IRENA
International Renewable Energy Agency

ENERGY SUBSIDIES

Evolution in the Global Energy Transformation to 2050

TECHNICAL PAPER 1/2020
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The International Renewable Energy Agency (IRENA) serves as the principal platform for international co-operation, a centre of excellence, a repository of policy, technology, resource and financial knowledge, and a driver of action on the ground to advance the transformation of the global energy system. An intergovernmental organisation established in 2011, IRENA promotes the widespread adoption and sustainable use of all forms of renewable energy, including bioenergy, geothermal, hydropower, ocean, solar and wind energy, in the pursuit of sustainable development, energy access, energy security and low-carbon economic growth and prosperity. **www.irena.org**

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ABBREVIATIONS

°C	degrees Celsius
CCS	carbon capture and storage
CO_2	carbon dioxide
CSP	Concentrated Solar Power
EV	electric vehicle
G20	Group of Twenty
GDP	gross domestic product
GJ	gigajoule
Gt	gigatonne
GW	gigawatt
GWh	gigawatt-hour
IEA	International Energy Agency
IMF	International Monetary Fund
IRENA	International Renewable Energy Agency
kWh	kilowatt-hour
LCOE	levelised cost of energy
MW	megawatt
MWh	megawatt-hour
OECD	Organisation for Economic Co-operation and Development
PJ	petajoule
PV	photovoltaic
RE	renewable energy
REmap	renewable energy roadmap analysis by IRENA
TWh	terawatt-hour
USD	United States dollar
VRE	variable renewable energy
WB	World Bank

KEY FINDINGS

The world's total, direct **energy sector subsidies** – including those to fossil fuels, renewables and nuclear power – are estimated to have been at least **USD 634 billion** in 2017.

Total fossil-fuel subsidies in many countries are dominated by subsidies to petroleum products.

Subsidies to clean and renewable energy (environmentally friendly subsidies) can help to improve the **efficiency of capital allocation** across the energy sector. This is because **externalities stemming from fossil-fuel use** – notably the costs imposed on society from their associated air pollution and climate change – are not typically fully priced.

Yet the **continued imbalance** remains staggering. In 2017, the costs of unpriced externalities and the **direct subsidies for fossil fuels (USD 3.1 trillion)** exceeded subsidies for renewable energy by a **factor of 19**.

By **2050**, total, annual energy subsidies could decline from USD 634 billion to **USD 475 billion per year**, according to the **REmap Case** set out by IRENA for realistic acceleration in the worldwide deployment of renewables. Total energy sector subsidies in 2050 are 25% lower than in 2017 and 45% (USD 395 billion) lower than they would be based on current plans and policies.

IRENA's roadmap for more sustainable energy development sees a **rebalancing of energy subsidies** away from environmentally harmful ones to fossil fuels and towards support for renewables and energy efficiency by 2050.

In the REmap Case, total **energy subsidies** decline from 0.8% of global Gross Domestic Product (GDP) in 2017 to **0.2% in 2050**.

Greater harmonisation of **subsidy calculation methodologies**, definitions of what constitutes a subsidy and the boundary conditions for the application of the definition would help provide greater clarity around both the current level and trends in total energy sector subsidies.

EXECUTIVE SUMMARY

The world's total, direct energy sector subsidies – including those to fossil fuels, renewables and nuclear power – are estimated to have been at least USD 634 billion in 2017. These were dominated by subsidies to fossil fuels, which account for around 70% (USD 447 billion) of the total. Subsidies to renewable power generation technologies account for around 20% of total energy sector subsidies (USD 128 billion), biofuels for about 6% (USD 38 billion) and nuclear for at least 3% (USD 21 billion).

The actual level of total energy sector subsidies is, in all probability, larger due to data gaps. Coverage of sub-national incentives for both fossil-fuel and renewables subsidies is likely not comprehensive, while the subsidy value for nuclear in this analysis is a placeholder value, reflecting the lowest realistic level of subsidies for existing nuclear power generation.

ENERGY SUBSIDIES IN 2017

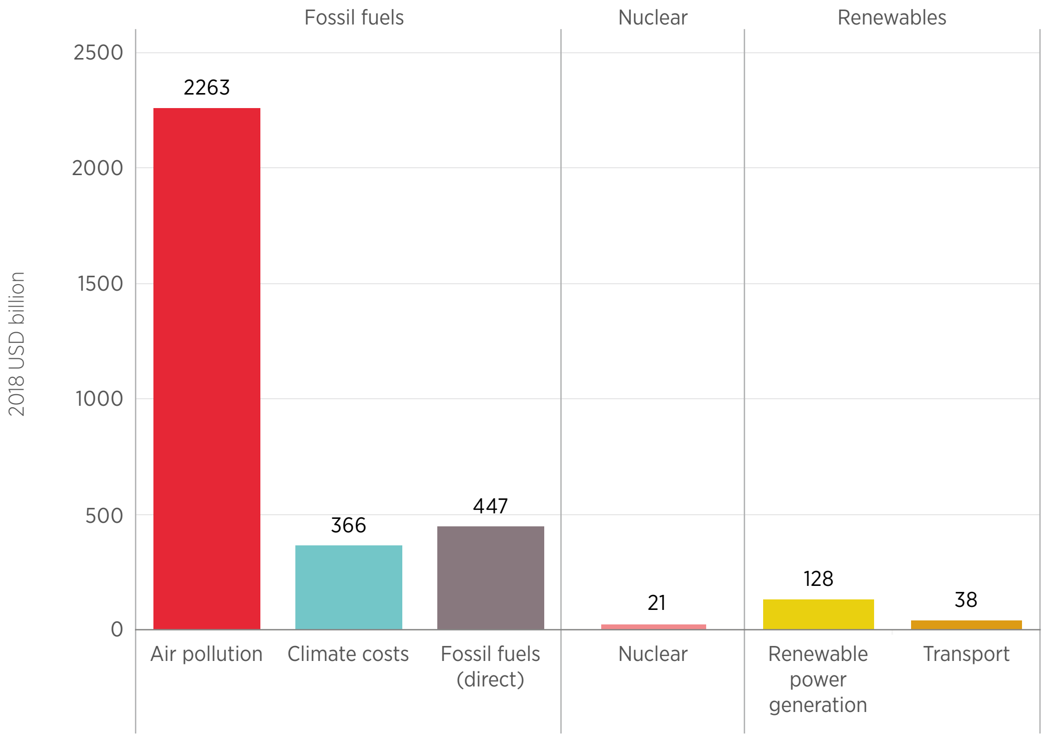
By combining existing estimates of subsidies to fossil fuels from the Organisation for Economic Co-operation and Development (OECD) and the International Energy Agency (IEA), this analysis finds the global total, direct fossil-fuel subsidies in 2017 to be at least USD 447 billion. Subsidies to petroleum products dominated the total, at USD 220 billion, followed by electricity-based support to fossil fuels at USD 128 billion. Subsidies to natural gas and coal in 2017 were estimated to be USD 82 billion and USD 17 billion, respectively.

Total fossil-fuel subsidies in many countries are dominated by subsidies to petroleum products. Half of the twelve countries with the largest fossil-fuel subsidies in 2017 had total subsidy levels dominated by support for petroleum fuels. The top five countries for fossil-fuel subsidies in 2017 had total subsidies of USD 189 billion, or 42% of the global total. The top ten countries accounted for 61% (USD 272 billion) of total fossil subsidies in 2017.

