset;
- Step 2: Validation and gap filling country experts. Priority was given to monetary data. Data on capacity additions was only collected if no reliable data in monetary terms was identified;
- Step 3: Convert data on capacity additions to monetary data 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.

Once the dataset was completed, we aimed to convert the investment data to easy to interpret graphs on key trends and developments with respect to investments in the energy sector. A selection of the results are provided below.

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 accompanying the subsidies task report (see also the section on energy subsidies of this report).

[32] For more conventional technologies investment data refers to total investments (new capacities + refurbishments). For newer technologies, investment data refers to new capacities only. Only capitalised refurbishments are defined as investments.
[33] Categories: Extraction (oil, gas and coal supply), production (oil refining, LNG liquefaction/regasification, coal-fired power plants, gas/oil-fired power plants, nuclear power plants, hydro power, solar PV, wind power, concentrated solar power, solar power, modern bio-heat, geothermal, ocean energy), transmission & distribution (electricity, gas and heat), storage (pumped hydro and battery storage) and electrification (heat pumps and electric passenger vehicles)

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.

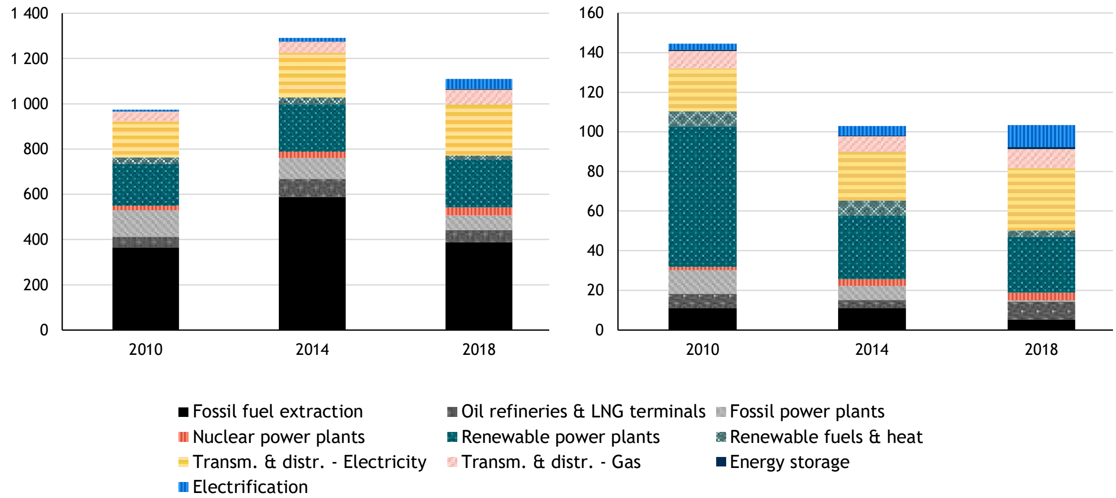
7.3 Energy investments

7.3.1 Overall trends and developments in energy investments

The total investment volume in energy assets across the EU27 and G20 countries went from approximately €1,000 billion in 2010 up to nearly €1,300 billion in 2014 and back down to €1,100 billion in 2018. Fluctuations are largely driven by changes in fossil fuel extraction, oil refineries and LNG terminals investments, which together accounted for €410 billion in 2010, €670 billion in 2014 and 440 billion in 2018 (see Figure 7-1, left panel).

Fossil investments (extraction, refining, LNG terminals and fossil power plants) still accounted for close to 50% of the total investment volume in 2018. Renewable power plants, fuel and heat production together accounted for roughly 20% of total investments in all years. Transmission & distribution investments accounted for 20 to 25% of total investments of which the majority went to electricity infrastructure. Other categories remained below 5% of the total investment volume.

Figure 7-1 Breakdown of investments by category: left panel EU27 + G20, right panel EU27 only (in billion €)



Source: Own elaboration based on data sources specified in task report.
Notes: Full breakdown only available for 2010, 2014 and 2018 as transmission & distribution investment estimates are only available for those years.

The EU27 accounted for a relatively small share of these investments with annual investment volumes declining from values around €140 billion (2010) to values around €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 (see Figure 7-1, right panel).

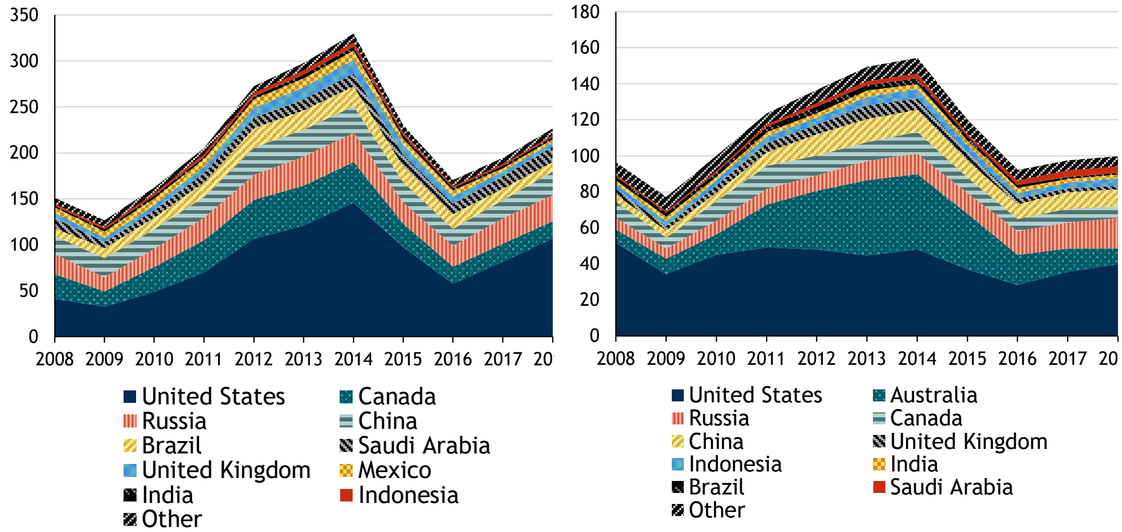
EU27 investments are dominated by renewables and transmission & distribution investments, which together accounted for 70 to 75% of total investments. Investments in fossil fuel extraction, refineries, terminals and power plants account for a much smaller share in the EU, with shares declining from around 20% in 2010 to around 15% in 2018.

7.3.2 *Focus on 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 together. The largest investments are made for oil extraction with typical annual investment volumes around €200 billion. Investments in gas extraction are around €100 billion annually. Coal supply investments were initially at a similar level as gas extraction but decreased significantly to values around €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.[34] The US is the largest global investor in oil extraction accounting for approximately 40% of all oil extraction investments made by EU27 and G20 countries (see Figure 7-2, left panel). 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.

Figure 7-2 Top 10 countries - investments in oil extraction: left panel oil, right panel gas (in billion €)



Source: Own elaboration based on data sources specified in annex B of the main energy investments task report.