In this analysis, the International Renewable Energy Agency (IRENA) has estimated supply-side support to renewables at around USD 166 billion in 2017. Total support to renewable power generation was around USD 128 billion in 2017, and transport sector support added a further USD 38 billion for biofuels. The European Union accounted for around 54% (USD 90 billion) of total estimated renewable subsidies in 2017, followed by the United States, with 14% (USD 23 billion), Japan with 11% (USD 19 billion), the United States with 9% (USD 16 billion), India with 2% (USD 4 billion) and the rest of the world with slightly less than 9% (USD 15 billion). Subsidies for renewable power generation were dominant in Japan (99%), China (97%), the EU (87%) and India (76%). Subsidies for biofuels dominated in the United States (61%) and the rest of the world (71%).

Robust estimates of subsidies to existing and new nuclear power globally are not available. Scaling up the lowest estimate of subsidies to existing nuclear capacity in the United States to a global level, however, yields a subsidy figure of around USD 21 billion for 2017. This must be considered a placeholder, with the possibility that much higher values are realistic; but it is also an acknowledgement that a value of zero is not a robust assumption. Comparable detailed analysis is not available globally, so although the United States may not be representative of the global experience, the estimates for existing nuclear subsidies in the United States per unit of generation, when scaled to global nuclear generation in 2017, could have ranged from around USD 21 billion to USD 165 billion. This is an area where further additional research is warranted, given the absence of comparable cross-country data on subsidies in the nuclear power sector.

Figure S-1: Total energy sector subsidies by fuel/source and the climate and health costs, 2017



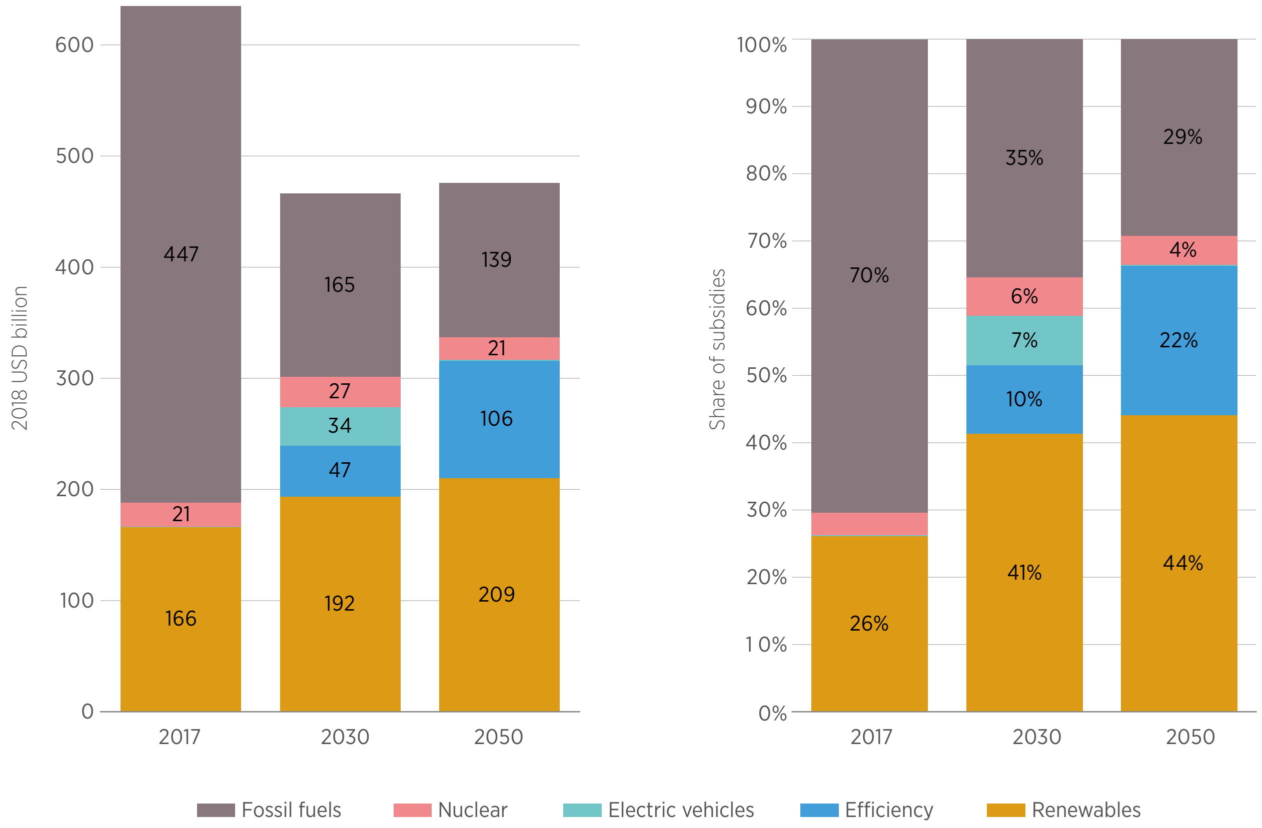
Environmentally friendly subsidies (EFS) to clean and renewable energy can help to improve the efficiency of capital allocation across the energy sector. This is because externalities stemming from fossil-fuel use – notably the costs imposed on society from their associated air pollution and climate change – are not typically fully priced. In 2017, a central estimate for the health costs arising from outdoor pollution generated by fossil fuel use was around USD 2 260 billion, with climate change costs of around USD 370 billion assuming USD 11/tonne of CO_2 (Figure S-1). Subsidies to renewable energy, albeit a second-best policy response from an economist's perspective, help to reallocate capital investment away from fossil fuels, going some way to mitigating the negative impacts of fossil fuel use in the absence of the full pricing of fossil fuel externalities.

Yet the continued imbalance remains staggering. In 2017, the costs of unpriced externalities and the direct subsidies for fossil fuels (USD 3.1 trillion) exceeded subsidies for renewable energy by a factor of 19. In this report, subsidies to fossil fuels are referred to as "environmentally harmful subsidies" (EHS) and those to energy efficiency, clean and renewable energy "environmentally friendly subsidies" (EFS).

EVOLUTION OF TOTAL ENERGY SUBSIDIES TO 2050

Between 2017 and 2030, total, annual energy sector subsidies could decline from USD 634 billion to USD 466 billion per year, according to the REmap Case set out by IRENA for realistic acceleration in the worldwide deployment of renewables, and be around USD 475 billion in 2050 (Figure S-2). Total energy sector subsidies in 2050 would therefore be around 25 % lower than in 2017 and 45 % (USD 390 billion) lower than they would be based

Figure S-2: Energy sector subsidies by source excluding climate and health costs in the REmap Case, 2017, 2030 and 2050



on current plans and policies. Under the current plans and policies (the Reference Case), oil and natural gas demand would be higher, and there is little progress in the reduction of per unit subsidies to fossil fuels. The increased use of renewables in the REmap Case brings a subsidy reduction compared to the Reference Case in 2030 of USD 341 billion, or 42% lower, rising to USD 390 billion lower in 2050. Overall, total energy sector subsidies in the REmap Case could be around USD 10 trillion lower than in the Reference Case over the period to 2050.

Direct subsidies for fossil fuels fall from USD 447 billion in 2017, to USD 165 billion in 2030 and to USD 139 billion in 2050 in the REmap Case, as per unit subsidies are reduced and fossil fuel demand declines. Existing subsidy programmes are reduced significantly and by 2050 over 90% of the subsidies to fossil fuels are to support carbon-dioxide capture and storage (CCS) in industrial applications. The share of fossil fuels in total energy sector subsidies falls from around 70% in 2017, to 35% in 2030 and to 29% in 2050. In 2050, the subsidies for fossil fuels from CCS in industrial applications (primarily to address process emissions) reach USD 126 billion, with over 60% required for the iron and steel sector, 23% for the cement sector and 14% in the chemicals sector.

IRENA's roadmap for more sustainable energy development sees a rebalancing of energy sector subsidies away from environmentally harmful subsidies towards environmentally friendly subsidies by 2050. As renewable power becomes increasingly competitive and early high-cost subsidies to solar PV, in particular, expire, the subsidies for renewable power generation decline to USD 53 billion in 2030 and are virtually eliminated by 2050, according to REmap projections. With more effort to decarbonise the more difficult end-use sectors, their share of subsidies begins to increase. The subsidies needed over and above the Reference Case in Industry by 2050 reach USD 166 billion[1], with USD 100 billion for energy efficiency and the balance for renewable heat. In the Buildings sector, subsidies grow to USD 28 billion in 2050, predominantly (88%) for renewable heating, cooling and cooking solutions.

In the REmap case, total energy sector subsidies decline from 0.8% of global Gross Domestic Product (GDP) in 2017 to 0.2% in 2050. The division of total energy sector subsidies as a share of GDP to a quarter of its 2017 value in 2050 is driven by the decline in total energy sector subsidies from USD 634 billion in 2015 to USD 475 billion per year in 2050, at the same time as global GDP is projected to grow by around 58%.

MORE WORK NEEDED ON TOTAL ENERGY SUBSIDIES

Analysis of energy sector subsidies has, in the past, focussed on fossil fuels. There are relatively few institutions examining global subsidies to individual fuels or technologies using a consistent methodology and accounting approach to their calculation. Moreover, because these institutions often use slightly different subsidy definitions and calculation methods, it can be difficult to compare existing subsidy data on a like-for-like basis. This can introduce unnecessary confusion in the minds of key stakeholders and can divert resources from focussing on policy reform.

Greater harmonisation of subsidy calculation methodologies, definitions of what constitutes a subsidy and the boundary conditions for the application of the definition would help provide greater clarity around both the current level and trends in total energy sector subsidies. This would reduce the uncertainty around subsidy estimates' comparability and potentially reduce unnecessary duplications of effort. A greater focus on subsidy trends in the energy sector would, in turn, allow a more robust, fact-based debate around efforts to reform energy subsidies. Such discussions are crucial as countries strive to meet their respective commitments to meet the climate goals set out under the Paris Agreement.[2]

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[1] The subsidies to finance investment in CCS for fossil-fuel operations are in addition to this figure.

[2] The historic 2015 climate deal, endorsed by nearly all countries worldwide, calls for limiting the rise in average global temperatures to "well below 2°C", and ideally 1.5°C, during the present century, compared to pre-industrial levels. Every country needs to cut carbon-dioxide (CO2) emissions in the energy sector for the world to achieve these aims, regarded as crucial to avert catastrophic climate change.

1 SUBSIDIES, PRIVILEGES, UNPRICED EXTERNALITIES AND THE ENERGY TRANSITION

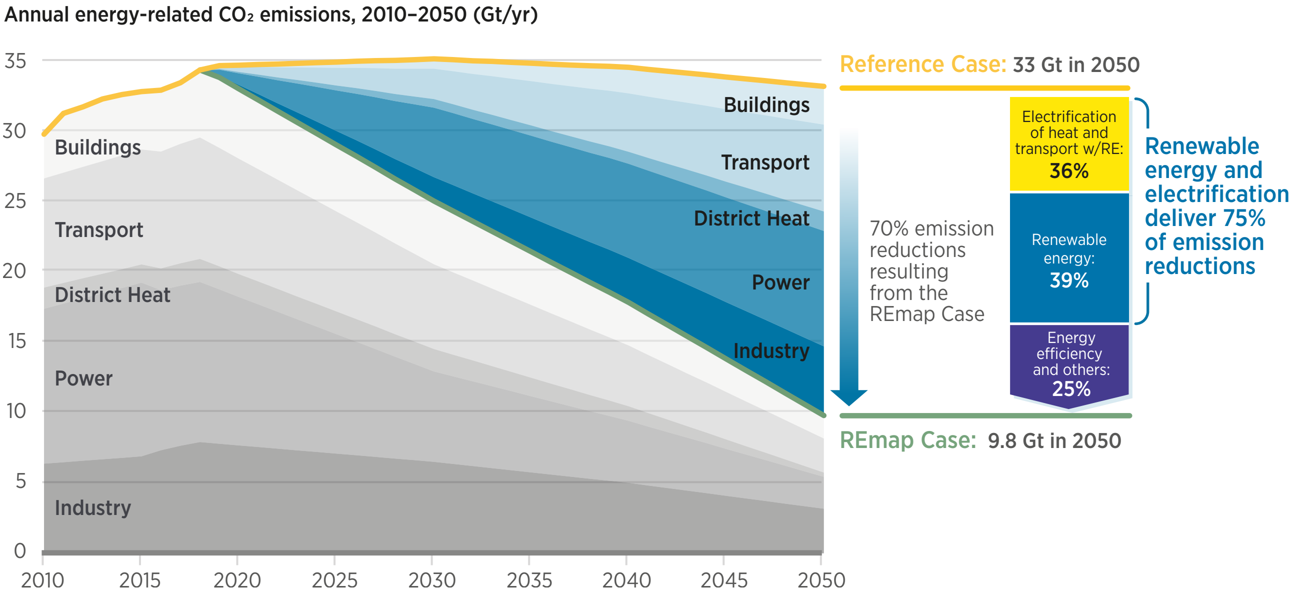
In order to meet the Paris Agreement objective that the global temperature rise be kept to "well below 2 °C", the global energy sector requires nothing short of a complete transformation, during the coming decades.

At the same time, while the political will to avoid dangerous climate change demonstrated by the countries of the world in signing the Paris Agreement is welcome, as the IPCC Special Report on "Global Warming of 1.5 °C" makes clear, time is of the essence.

To meet the Paris goals, current annual emissions of CO_2 from the energy sector need to fall as soon as possible, while sustaining a downward trend to net zero in the shortest time possible.

The International Renewable Energy Agency (IRENA), in the report *Global Energy Transformation: A Roadmap to 2050* (IRENA, 2019a), has provided just such a pathway for renewables and energy efficiency, outlining the crucial elements for the world to achieve the Paris goals (Figure 1).[1]

Figure 1: Global energy sector carbon-dioxide emissions in the Reference and REmap Cases, 2010–2050



Source: IRENA, 2019b.

Note: The chart covers only CO_2 emissions from the energy sector; it does not include other greenhouse gas emissions or land use changes.

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[1] See IRENA (2019a) for more details of how the Reference and REmap Cases discussed in this report are developed.

The IRENA analysis demonstrates that renewable energy technologies are increasingly cost-competitive in many geographies and markets and that the energy transition will yield significant economic benefits (IRENA 2019b).

New-build renewable power generation technologies, increasingly without subsidies, will even displace existing coal, or nuclear power plants. This is because their total lifetime costs are lower than these older plants' variable operating costs. This trend implies that the energy transition is both ecologically and economically sustainable.

Given the urgency of fighting global warming, however, the transformation of the energy sector will require the development and deployment of existing and new technologies that today play only a minor role. Some of these technologies may, however, have higher costs than polluting incumbents, at least initially. Minimising the costs and maximising the benefits of energy sector transformation are therefore important considerations for policy makers, with these needing to be balanced against the increasing cost of delaying climate change mitigation action.

Many metrics to assess the costs of the energy transition are available to policy makers, who are interested in minimising the costs of the energy transition (and maximising the benefits). Different metrics also yield different insights, depending on the questions being posed and the interest of those asking.

Important metrics that can help inform decision makers include changes in GDP and net societal wealth, taking into account the environmental costs and benefits. In practical terms, though, policy makers need to understand what is driving these high-level changes and how sensitive they are to different inputs or assumptions about technological progress, performance improvements and cost reductions.