The top investors for gas extraction over the last decade are similar to the top oil investors, with the United States also at number one and Russia, Canada and China among the top five investors (see Figure 7-2, right panel). The main difference with the top oil investors is Australia which ranks second for gas

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

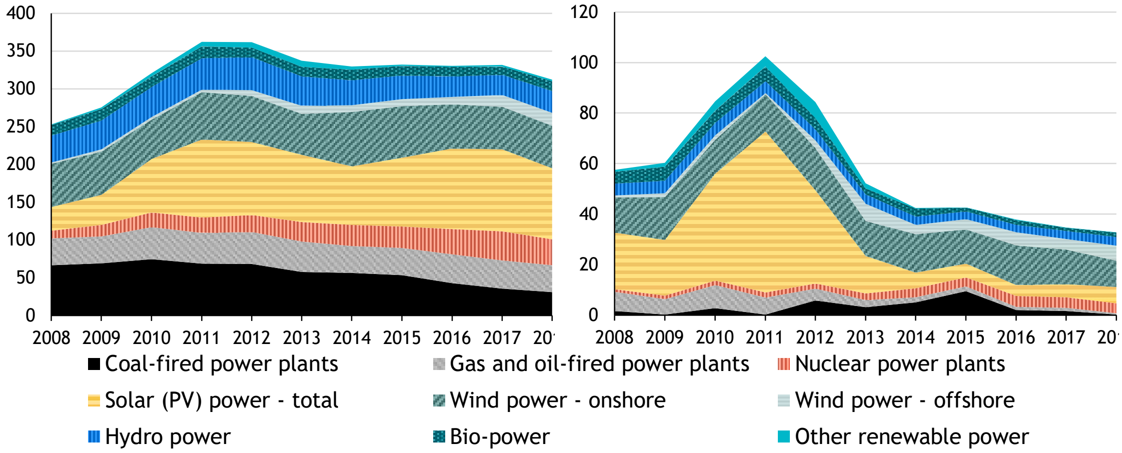
extraction but is not part of the top 10 for oil extraction. There are no EU countries among the top ten investors.

Investments in coal extraction are still dominated by China, accounting for two thirds of total coal extraction investments, even though China's investments in coal extraction halved between 2012 and 2018. Other countries with significant investments in coal extraction are India, Australia and Russia, which together account for a quarter of coal extraction investments.

7.3.3 Focus on 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 (see Figure 7-3, left panel). Considering individual technologies, investments in coal-fired power have decreased most significantly, from a share of 26% (€70 billion) in 2008 down to 10% (€30 billion) in 2018. Most of the fossil generation share went to renewable power generation which increased its share from 56% (€140 billion) to 68% (€210 billion), but also investments in nuclear power grew, from 4% (€10 billion) to 11% (€35 billion) 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 7-3 Power sector investments: left panel EU27 + G20, right panel EU27 only (in billion €)



Source: Own elaboration based on data sources specified in annex B of the main energy investments task report. 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 7-3, right panel). In particular in the years 2010 to 2012, large investments were made which pushed total EU power sector investments up to €100 billion per year. From 2013 onwards, only onshore wind investments remained at a substantial level while in particular solar PV investment declined sharply, which is again owing to cost reduction of solar investments, even amid increasing capacities. 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.

7.4 Impact of subsidies on energy 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 chapter starts with the power sector analysis, performed by the FTT:Power energy sector model, then presents three sector case studies which use descriptive and econometric analysis. The case studies analyse the link between subsidies and investment or take-up of fossil fuel extraction, transport electrification: the take-up of electric vehicles and heating: the take-up of heat pumps.

7.4.1 Power sector analysis

Scenarios

To model the impact of power sector subsidies on installed generation, the FTT:Power model was 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;
- *Removing only fossil fuel subsides 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 6). 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 6). This model simulation captures an alternative power sector development pathway, that would have happened without the introduction of any fossil fuel and renewable subsidies.

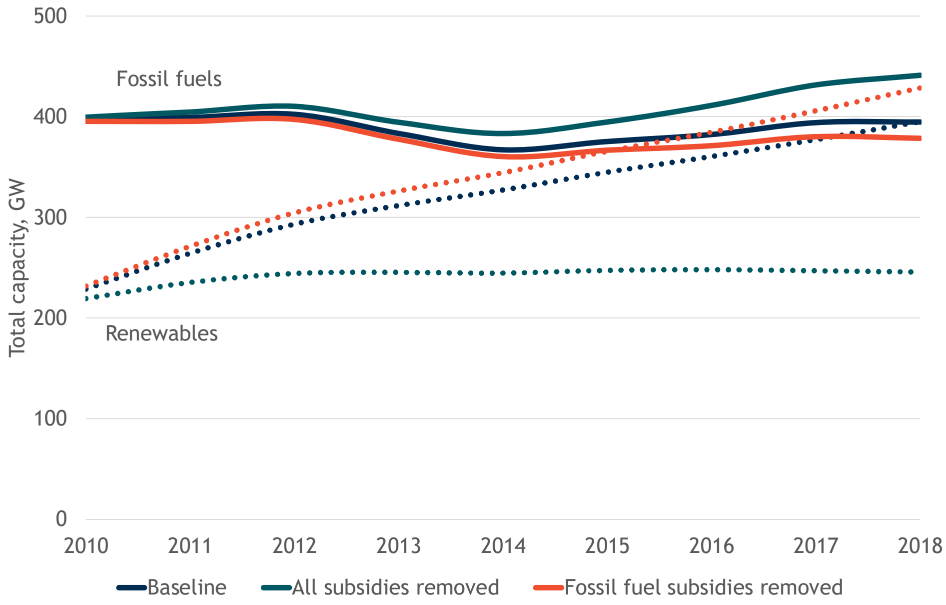
It is important to highlight that subsidies included relate only to subsidies impacting power generation technologies directly (for example, subsidies to prevent coal mine closures, despite being fossil fuel subsidies, were not included).

Impact of subsidies on renewable capacity

Overall, the modelling results suggests that fossil fuel subsidies have had a limited impact on hindering the installation of new renewable generation. This reflects that for most regions across EU27, 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. Figure 7-4 shows that total installed capacity of renewable generation would only be 8% higher by 2018 if fossil subsides were removed.

The modelling also suggests that renewable subsidies have had a substantial impact on supporting the investment in renewable capacity across most of the EU27 and G20. For the EU27, without renewable subsidies (as in the 'All subsidies removed' scenario), the growth in renewable capacity observed would have been limited, with renewable capacity potentially 40% lower by 2018.

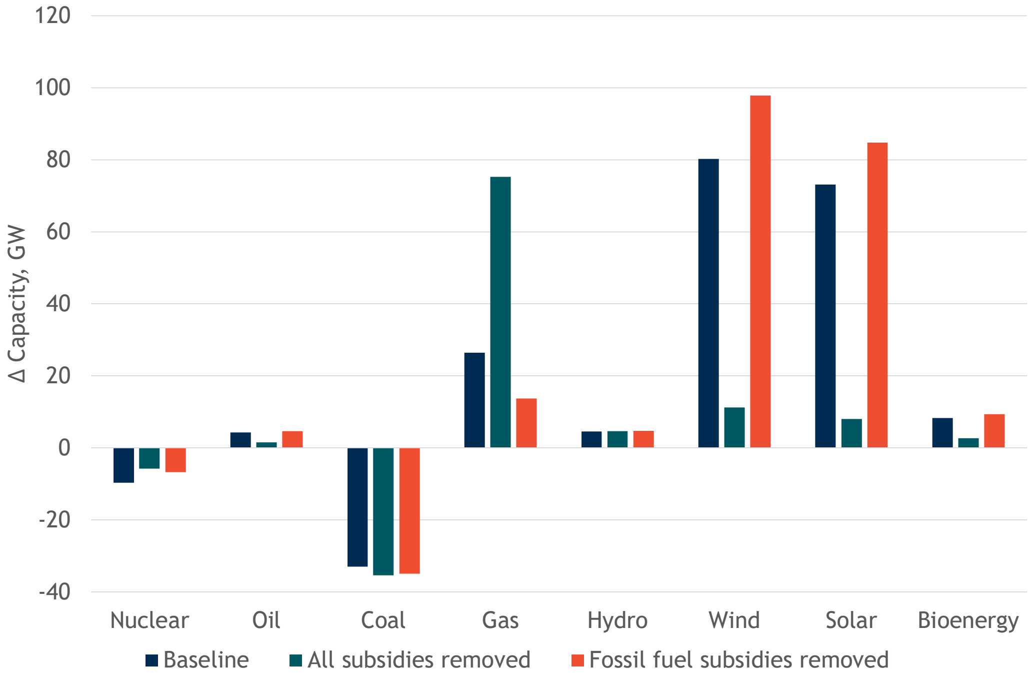
Figure 7-4 EU27 fossil fuels vs. renewables capacity, 2010-18, GW capacity



For G20 countries, there was limited coverage of fossil subsidies but where they were reported, their expected impact on the uptake of renewables was relatively limited. Either reflecting that the average level of support was too small to have a significant impact or that countries have such low levels of uptake of renewables, the removal of fossil fuel subsides alone would be insufficient to encourage investment in renewable capacity.