Policy makers will therefore seek other cost metrics that allow them to understand these nuances. These can include, for example, looking at the costs of the transition in different sectors by examining changes in overall electricity system costs, including generation, ancillary services, transmission and distribution. Other cost metrics can provide greater granularity, helping understand in more detail the drivers of overall costs and how they can be minimised.

As an example, examining renewable electricity generation technology data on installed, operational and maintenance costs, technology trends, performance, the cost of finance and the levelised cost of electricity (LCOE) allows for a deeper understanding of what is driving costs in different regions. This may also highlight where policy efforts may be required to reduce costs. At the same time, specific sub-sectors will be interested in their own energy use and how it interacts with the others (*e. g.,* the implications for the transmission and distribution systems of renewable power generation siting).

With policy makers focused on cost-minimisation, the price benchmarks used for long-term decision making need to be accurate and must reflect total costs. Ignoring the health and environmental costs of incumbent resources can result in sub-optimal investment decisions. So too can improperly capturing and calculating energy subsidies, both now and over the evolution of any energy sector transformation. These factors have an important impact on the economic efficiency of the energy sector, as they change capital allocation, investment and operational decisions by sector stakeholders.

For virtually all of the modern era of energy usage, the energy sector has operated with a range of subsidies that have, to a greater or lesser extent, distorted market functioning (indeed, the sector has often actively sought these). In many cases, what policy makers or industries considered temporary subsidies – both well-intentioned and egregious ones alike – have persisted for decades, as industry has actively sought to ensure their continuation. In some instances, industry has even actively framed the debate to exclude such policies, on the basis that they are not subsidies.

Indeed, what is typically lacking in discussions around subsidies is transparency – about the reasons why energy subsidies for different technologies or end-uses may be needed, or about when they can be beneficial or, conversely, when they should be avoided or phased out. In addition, transparency about the level of subsidies awarded to different energy sources, technologies or sectors is also sometimes lacking. This often originates in the decisions by different stakeholders about what to characterise as a subsidy, although confusion can also arise around subsidy levels, because the boundary conditions for the calculation of what is and what is not a subsidy can vary between different estimates, with a range of accounting methods for calculating them available.

This report sets out some of the basic definitional issues that face policy makers and others when assessing subsidy levels in the energy sector. It also identifies subsidies to the sector, looks at the strengths and weaknesses of different subsidy definitions and discusses the evolution of energy subsidies up to the year 2050, under the REmap Case.

1.2 WHAT PURPOSE DO SUBSIDIES SERVE AND HOW TO DEFINE THEM?

Subsidies can arise as the result of deliberate interventions by governments, or as the unintended consequences of policy decisions, or from market failures. Energy subsidies are not necessarily bad *per se*, but this depends on how and why they are being implemented.[2] What matters are the objectives being pursued and how the subsidies may interact with other policy priorities.

Energy subsidies can be pursued in order to achieve specific policy goals, such as:

- Provide affordable energy for low income members of society.
- Correct markets for unpriced externalities.
- Induce technology learning and drive down the costs of new technologies.
- Reduce import dependence and enhance energy security.
- Create new economic activity and jobs.

For instance, policies that cap the price of kerosene for cooking and lighting below international prices are sometimes used to ensure affordable energy for the poorest members of society. This may have a negative interaction with health, environmental and macroeconomic policy goals, however, by encouraging higher use of kerosene than would otherwise occur. One macroeconomic consequence might be a negative impact on a country's balance of payments, if that fuel has to be imported.

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[2] Although energy subsidies may not be "bad", the way they are designed may not be the most efficient way of achieving legitimate policy goals. Subsidies designed to correct market failures should ideally do so in the most efficient manner possible in order to maximise the benefits. The German overseas development agency has created guidelines for how to approach the trade-offs between efficiency and policy goals in order to develop subsidies that are as efficient as possible (GTZ, 2009).

In addition, a subsidy may be an inefficient way of achieving the stated goal, if the subsidy to kerosene is predominantly captured by middle income households, or the benefits of access are offset by the negative health impact and cost of air pollution. As a result, a better way to ensure the less well-off of society have access to affordable energy might be a targeted direct cash grant, that doesn't distort price signals to all. This one example serves to highlight the complexity of analysing energy subsidies, without yet touching on the difficulty of trying to calculate overall energy subsidy levels.

At the same time, however, subsidies can be a legitimate policy tool used to improve economic efficiency when market failures occur.[3] Energy markets rarely achieve the ideal "perfectly competitive market" that economists use as a benchmark to judge whether public intervention is merited. As a result, subsidies or other interventions in market structure and/or operations can be justified, as they will lead to an improvement in economic efficiency (WTO, 2006; and GTZ, 2009).[4]

In the energy sector, the most common market failures that policy makers seek to address are those of market concentration or market power (*e.g.,* a lack of competition that allows producers to raise prices above efficient market levels) and where there are negative externalities[5] (*e.g.,* costs of production/use that are not paid by those responsible for their generation).

A related area where subsidies can be justified is when a technology or industry benefits from strong learning-by-doing, sometimes referred to as "dynamic economies of scale". The effect of this is that the cost of production declines with cumulative manufacturing experience.

At the same time, an induced or implicit fossil-fuel subsidy exists almost everywhere, as these energy sources do not typically pay the full price of their negative externalities during production, manufacture and use.

Key negative externalities include local air pollutants that affect local environment and biodiversity, as well as impose significant health costs; and greenhouse gas emissions that contribute to dangerous and costly climate change.[6]

Given the agents responsible for many of these negative externalities are not those who carry the costs, over-production occurs relative to what would be optimal for society. Unpriced externalities, or ones where the costs are not *fully* borne, by those responsible for their generation result in lower prices and hence higher production than the economic optimum.

Figure 2 illustrates this in a simple manner.[7] Imagine that a company is managing a fleet of fossil-fuel fired electricity generation plants. They are generating external costs which are borne by others. Their marginal cost curve when compared to demand (D) yields a price of $P_{private}$ and output of $Q_{private}$. Ensuring the producer paid the full costs of their negative externalities would raise their marginal cost curve, resulting in higher prices (P*) and lower demand (Q*). If the cost of these externalities can be accurately calculated, this would lead to an efficient equilibrium.[8]

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[3] From an economist's perspective, subsidies are difficult to justify in "perfect" markets, where full competition occurs, particularly in the absence of externalities.

[4] Such interventions are virtually never "costless" in that they involve some inefficiencies or costs in administration and implementation. Policy makers and regulators must therefore determine how to intervene at least cost, in order to maximise efficiency gains.

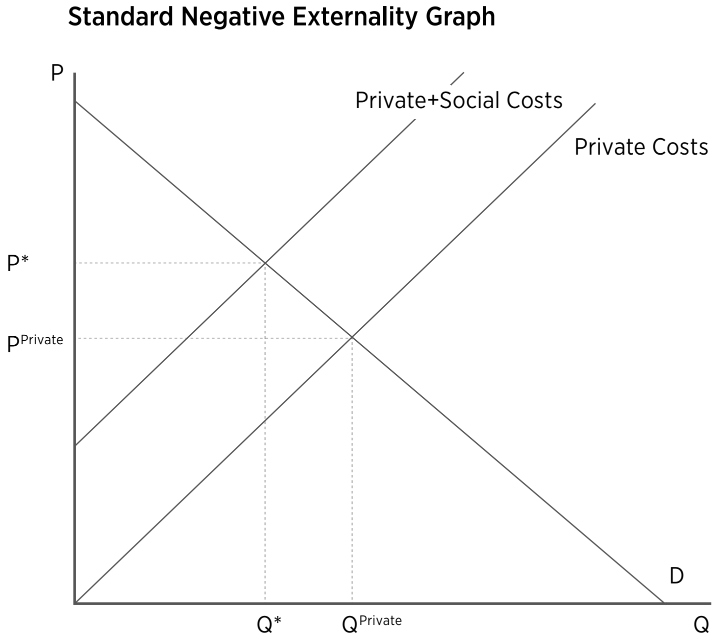
[5] Externalities can be either positive or negative, although in the energy sector they have historically been predominantly negative, given the pollution and health costs associated with the use of fossil fuels.