The largest changes in renewable capacity in response to renewable subsidies was in Wind and Solar technologies, which have seen substantial growth in capacity over the period and this growth has been supported by high levels of subsidies across the EU27 and many G20 countries.

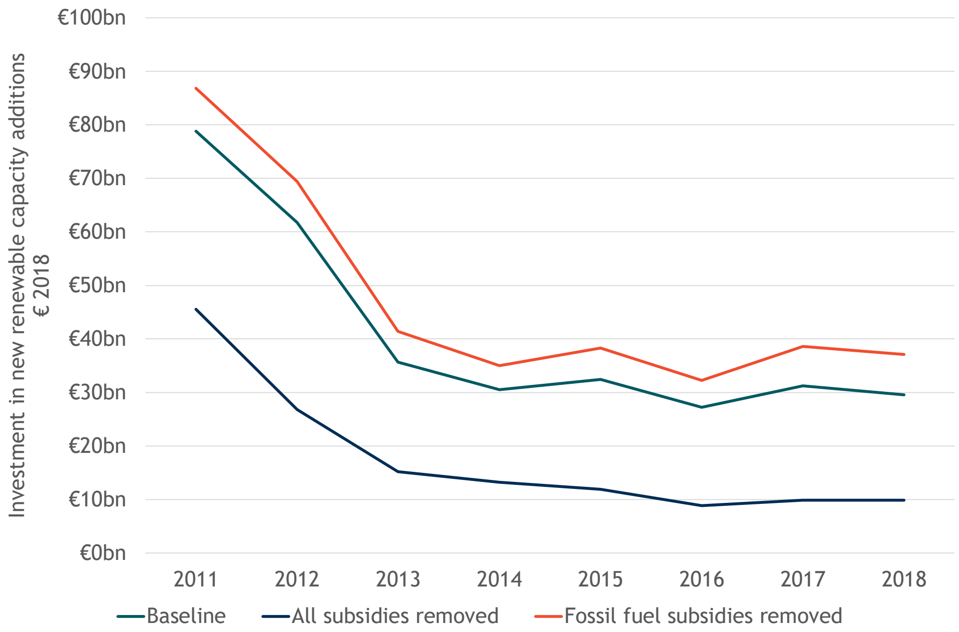
Figure 7-5 EU27 change in capacity by technology, GW, 2010-18



The modelled impact of subsidies on annual investments in renewables capacity over the period for the EU27 is shown in Figure 7-6. This shows that the impact of fossil fuel subsidies on hindering renewable investments was relatively consistent over the period. In absolute terms annual investments in renewable capacity could be expected to have been between €4.5 bn and €8.5 bn higher if fossil fuel subsidies were removed.

Without any subsidy support, to fossils or renewables, modelling suggests that annual investments in renewables would have fallen sharply across the period. The largest impact was 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 renewable support in many member states. Over time the investments in new capacity would have remained substantially lower across the whole period. The average level of support for renewables has remained relatively high over the whole period which has helped to support the continued investments in renewable capacity.

Figure 7-6 Impact of Subsidies on investment in net renewable capacity additions in EU27



7.4.2 *Sector case studies*

The three case studies give an overview of how fossil fuel and renewable subsidies hinder or increase the take-up of low carbon technologies across different sectors of the economy.

- *The fossil fuel extraction case study* finds that fossil fuel subsidies have weak and mixed effects in increasing extraction, and that EU27 and non-EU G20 patterns differ substantially;
- *The transport electrification case study* shows dynamically expanding EV sales, with some response to EV related subsidies. However, without additional info on EV prices and a sample large enough to conduct econometric estimates true causal relationships could not be identified. The descriptive analysis shows that per EV subsidy values either remained stable or fell in many countries, despite the growing sales of EVs. This suggests that subsidies for EVs is not the main factor driving increasing take-up but other factors. This is supported by the literature and recent EU policy that highlights equally important factors over the period including the fall in battery costs lowering upfront cost of EVs and need for improvements in availability of charging infrastructure;

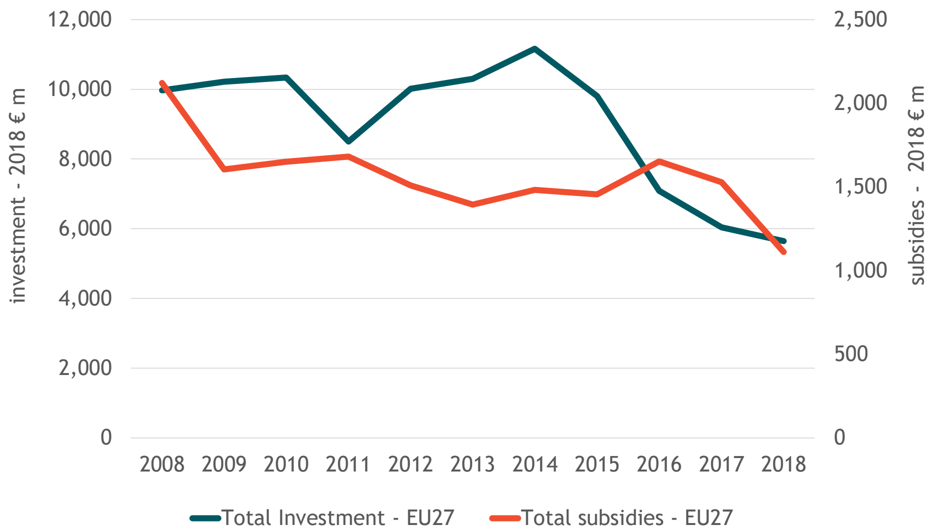
- *The heating case study* shows that energy efficiency subsidies for building heating have no or weak impact on heat pump sales in Europe depending on the estimated model. Heat pump prices, household energy demand and energy prices proved to be robust drivers of the take-up.

Case study: Fossil-fuel extraction

Despite the fiscal strains on national budgets, adverse environmental impacts, and international commitments countries have been slow to phase out subsidies to fossil fuel extraction. Public expenditure is usually justified by energy security, balancing price competition, guaranteeing affordable fuels and protecting domestic employment. However, the efficiency of public expenditures on the extraction sectors is not clearly supported by the empirical literature, with other factors such as technology costs and fuel prices also playing a strong role in determining investments. This case study analysed the role fossil fuel subsidies play in supporting investments in fossil fuel extraction.

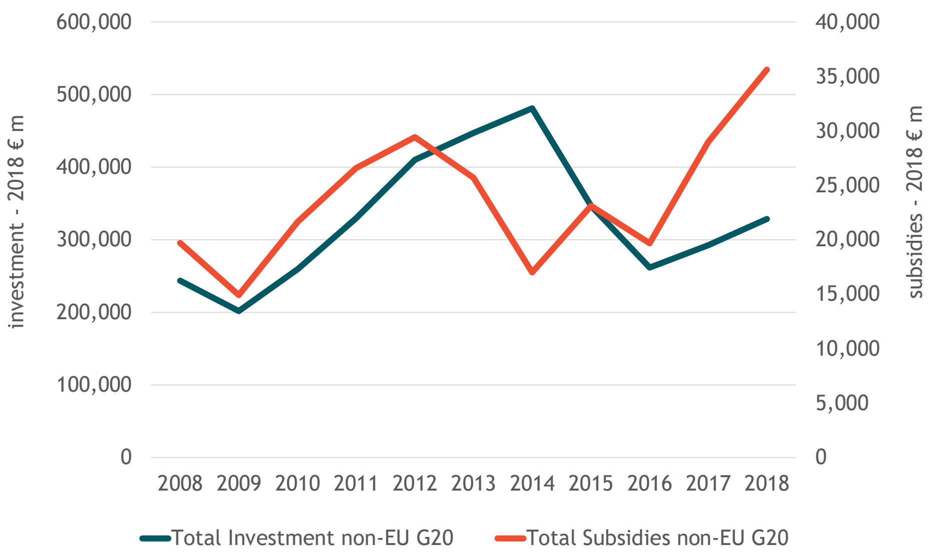
As shown in Figure 7-7 and Figure 7-8 non-EU G20 countries saw much larger investments and subsidies in fossil fuel extraction over the period than for the EU27 Member States. In the EU27 fossil fuel extraction is a declining industry and most countries, have minor subsidies except for Germany and Poland which have high support for coal.

Figure 7-7 Total investment and subsidy values for the EU27, 2018 € millions, 2008-2018



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

Figure 7-8 Total investment and subsidy values for the Non-EU G20, 2018 € millions, 2008-2018



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

The graphs show some co-movement at a group level over time and reveal that for the EU27 both subsidies and investments decrease, while for the Non-EU G20 this trend is not observed. The graphs also show that the co-movement is not present for the whole-time frame sometimes lagged dynamics or opposite sign impacts can be observed. This suggest that the group level values hide quite different country level dynamics.

To better understand the causal relationship regression analysis was conducted using different estimation techniques and set of control variables. The model in its general form is shown in the equation below.

Equation 7-1 The model of fossil fuel extraction investments and subsidies

$$\ln(Investment{:}\ FF\ extraction_{it}) = \beta_0 + \beta_1 \ln(Subsidies{:}\ FF\ extraction)_{it} + \beta_4 \ln(GDP)_{it} + u_{it}$$

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

The regression results suggest that for the EU27 and the non-EU G20 the link between subsidies and investment is quite different. While for the EU27 subsidies have a weak positive impact in most models, in the Non-EU G20, real GDP has the strongest positive impact suggesting that economic conditions are a more significant drivers than extraction subsidies. Note that due to the small sample size and limited set of control variables, the results should be generalized cautiously.

Table 7-1 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

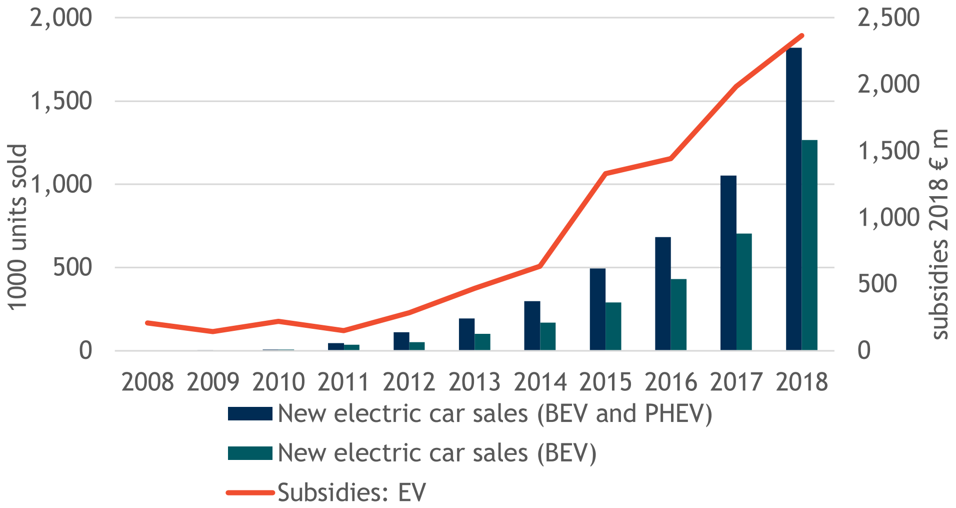
Source: Own calculation

Case study: Transport electrification - electric vehicle take-up

The take-up of electric vehicles (EVs) in the passenger car fleet is a key aspect of decarbonising the transport sector. Although markets are developing dynamically for both battery-electric and plug-in hybrid vehicles (BEVs and PHEVs), high upfront costs and lack of infrastructure are still strong barriers to the take-up. This case study explores how subsidies providing price support for passenger vehicle purchases and subsidies aiming to develop the charging infrastructure increase take-up.

Figure 7-9 shows the total observed subsidy and sales values for EU27 and Non-EU G20 countries. The graphs show increasing subsidy and sales values over time and BEV's dominating the sales value.

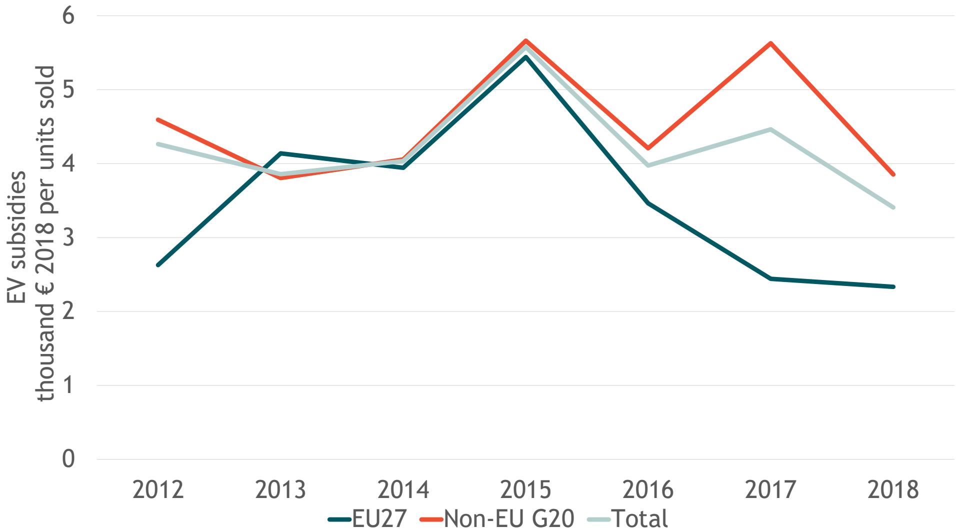
Figure 7-9 Total EV sales and subsidies (EU27 and Non-EUG20)



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

While Figure 7-9 shows a substantial growth in absolute spending on subsidies, Figure 7-10 reveals that the subsidies per vehicle sales across EU27 and G20 countries did not increase over the period and may even have decreased over time in some countries. In countries where average support has fallen, this reflects continued revisions to levels of support per vehicle and also changes in the eligibility of EV sold to subsidies. In particular, PHEVs have received lower levels of support in the last few years in countries such a France and in many countries upper limits on value of EVs that can receive support.