[6] There are a wide range of other negative externalities that are often not adequately priced, including pollution of water sources in the mining and extraction process, habitat loss, heavy metals that contaminate the land, crop yield reduction, increased building cleaning, accelerated degradation of building materials, land acidification, etc. See NRC, 2010 for more details.

[7] This is a very specific example of when negative externalities and subsidies shift the marginal cost curve up and down. It is not meant as a detailed discussion of the economics of subsidies or negative externalities. For a detailed economic assessment of how different types of subsidy affect demand and supply in different ways see Coady, *et al.*, 2015; GTZ, 2009; and McKitirck, 2017.

[8] The scope of this report does not extend to discussing the difficulties in calculating the "accurate" cost of many externalities and hence what constitutes an efficient outcome.

Figure 2: Negative externalities and their impact on supply and demand



Unfortunately, there has been little progress in ensuring that fossil fuels pay the full cost of their negative externalities, whether from local or global pollutants. In the absence of taxes or quotas set at optimal levels (to create a market), policy makers have often looked for alternative options to deploy renewables to address market failures in the energy sector and unlock the dynamic economies of scale many renewable technologies exhibit. The use of subsidies in this context can be seen as governments trying to ensure that the market operates more efficiently than today.

Subsidies that support renewable technology deployment that lead to the displacement of fossil fuels when the negative externalities of fossil fuels remain unaddressed therefore help improve the economic efficiency of the energy sector. They do this by shifting energy generation and use towards technologies that reduce those negative externalities. In many cases, subsidies have also been promoted because of the dynamic economies of scale that apply to the small, modular renewable energy technologies (notably solar and wind). In this respect, subsidies are the means to unlock low-cost technologies for the benefit of all of society. In these circumstances, subsidies in the early, high-cost period can be considered learning investments. Crucially, this mean that subsidies for renewable energy technologies like solar and wind power can be temporary, required only during a period of learning-by-doing, as costs then fall, to become competitive with fossil fuels – even if these fossil fuel producers of negative externalities do not bear their full costs.

Notably, in the presence of unpriced or partially-priced negative externalities, subsidies for renewables represent efforts by policy makers to improve economic efficiency in the energy sector, while also unlocking cost reductions.

Indeed, given the fact that the negative externalities of fossil fuels remain predominantly unpriced, the subsidies given to fossil fuels today represent a perverse incentive and amplify an already serious market failure with significant socio-economic and environmental costs. For example, the World Bank data suggests that the average effective rate of the world's carbon pricing schemes was just USD 1/t CO_2 in 2017 (World Bank, 2019).

Figure 3: Negative externalities and subsidies for fossil fuels – impact on supply and demand

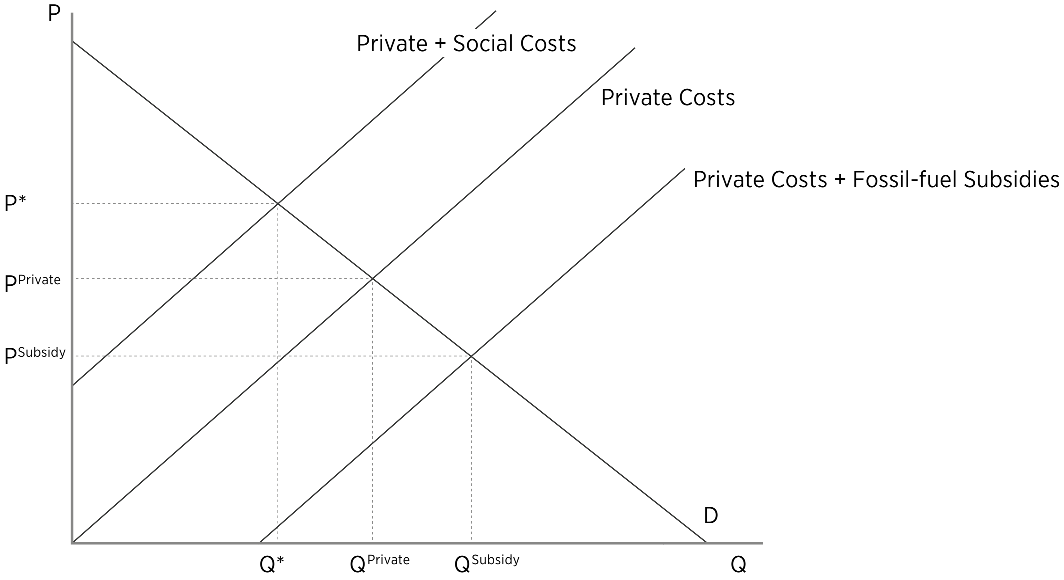


Figure 3 highlights the impact of subsidies that allow greater supply than is economically justified by allowing fossil fuels with negative externalities to be produced at a lower cost. The subsidies shift the supply curve to the right. At equilibrium in the market, the gap between the equilibrium when the negative externalities are taken into account (P* and Q*) widens even further (to $P^{subsidy}$ and $Q^{subsidy}$) than in the situation without subsidies for fossil fuels.

Different definitions of energy subsidies

Today, there is no systematically applied, standardised definition of what an energy sector subsidy is, despite the prevalence of subsidies in the energy system. Even without this uncertainty around definitions, given the breadth and complexity of support given to different energy sub-sectors or fuels, calculating subsidy levels or unpriced externalities can be difficult (Sovacool, 2017).

This lack of clarity in the classification and calculation of subsidies and their impact can sometimes distract from the critical issue of accelerating the energy transition, when estimates of subsidies for various sectors, technologies or fuels are used to advance specific proposals. Conversely, better, more transparent data and analysis of energy sector subsidies may allow policy makers to focus more clearly on achieving change while more efficiently deploying scarce resources.

Therefore, the first challenge in trying to calculate the amount and source of subsidies in the energy sector is what definition of subsidies should be used.

A key issue that will become apparent in this report, is that at their highest level, subsidy definitions are often broad and simple in order to ensure that the myriad forms which energy subsidies can take are captured. The drawback of this approach is that although the spirit of their design is to ensure the net is cast as wide as possible in determining what is a subsidy, in reality, this approach makes the decision about which individual policies or programmes should be included in subsidy calculations somewhat subjective. This problem is compounded by the different accounting methodologies used to calculate actual subsidy levels, with these sometimes missing a range of energy subsidies.

Table 1: Different definitions of energy subsidies and their strengths and weaknesses

DEFINITION	FOCUS/ METHODOLOGY	STRENGTHS	WEAKNESSES
WORLD TRADE ORGANIZATION (WTO) "A financial contribution by a government or any public body within the territory of a Member", or when "There is any form of price support...(where) a benefit is thereby conferred."	• How energy subsidies distort trade • Dispute settlement	• Near universal acceptance • Often referenced • Used by many as basis for their analysis	• Not widely used by some of the main institutions involved in subsidy reform
INTERNATIONAL ENERGY AGENCY (IEA) "Any government action directed primarily at the energy sector that lowers the cost of energy production, raises the price received by energy producers or lowers the price paid by energy consumers. It can be applied to fossil and non-fossil energy in the same way."	• On consumer subsidies, rather than producer subsidies • Fossil and renewables • Price-gap approach	• Broad definition • Explicitly covers all energy	• Applied only to consumer subsidies • Disagreement over reference prices • Can miss a range of subsidies • No nuclear numbers
ORGANISATION FOR ECONOMIC CO-OPERATION AND DEVELOPMENT (OECD) "Both direct budgetary transfers and tax expenditures that in some way provide a benefit or preference for fossil fuel production or consumption relative to alternatives."	• The inventory of support is first step to identifying subsidies to a sector • Inventory approach	• Broad definition of "support" • Inventory approach adds to transparency	• Can miss a range of supports delivered via price measures (prevalent in developing countries) • No estimates for nuclear or renewable subsidies
WORLD BANK (WB) "A deliberate policy action by the government that specifically targets fossil fuels, or electricity or heat generated from fossil fuels."	• Support countries in their subsidy measurement	• Good overview of approaches to subsidy calculation	• No recent subsidy calculations of their own • No estimates for nuclear or renewable subsidies
INTERNATIONAL MONETARY FUND (IMF) "Pre-tax consumer subsidies arise when the prices paid by consumers, including both firms (intermediate consumption) and households (final consumption), are below supply costs including transport and distribution costs. Producer subsidies arise when prices are above this level. Post-tax consumer subsidies arise when the price paid by consumers is below the supply cost of energy plus an appropriate "Pigouvian" (or "corrective") tax..."	• Understanding magnitude of subsidies to support reform • Price-gap and inventory approach	• Includes unpriced negative externalities	• Data intensive • No estimates for nuclear or renewables

Table 1 provides an overview of five different definitions of energy subsidies that have been proposed by institutions either active in calculating energy subsidy levels and/or active in the debate over energy sector subsidy reform (see Annex A for more details). Although they all have a common theme, they choose to articulate what is a subsidy in slightly different ways. In some cases, this is influenced by the area of competence of the organisation or the mandate under which they were invited to examine energy subsidies. In others, it is more aligned with the method of calculation of the subsidies envisaged.

In the European Union (EU), the European Commission (EC) uses the OECD definition and approach when calculating subsidies in the energy sector, while noting that this has limitations – some of which they seek to mitigate through various means (Trinomics, 2018). This leads to a wider definition of subsidies than that of State Aid (see Annex A), but makes the subsidy efforts more directly comparable with others.

Some, notably the Overseas Development Institute and Climate Action Network Europe, have used the WTO definition to calculate subsidies from fiscal support, public finance and State-Owned Enterprise (SOE) investments at home and abroad (Gençsü *et al.*, 2017).

The definitions above, not surprisingly, have many common elements. Yet, they also vary in a sufficiently significant number of ways to suggest that different calculation methods for subsidies (*e.g.,* a price-gap approach, rather than programme-by-programme accounting) are more appropriate, or have implications for the scope of what could be considered a subsidy. They can also potentially be divided into those describing ways in which subsidies are created or conveyed (*e.g.,* WTO and OECD), or those that have slightly more of a focus on the way subsidies impact the sector (*e.g.,* IEA and IMF). The World Bank definition (Kojima and Koplow, 2015) is somewhere in between, as it touches first on the mechanisms creating subsidies, before indicating the qualifying effects for something to be considered a subsidy. The distinction between subsidies mainly meant to confer benefits on a specific group and those focused on price impact has implications over whether to apply an inventory or a price-gap calculation method (Skovgaard, 2017).

There are other important dimensions to energy susbdies, such as whether they act by benefitting consumers or producers, and how they operate in practice (*e.g.,* by lowering the prices of different fuels, or through direct financial transfers to producers, tax rebates, subsidised loans, exemptions from environmental rules, etc.). To generalise, producer subsidies tend to be more important in developed countries, while consumer subsidies are more prevalent in developing countries. However, they often exist side-by-side in many countries, where a complicated series of subsidies benefitting different stakeholders in a range of different ways have emerged over time.

The IEA, OECD and IMF definitions all allude, either explicitly, or more implicitly, to the importance of both producer and consumer subsidies. As will be seen in coming sections, however, they take quite a different approach to measuring subsidies – meaning that their capture of both of these is not necessarily comprehensive. It's also worth noting that the IMF, OECD and WTO subsidy definitions are not narrow energy sector subsidy definitions, but are broad definitions of subsidies in general.

Historically, the focus of much of the work on energy subsidies has been on the reform of "inefficient" subsidies or those that encourage the "wasteful consumption" of fossil fuels. This is especially true in the G20 context, due to the specific wording of the document framing the G20 work on fossil-fuel subsidy reform. This is to some extent reflected in the OECD and World Bank definitions of subsidies, where the institutional focus is generally, but not always, on fossil-fuel subsidy reform. Interestingly, the IMF analysis of energy sector subsidies, despite a neutral approach in its definition, focusses exclusively on fossil-fuel subsidies (Coady, *et al.*, 2015). The IMF analysis is, however, notable as the only definition that takes into account negative externalities. The IEA definition is explicit in saying it can be applied equally to fossil and non-fossil energy sources, but only applies their definition and methodology to fossil fuels and renewables, excluding nuclear.

This report does not propose a new definition of subsidies, nor should it be interpreted as a critique of existing ones. Although a more general distinction between environmentally harmful subsidies to fossil fuels and environmentally friendly subsidies to renewables, other clean energy and energy efficiency technologies would be welcome. Instead, it tries to highlight the differences between definitions and their impact on the scope of subsidy analysis, the calculation methods used and the resulting comparability of energy sector subsidy estimates. This is important, because any analysis of energy sector subsidies ought to provide the most comprehensive possible estimate of their total. Not only the definition of energy subsidies matters here, but also the calculation method and whether this captures *comprehensively* both producer and consumer subsidies.

Expanding on definitions: Categorising and calculating subsidy levels

Although the differences in definitions can explain some of the differences in subsidy estimates, what is clear is that the focus of different institutions can not only affect their decision about what methodology to use in the calculation of subsidies, but also what types of policies are included in their analysis. This can be due to:

- The policy question being addressed by the institution.
- Fundamental differences in the conception of what policies represent energy sector subsidies.
- Data limitations, or limits in the institutional resources available for subsidy analysis.

Different institutions have historically had different motivations for cataloguing and analysing energy sector subsidies. These differences can influence the methodology and scope of subsidy analysis. For instance, the OECD inventory approach to subsidies allows a detailed understanding not only of the order of magnitude of subsidies, but which specific policies would need to be reformed. This approach is logical in the context within which the OECD tries to advocate for better policies. In a similar vein, the IEA has historically undertaken subsidy estimates as part of its energy modelling exercise. A price-gap approach leverages the IEA's existing model inputs to provide subsidy level estimates and highlight trends in their magnitude and incidence over time. Given that the IEA focus is on informing their member states through its analysis, rather than on making specific policy recommendations for reform, the lack of detailed policy programme information is not a significant drawback.

Fundamental differences in what constitutes a subsidy can, however, have a material impact on what policies are considered subsidies. At a very detailed level, this can be the difference between including a tax preference or excluding it, based on specific criteria. For instance, in Europe, in many countries, the EC excludes the lower tax rate for diesel, rather than petrol. They do so because they have defined a tax expenditure subsidy as, "The exemption, exclusion or deduction from the base tax" (Trinomics, 2018). Others, however, have taken a different approach and included this lower tax rate on the basis that this differential represents a subsidy under the WTO definition of subsidies (ODI & CAN Europe, 2017). Yet, the largest fundamental difference arises from whether the negative externalities of fossil fuels are counted as subsidies. The IMF definition explicitly includes these, which yields order-of-magnitude differences in energy sector subsidy compared to those of their peers.