Figure 7-10 Total EV subsidies per EV sales, 2012-2018



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

Therefore, as average support has not increased over time, it cannot be the main driver of strong sales growth over the period. However, that is not to say that subsidies did not play a significant role in incentivising EV sales, as the literature identifies that upfront costs are a key barrier to EV take-up and subsidies help close the gap in cost between EVs and traditional petrol & diesel vehicles. 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 highlights several other factors that are 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 CO_2 standards have also helped to ensure that more EVs have come to market.

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

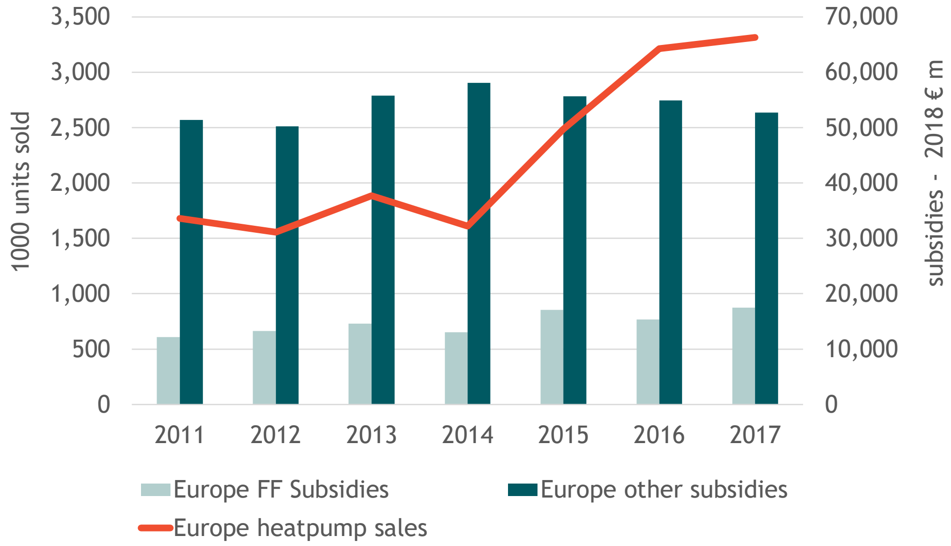
Heat pump sales have been increasing steadily in the past decades at a global scale, with the EU leading the way. Growing consumer awareness of heat pumps and recurrent summer heat waves in Europe helped the market expansion. Buildings energy efficiency subsidies accelerated this process but in most member states there is still a strong fossil fuel price support in place, which might work against the 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.

Heat pump sales are only observed for EU27+UK and for the time frame 2011 to 2017, which determines the scope of the analysis.

Figure 7-11 shows the total heat pump sales and energy efficiency subsidies directed to heating in buildings. Neither type of subsidies has a clear trend in the aggregate indicator, non-fossil fuel subsidies are about five times higher than fossil-fuel ones over the observed timeframe. Total heat pump sales are relatively stable until 2014, then take off and approximately double by the end of the timeframe.

Figure 7-11 Total heat pump sales and subsidies



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

While scatter plots and inspecting trends did not reveal a clear link between investments and subsidies, we proceeded to regression analysis. The regression analysis controls for other important determinants of the sales, clearing up the relationship between the subsidies and the take-up. The regressions were estimated on the full sample and on the subsample of countries which have both fossil fuel and non-fossil fuel heating subsidies observed. Different sets of control variables were used to ensure robustness on both subsamples. The equation below shows the general regression model used to assess the take-up of heat pumps and its main drivers.

Equation 7-2 The model of heat pump take-up and subsidies

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

Table 7-2 Regression results for heat pump take-up, the impact of heating subsidies

	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***	-0.092	-0.083	-0.098
	(0.172)	(0.171)	(0.162)	(0.062)	(0.061)	(0.062)
ln(Other subsidies)	0.194	0.166	0.182	0.122	0.134*	0.125
	(0.121)	(0.117)	(0.116)	(0.081)	(0.071)	(0.080)
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 based on the subsidies and investment data

The results reveal that fossil fuel subsidies have weak negative or non-significant impact on the take-up depending on the subsample used for the estimation. Non-fossil fuel subsidies do not have a significant effect in most models, which can be due to the mixed set of subsidies in this category. Some of them may increase the take up of the alternatives of heat pumps (e.g. solar). Heat pump prices have a strong negative impact on take-up in all specifications, suggesting that high upfront costs are strong barriers to use.

In line with the expectations, higher household energy demand increases take-up, which is used as a proxy for market size and economic conditions. High gas and electricity prices are included to account for the price incentives for take-up. High gas and electricity prices if used for heating and cooling may create an incentive for take-up. Electricity on the other hand is often used for operating heat pumps, therefore, high prices may also have negative impact and turn households to invest in alternatives (e.g. solar thermal). Gas prices are insignificant and electricity prices have a negative impact on take-up.

8 Synthesis analysis

The following sections provide a synthesis of some of the key results across the different dimensions of energy costs, subsidies, taxes and investments investigated in this work.

8.1 Total cost of energy

By combining levelised costs, with normalised network and external costs, per MWh totals for each technology can be calculated. This is consistent with the concept of a 'total cost of energy, although there are a number of caveats to the approach:

- For network costs, the actual cost of service for network users usually depends (in addition to O&M and system services costs) on the annual capital remuneration for the residual regulatory asset base of network operators, rather than investments made in that year. However, the investments and O&M costs for 2018 are employed here, providing values in the same order of magnitude as that reported by Eurostat.[35] Both transmission and distribution costs are included. This better reflects the cost to serve a broad range of energy consumers rather than the tariffs which would be paid by electricity producers. Electricity network costs are mostly recovered in the EU from consumers, as discussed in the network costs report;
- For external costs, the work presents the externalities examined in this work which have associated uncertainties. The external costs do not include all externalities including both potential positive (e.g. economic multipliers) or negative externalities (Noise, accidents; etc).

Nevertheless it can be instructive to combine the data and analysis that has been generated in this work, as presented in Figure 8-1 below, which effective combines the data presented earlier in Figure 2-2, Table 3-2, Table 3-3 and Figure 4-2[36].

Total costs of energy per technology range from €83/MWh for onshore wind to €258/MWh for Lignite. Overall, onshore and offshore wind, hydropower, geothermal power and nuclear energy have the lowest total costs of energy, combining relatively low LCOEs with low external costs. Solar PV and natural gas form a mid-level of total costs, the former with still relatively high LCOE but low externality costs, the latter with lower LCOE than solar PV but higher external costs. The coal technologies, biomass and solar CSP are the most expensive from the total cost perspective.

Average network costs of €21/MWh are applied, studies estimate costs for renewable energy may be between €1-€12/MWh higher with an average of around €3/MWh. In reality, renewable energy technologies can impose a higher system services cost than either fossil fuel-based and nuclear power plants given their intermittency. However, the system services costs occasioned by renewable energy projects will vary according to factors such as their generation profile and intermittency, penetration level (i.e. participation in the energy supply mix) correlation with other generators and loads, and availability and cost of flexibility resources. As such, the contribution of system services costs arising from intermittent renewables to final energy prices can vary significantly. This share is, nonetheless,