In addition, data limitations, or the difficulty of calculating some subsidy types, can lead to the underestimation of energy subsidies. For instance, there have been very few attempts to try and identify the monetary value of credit-based subsidies (*e.g.,* loan guarantees or "concessional" reduced-rate loans),[9] while government-mandated liability caps (either for pollution or accidents) are almost universally excluded, given the difficulties of accurately calculating their value. This in part reflects the difficulty in finding sufficient data with which to calculate a subsidy. The public sector concessional financing of energy infrastructure by export credit agencies, national development banks and other development finance institutions is large and may have averaged USD 123 billion annually between 2013 and 2015, with 58 % of that going to fossil fuels, 15 % to clean energy[10] and the remaining funding to a miscellanea of other energy sector investments (OCI, 2017).

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[9] There are various efforts to call attention to these subsidies. Oil Change International (OCI, 2017) has highlighted the issue and the OECD has proposed an approach that could be used to calculate these subsidy values if sufficient data could be collected (OECD, 2018).

[10] Which they define as, "Energy that is both low carbon and has negligible impacts on the environment and on human populations, if implemented with appropriate safeguards. Some energy efficiency and some renewable energy – energy coming from naturally replenished resources such as sunlight, wind, rain, tides, and geothermal heat." "Other" includes nuclear, bioenergy, waste incineration, large hydropower and biofuels. Their reasoning for this is that these energy sources "can have significant impacts on the environment and on human populations that make it difficult to consider them truly 'clean'.

The volume of financing doesn't represent the subsidy level, however. Calculating the subsidy value of these types of credit subsidies would require detailed data on not only the loan's rate, but also the terms and conditions of the loan relative to what might have been a market rate and terms and conditions for such a project. This is challenging, because this level of detail is not typically in the public domain, while estimating an accurate counter-factual market rate and terms and conditions can be very difficult.

Despite these challenges, the OECD (OECD, 2018) rightly highlights that "Data on government credit support is nevertheless an important element that sheds light on government contributions to carbon-intensive infrastructure and to the risk of stranded assets. Work on gathering and reporting such information could provide a more accurate picture of the grant-equivalent value of the government-mediated credit instruments than would information on the principal value of those instruments alone."

This is also true for government-granted public liability limits (notably for nuclear) in such cases as: accident; weakly enforced environmental regulations; exceptions for polluters in environmental regulations (*e.g.,* higher emission limits for coal-fired power plants); weak regulations for environmental or remedial contingencies at the end of project life (*e.g.,* self-bonding for coal ash disposal or mine rehabilitation); government ownership of high-risk or expensive parts of energy infrastructure or fuel cycles; and the transfer of end-of-life liabilities to the public sector. These are some of the more prevalent subsidies that are typically left uncalculated.

As is clear from this discussion, the importance of how energy subsidies are categorised and calculated is great. One recent categorisation (Sovacool, 2017) identified 17 different types of energy subsidies (Table 2) grouped into five families, with these having three possible types of impact.

Other areas not discussed in Table 2, but which are also relevant, include the transfer onto the government/public sector of costs for remedial action to address environmental pollution (this would fall under the fourth category in Table 2), or the weak or absent enforcement of environmental regulations. In some cases, the process for this enforcement to occur is not transparent and often not considered a subsidy, despite the ultimate result. For instance, some countries' bankruptcy laws can result in these types of transfers, even if new, liability-free owners continue the operations.

Unfortunately, the method of calculating energy sector subsidies can thus have an impact on what subsidies are captured. The limitations of each method are therefore important to understand.

There are three commonly used approaches to calculating subsidy levels (Sovacool, 2017 and Koplow, 2018), including:

- Programme-specific estimation – an inventory approach where sources of energy subsidies are identified and quantified.

- A price-gap analysis – an approach that tries to identify producer support[11] and consumer support estimates based on comparing actual prices to some reference price.

- Total support estimates – tries to identify total consumer and producer support levels, typically to-date, by combining the above two approaches.

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[11] This will not capture certain producer subsidy programmes, however. For instance, producer subsidies in markets with international market pricing for consumers.

Table 2: A typology of global energy subsidies

TYPE OF SUBSIDY	EXAMPLE(S)	HOW IT WORKS		
		LOWERS COST OF PRODUCTION	RAISES PRICE TO DISFAVORED PRODUCER	LOWER PRICE TO CONSUMER
DIRECT FINANCIAL TRANSFER	Grants to producers	●		
	Grants to consumers			●
	Low-interest or preferential loans	●		
PREFERENTIAL TAX TREATMENT	Rebates or exemptions on royalties, sales taxes, producer levies and tariffs	●		
	Investment tax credits	●		●
	Production tax credits	●		
	Accelerated depreciation	●		
	State sponsored loan guarantees	●		
TRADE RESTRICTIONS	Quotas, technical restrictions, and trade embargoes		●	
	Import duties and tariffs		●	
ENERGY-RELATED SERVICES PROVIDED BY GOVERNMENT AT LESS THAN FULL COST	Direct investment in energy infrastructure	●		
	Publicly sposored R&D	●		
	Liability insurance	●		
	Free storage of waste or fuel	●		
	Free transport	●		
REGULATION OF THE ENERGY SECTOR	Demand guarantees and mandated deployment rates	●	●	
	Price controls and rate caps		●	●
	Market-access restrictions and standards		●	

Source: Based on Sovacool, 2017.

In this framing of calculation methods, the inclusion or exclusion of calculations referring to externalities is assumed to be a definitional issue, rather than driven by the calculation methods themselves.[12]

Table 3 provides an overview of each approach and its strengths and weaknesses. As noted above, the question of which calculation method to use is often not an independent decision, but one influenced by the definition of subsidies used and/or institutional factors. From a knowledge perspective, however, the goal should be to arrive at the most comprehensive energy sector subsidy estimates. In this respect, taken individually, both the inventory and price-gap approaches must be seen as only partial solutions to arriving at total energy sector subsidy estimates, as they both have areas of weakness in terms of what subsidies they can capture. In this respect, combining the two approaches should yield a better estimate of total subsidies.

As an example, although the inventory method is good at identifying individual support programmes that provide subsidies to fossil fuels, yet often have no impact on international prices, they can miss some interventions that act explicitly to reduce consumer or producer prices. Combining the inventory approach and price-gap method can, in theory, provide more comprehensive subsidy estimates. The challenge in combining these two approaches lies in ensuring that double-counting of support is avoided. For instance, direct payments to fuel providers to compensate for below-market government pricing policies need to be removed from a combined calculation using both methods, otherwise this practice would be captured in the price-gap calculation and inventory approach. Both the OECD and the IMF (Coady, *et al.*, 2015 and OECD, 2018) have undertaken efforts to integrate the two approaches, in order to come up with more comprehensive fossil-fuel subsidy estimates.

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[12] The methodological issues of how subsidies that arise from unpriced negative externalities are calculated is another aspect of this.

Table 3: An overview of the common methods of subsidy calculation and their relative merits

APPROACH	STRENGTHS	LIMITATIONS
INVENTORY • Quantifies value of specific government programmes to particular industries and then aggregates programmes into overall level of support. • Transfers include reductions in mandatory payments (*e. g.*, tax breaks and shifting of operating risks to the public sector, not just cash. Mandated purchase requirements are often captured, at least qualitively).	• Captures transfers whether or not they affect market prices. • Can incorporate the value of risk transfers (*e. g.* via lending or insurance subsidies) rather than just the direct government costs. • Can feed into a variety of evaluative frameworks and support detailed policy reviews needed for reform efforts	• Does not address quiestions of ultimate incidence of subsidies or pricing distortions. • Sensitive to decisions on what programmes to include. • Requires detailed, programme-level data. • Differential baselines across political jurisdictions (particularly regarding taxes) can complicate aggregations and cross-country comparisons.
PRICE GAP • Evaluates positive or negative “gaps“ between the domestic price of energy and the delivered price of comparable products from abroad.	• Can be estimated with relatively little data; very useful for multi-country studies even if there is limited access to government documents. • Good indicator of pricing and trade distortions.	• Sensitive to assumptions regarding “free market” reference prices and transport prices and to frequency and geographical dispersion of key data inputs. • Understates full value of support as it ignores transfers that do not affect end-market prices and may miss important supports such as purchase vouchers or cross-subsidies. • Estimates for non-traded goods (*e. g.,* electricity) require much more detailed analysis to generate reference prices.
TOTAL SUPPORT ESTIMATE • Systematic method to aggregate transfer plus market support to particular industries.	• Integrates transfers with market supports into holistic measurement of support. • Separates effects on producer and consumer markets.	• Limited empirical PSE/CSE data for fossil fuel markets, although this is improving for OECD countries and a handful of others • Data intensive.