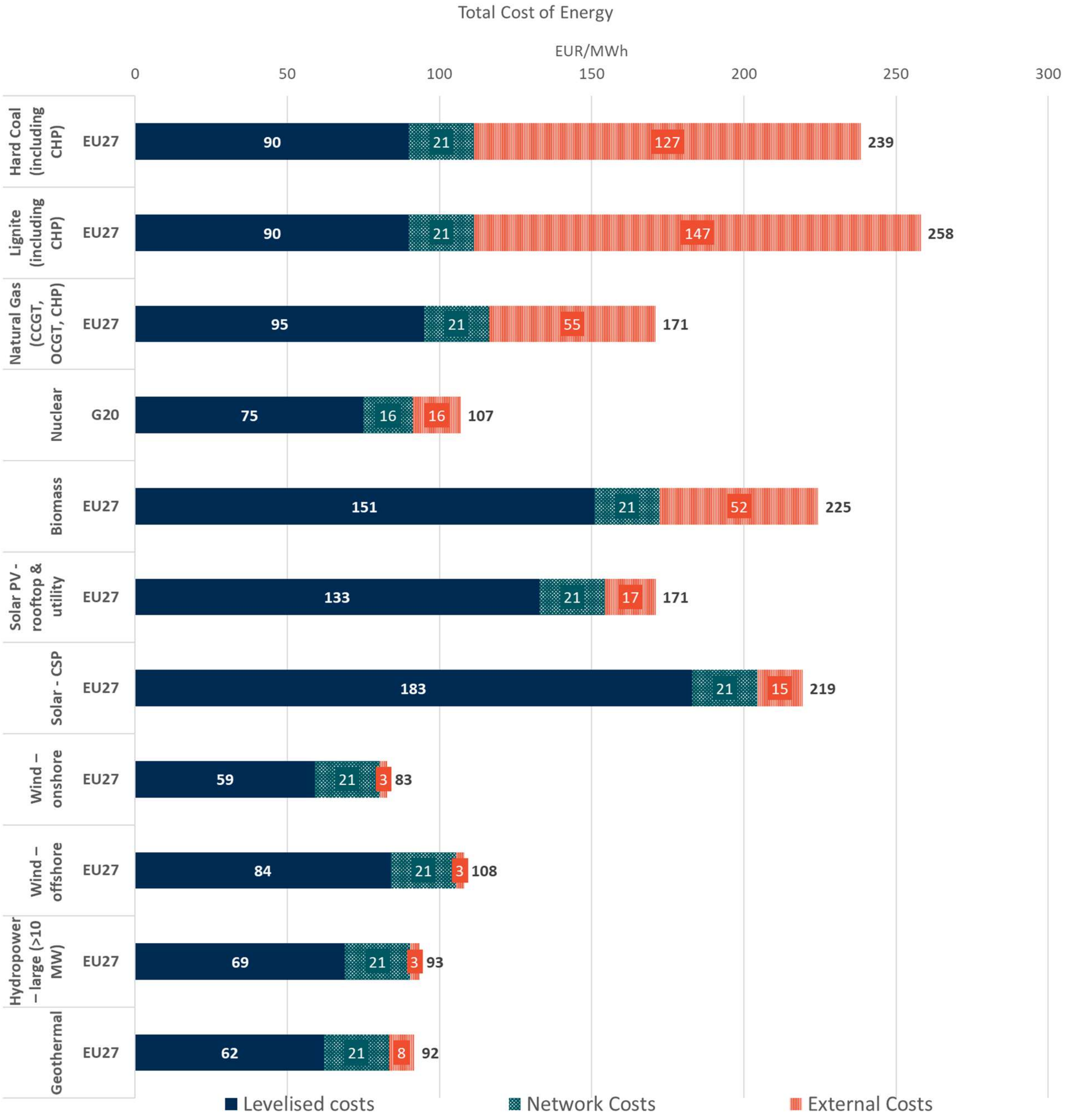
[35] See Electricity prices components for household consumers - annual data (from 2007 onwards) (nrg_pc_204_c) and Electricity prices components for non-household consumers - annual data (from 2007 onwards) (nrg_pc_205_c).
[36] For external costs the values presented are those including internalization of externalities, a variation on those presented in Figure 4-2.

still limited. ENTSO-E indicates a range of €1-€12/MWh for typical TSO system services unit tariffs in 2018, with an average of €2.7 /MWh.[37] A review of balancing costs for wind and solar in the literature indicates a similar range.[38] While this average system services cost cannot be attributed only to intermittent renewables, even so it would represent around 3% of the total cost for onshore wind power in the figure below (the intermittent renewable with the lowest total costs). The importance of such system services costs can be significantly higher for certain cases, for example islanded or peripheral systems or with a high renewables penetration. However, measures may be taken to limit system service costs as the penetration of renewables grow. Also, in other cases fossil fuel-based technologies may be responsible for the majority of system service costs.[39] No such adjustments are applied to renewables in the figures below, but these potential differences should be kept in mind. A lower average cost of €16/MWh is observed for nuclear power as these figures are for the G20 as robust LCOE data for nuclear was not available in the EU27.

Taking this total cost perspective reinforces the advantages of wind energy, hydropower, geothermal and nuclear power over the fossil energy technologies, but solar PV would need to reduce its LCOE to join this group. For the fossil technologies, reducing their climate impact through CCS or other measures could significantly reduce their external and then total cost, but this would not close the gap to the group of lowest total cost technologies as these already have lower LCOE and the scope for LCOE reduction in the fossil sector is limited in the current policy context. Using higher network costs for renewable energy technologies would not significantly change the overall conclusions.

[37] ENTSO-E (2018) Overview of Transmission Tariffs in Europe: Synthesis 2018
[38] See review in Joos and Staffell (2018) Short-term integration costs of variable renewable energy: Wind curtailment and balancing in Britain and Germany. Renewable and Sustainable Energy Reviews vol. 86.
[39] For example, in the UK, compensation to curtailed gas-fired power plants largely exceeded that to wind power plants in the 2013-2017 period. Joos and Staffell (2018) Short-term integration costs of variable renewable energy: Wind curtailment and balancing in Britain and Germany. Renewable and Sustainable Energy Reviews vol. 86.

Figure 8-1 Estimates of the EU27 average 'Total cost of energy' for electricity technologies, €2018/MWh



8.2 Energy taxes and subsidies

Energy taxes, charges, levies and subsidies are closely linked in many ways. First, revenues from taxes on energy consumption and production, pollution and energy-related infrastructure are sometimes used by governments to finance programmes supporting certain groups of consumers or certain technologies. For example, several countries used yields of certain taxes, charges or levies to finance reduced tariffs for certain users through cross-subsidy systems. Likewise, the revenues of certain taxes, charges or levies are sometimes directly earmarked for financing energy efficiency programmes.

Energy taxes, charges or levies and subsidies and their respective changes are also directly linked when it comes to charges financing the development of certain technologies. In particular, the development of renewable energies through the establishment of policies such as feed-in tariffs or feed-in premiums have often been financed by surcharges on the consumption of electricity by end consumers. Thus, the additional annual €51 bn of renewable energy subsidies observed between 2008 and 2018 in the EU 27 were almost exclusively financed by surcharges. Therefore, the implementation of new FiT/FiP or their reliefs, as well as the change of rate, have generally impacted upon the energy bills of consumers in the short or long term, not on government budgets.

Finally, a strong relationship is established between taxes and tax reductions and exemptions (known technically as 'tax expenditures')[40]. Tax expenditures and taxes can to some extent be seen as two sides of the same coin. Indeed, tax expenditures are the product of a tax base, a standard tax rate and finally a partial or complete exemption. Thus, when one of these three parameters changes, it has consequences for the amount of tax revenue and the amount of tax expenditure. For example, if the standard rate of a given tax were to fall or the tax base was reduced and the conditions for exemption from that tax were kept constant, then the income and the subsidy would be reduced. Conversely, a higher reduced tax rate (at constant standard rate and tax base) will automatically imply a decrease in tax revenue and an increase in tax expenditure.

Tax expenditures amounted to €57 bn in 2018 representing more than a third of the total amount of subsidies paid in the EU27 of €159 bn. Excise tax expenditures on fossil fuel and electricity reached €40 bn in the EU27 in 2018, which represents a reduction of 18% of the tax revenues (€219 bn) otherwise due (see Figure 8-3). Sweden and Belgium had the highest levels of tax expenditures (reductions) on these taxes recording ratios of 45% and 43% compared to revenues, respectively, in 2018. The largest economies in the EU record ratios of around 20%, the Netherlands and France with ratios of 22%, followed by Italy (18%) and Germany (17%). Of the other Member States 12 have ratios below 10%.

Likewise, new taxes, charges and levies have appeared since 2008. They have contributed to increasing energy tax revenues but, in many cases, these new taxes, charges and levies came with partial or full exemptions in order to protect some consumers from the new tax burden. Thus, when we study the joint evolution of excise tax revenues and excise tax expenditures in the EU27, we see that revenues have increased by 9% between 2008 and 2018, while excise tax expenditure increased by 11%

This is mainly due to the increase in standard rates over the period accompanied by relative stability in reduced rates and exemptions. This widening gap has caused the total amount of excise tax expenditures to increase at a fairly similar rate to revenues (see Figure 8-4), which shows that in most cases, changes in excise taxes and excise tax expenditures related have followed a common trend.

The analysis by economic sector (Figure 8-2) shows that the EU28 industry and agriculture has reduced their ratio of excise tax expenditures to excise tax revenues between 2008 and 2018, whereas a reverse trend is observed for the transport, services and households. However, the industry and agriculture sectors still enjoy significantly larger excise tax breaks than they pay excise taxes (ratios exceeding 100% in the graph below), while the households, transport and services sectors record respectively

[40] Tax expenditures are a form of subsidy and can be partial exemptions (called "tax reductions" in the report, e.g. a reduced rate of 5% instead of the standard rate of 18%) or full tax exemption (called "tax exemptions", e.g. zero-rate instead of the standard rate of 18%). These exemptions can apply either to the tax rates or to the tax base. Tax reductions and exemption differ from tax credits that apply directly on the amount of due tax, not on the tax rate or on the tax base.

ratios of 15%, 8% and 2%, meaning that their contribution to excise tax revenues is much larger than the excise tax expenditures they benefit from.

Figure 8-2 Shares of excise tax expenditures against excise tax revenues per economic sector in the EU27 in 2008 and 2018 (%)

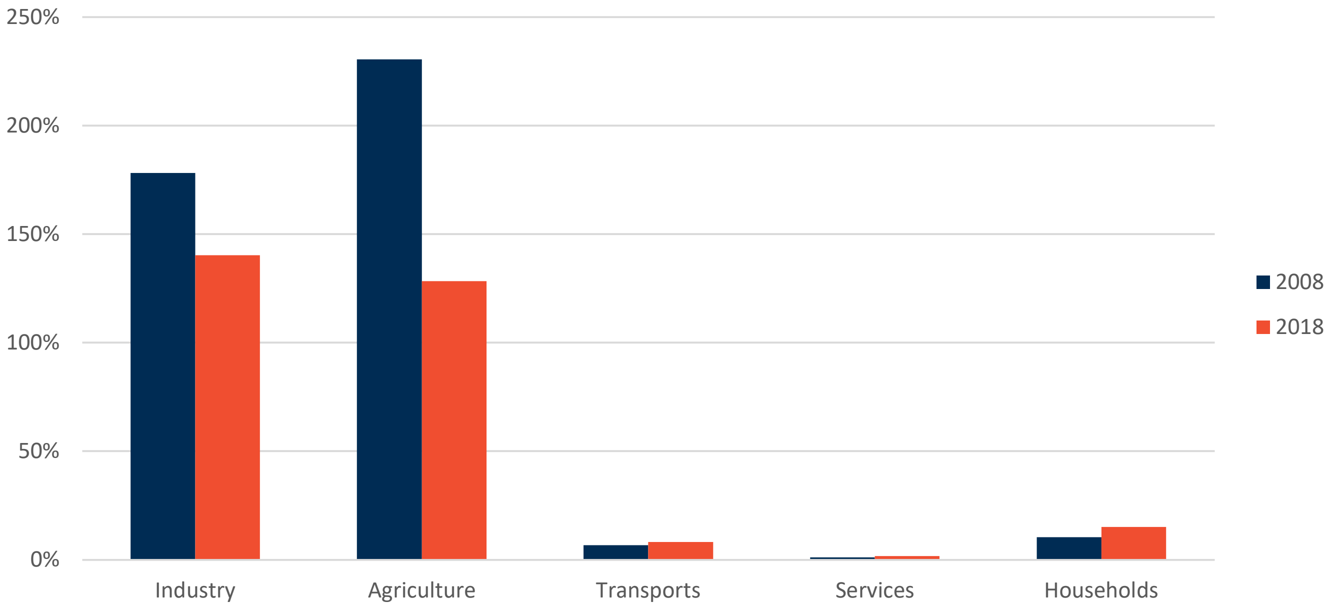


Figure 8-3 Excise tax expenditures vs excise tax revenues on fossil fuels and electricity in Europe in 2008 and 2018 (€2018, %)

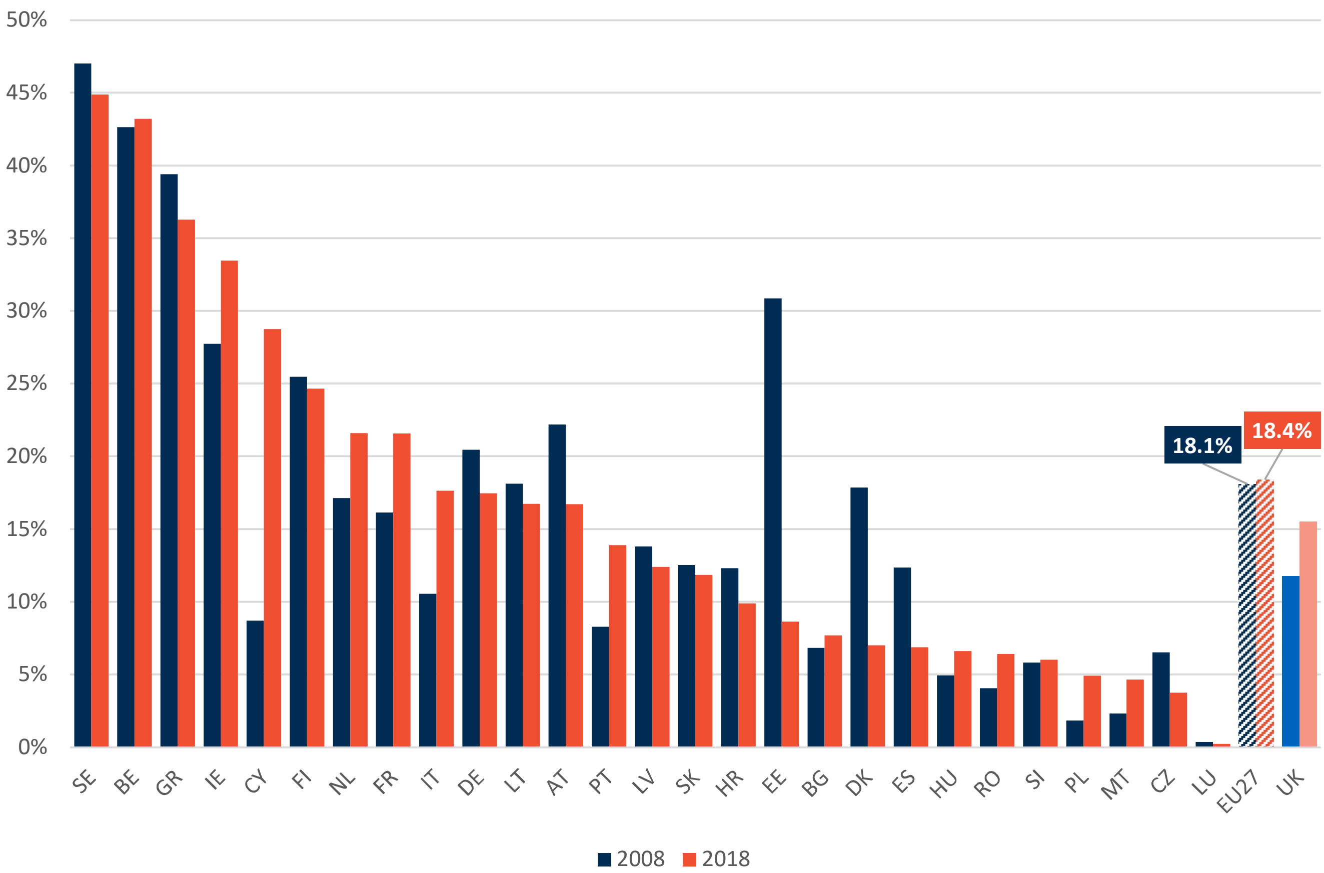
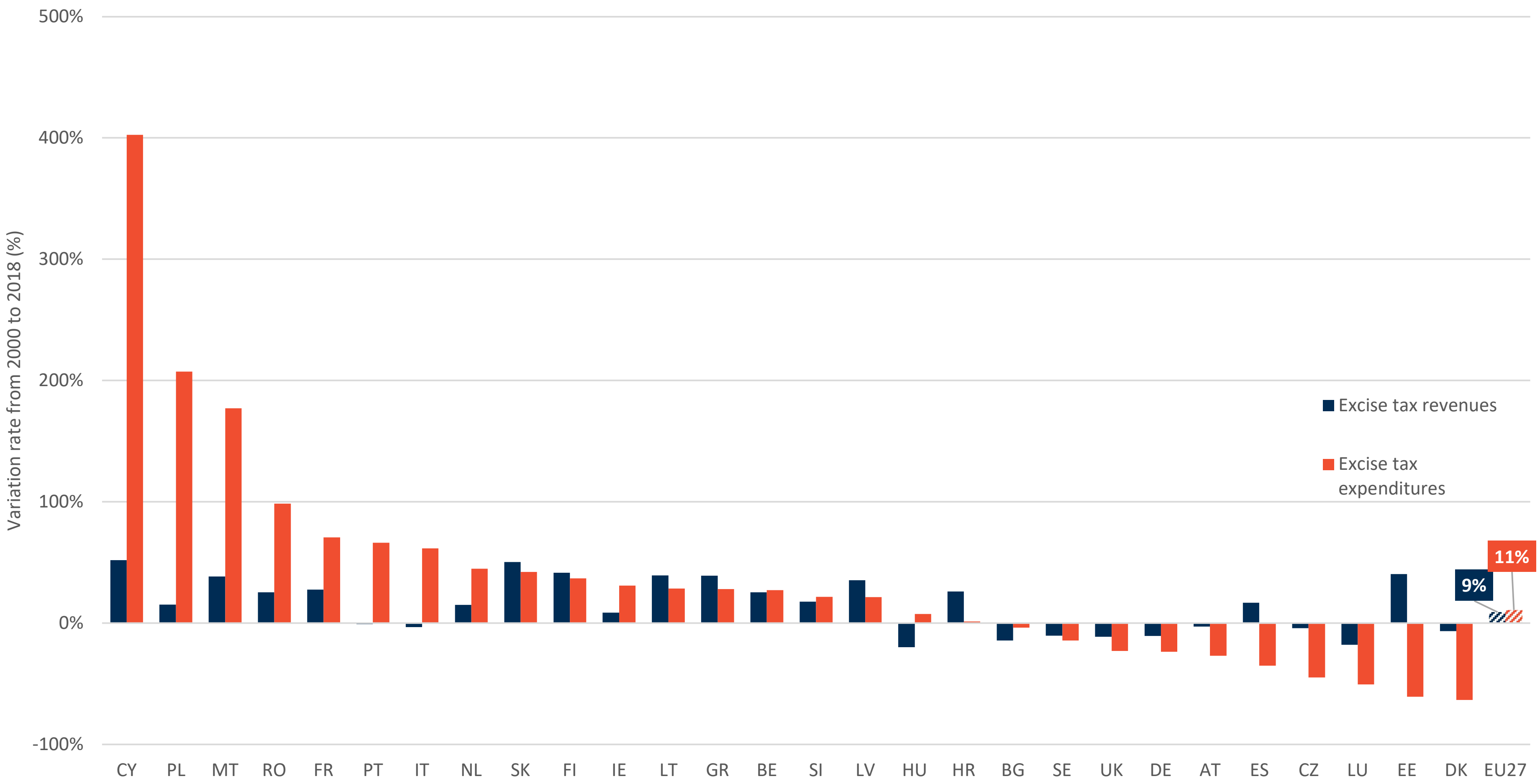


Figure 8-4 Evolutions of the excise tax expenditures and excise tax revenues on fossil fuels and electricity between 2008 and 2018 (€2018 in %)



8.3 Energy taxes and external costs

Comparing energy taxes with total externals costs can give a view on to what extent the externalities of the energy system are being internalised. As noted in the external costs and taxes sections this is not straightforward as whilst a large share of the external costs arise in energy production the energy taxation system focuses taxes on energy consumption. The exception being a handful of climate measures which apply to producers. Nevertheless, looking at energy consumption taxes and comparing to energy production externalities can give some indication of the extent to which the two compare.

In the EU27 taxes on energy consumption and production equate to around 40% of total energy production externalities. For energy production, if the consumption taxes total of €104 billion[41] were to be compared with the total EU27 external costs of €340.6 billion for electricity and heat production presented in Table 4-2, then we might estimate that around 30% of the external costs of energy production are internalised in energy consumption. If the previously identified internalisation of €34.5 billion of the energy production external costs (see section 4.6) were also added to this total then around 40% of external costs could be argued to be internalised.

Focusing only on electricity then the value of electricity consumption taxes equates to around 63% of external costs of electricity in the EU27. Focusing only on consumption taxes on **electricity consumption** then total taxes of €77 billion can be identified (74% of total consumption taxes). These taxes can be compared to the external cost of electricity of €151 billion, or €123 billion after existing internalisation of EU-ETS and other climate measures. The taxes on energy consumption would then represent around 63% of the energy production externalities (after internalisation). The comparison is apt as is noted in the report on energy taxes, '*energy inputs to the electricity sector are not taxed to avoid double taxation – only the final consumer is taxed on electricity consumption, not the power producer on the consumption of input fuels*'.

At the MWh level external costs of around €27/MWh for electricity in the EU27 can be estimated. Taking the average electricity system external costs of €59/MWh with internalisation and combining these with the energy consumption taxes on electricity of €32.1/MWh in 2018 (see Figure 11 in the tax task report) an estimate of external costs of €27/MWh can be calculated.

Subject to various uncertainties it could be concluded that EU electricity consumption taxes total around 50%-60% of the EU electricity production externalities and could be read as an internalisation of the same.

[41] This value is a sub-set of the total value of €263 billion presented in chapter 5. The total in chapter 5 includes taxes on transport fuels, which are excluded for the purpose here of comparison with the electricity and heat generation externalities.

Annex A - Abbreviations

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

EU28	Code	Non-EU G20	Code
Austria	AT	United Kingdom	UK[42]
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		

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

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