Source: Based on Koplow, 2018.

2 ENERGY SECTOR SUBSIDY ESTIMATES

The present part of the analysis examines the levels of energy sector subsidy estimates made by some of the major institutions that have produced reports on global subsidy levels.

The focus is on comprehensive studies that look at global subsidy levels. This is in order to ensure that the numbers presented are as comparable as possible. There are, however, a number of important regional subsidy estimates, particularly for fossil fuels, that can in some cases provide useful detail to complement or inform these global estimates. Notable examples include fossil and renewable energy subsidies in Europe (Trinomics, 2018; and Gençsü and Zerzawy, 2017), fossil-fuel subsidies in Asia (ADB, 2016), and federal tax subsidies in the United States (CBO, 2016; and CRS, 2017). There is also a significant body of analysis and data at a country level compiled by the International Institute for Sustainable Development's Global Subsidies Initiative.

An important point is that although the definitions and calculation methods outlined above apply to the energy sector in general – and indeed often explicitly state so – the much greater part of analysis of energy sector subsidies to date, whether by governments, think tanks, research institutions or academics, has focused on fossil-fuel subsidies. As will become clear in the sections that follow, relatively little work has been done examining global subsidies to renewable energy (although this is changing as their importance to the energy system grows). The situation is even worse for nuclear, as comprehensive efforts to calculate nuclear subsidies at a global level are not available.

The sections that follow look at subsidy estimates to renewable energy – including new results from IRENA – fossil fuels and nuclear. The analysis here does not attempt to examine the current level of subsidies to energy efficiency or other demand-side technologies. their relative importance in the evolution of total energy sector subsidies to 2050 is, however, discussed in the final section of this report.

2.1 RENEWABLE ENERGY SUBSIDIES

To-date, analysis of energy sector subsidies at a global level has predominantly focused on environmentally harmful subsidies to fossil fuels,[13] given their dominance in the global energy system and total energy subsidies. There are therefore fewer estimates of the financial support given to renewables, calculated on a comprehensive and comparable basis. As a result, available data are often partial, collected on a different basis and difficult to compare. The exceptions are the data in the IEA's World Energy Outlook, which takes a price-gap approach to estimating renewable energy subsidies, and the analysis in this report by IRENA (both will be discussed below).

Before discussing the global IEA and IRENA subsidy estimates for renewable energy, the data available for individual countries is worth examining in individual countries. This only provides a partial view of subsidy levels, yet it is a useful benchmark against which other estimates can be compared.

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[13] "Inefficient fossil-fuel subsidies" in this report refers to the fact that they are inefficient in an economic sense, given that they multiply the impact of the negative externalities of fossil fuels. The other common usage of this term in subsidy discussions relates to the G20 commitment to phase-out "inefficient" fossil-fuel subsidies, where the interpretation of the meaning is effectively based on "national circumstances" (G20, 2009).

Table 4: Selected country and regional estimates of renewable energy subsidies in 2017

	POWER GENERATION USD BILLION	**CALCULATION METHOD**	**BIOFUELS** USD BILLION	
EUROPEAN UNION*	78	Inventory and price-gap	10.9-11.9	Price-gap
CHINA	~15	Inventory	0.4	Price-gap
JAPAN	19	Inventory	~0.2-0.3	Price-gap
UNITED STATES	6.7	Inventory	14.1	Inventory and price-gap
INDIA	2.2	Price-gap	0.9	Price-gap

*Total subsidies to all renewables are higher, as an additional USD 5.7 billion was categorised as "All/several/others" to catch cross-cutting measures.

All values in this table are in real 2018 USD, that is to say taking into account the effect of inflation.

Sources: IRENA analysis from CEER, 2017; CRS, 2017; USDA, 2017a; IEA Bioenergy, 2016; IISD, 2008; IRENA analysis; METI, 2018; IISD, 2017; and Trinomics, 2018.

To give a few examples, data is available for: the German electricity surcharge that funds the deployment of renewable power generation[14] (calculated using a price-gap methodology that also includes some administrative aspects); the United Kingdom's Renewables Obligation Certificates, Feed-in-Tariffs (FiTs), Contracts for Differences (CfDs) and Renewable Heat Incentive (BEIS, 2016 and 2018); and the United States' support through the production and investment tax credits for wind and solar (Congressional Research Service, 2017). There are also the regional subsidy estimates that have been mentioned. All of these sources usually apply either a price-gap or inventory of programme costs methodology, making comparability and completeness an issue. For attaining an order of magnitude of what total subsidies may look like globally to renewable energy, however, this is a useful starting point.

Efforts to consolidate individual country subsidy level estimates on a comparable basis are not common, but do exist. The EU is active in trying to catalogue support for renewable electricity, with estimates for both total cumulative support payments and support to newly commissioned projects based on premiums over wholesale prices (CEER, 2017 and Trinomics, 2018). Recent work provides a more comprehensive overview of subsidies to the renewable energy sector by including tax expenditures, direct transfers and R&D expenditure (Trinomics, 2018). Yet, there does not appear to have been a systematic effort, to-date, to create a global inventory of these programmes' total level of subsidies, updated on a regular basis.

Table 4 provides an overview of the amount of subsidy received by renewables from a variety of sources in China, India, Japan, the United States and the EU. These estimates, it should be stressed, are, in some cases, a summation of different sources using different definitions and methodologies. As such, the totals should be treated with caution and country comparisons should be avoided as the coverage of subsidies and their calculation methods differ. They do, however, provide a lower bound from which global subsidy estimates for renewable energy can be compared, to ensure they are robust.

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[14] The so-called EEG surcharge (EEG Umlage) from the Renewable Energies Act (EEG), which gives power plant operators a fixed tariff for every kWh of renewable power that they fed into the grid over a 15-year or 20-year period, but also includes direct payments and premiums under other measures (*e.g.,* from offshore wind auctions). See https://www.bundesnetzagentur.de/EN/Areas/Energy/Companies/RenewableEnergy/Facts_Figures_EEG/FactsFiguresEEG_node.html

In the EU, support for renewable power generation is typically provided via FiTs, Feed-in Premiums (often delivered through CfDs), Green certificates (GC),[15] and investment grants. Total support to renewable power generation in 2015 was estimated at around USD 71 billion[16] (Trinomics, 2018), with Germany accounting for around USD 26 billion, Italy for around USD 13 billion, the United Kingdom for USD 6 billion and Spain for USD 6 billion (CEER, 2017). Total subsidies were slightly higher in 2016 and IRENA has estimated the 2017 subsidies at USD 78 billion. No recent estimates of EU subsidies to biofuels exist, but a price gap analysis suggests they could have been in the range of USD 11-12 billion in 2017.[17]

China has become an important global driver of renewable power generation deployment, with total installed capacity of 619 GW at the end of 2017 (IRENA, 2018b). In China, solar PV and wind power have benefitted from FiTs to accelerate their deployment. The premium over reference prices to fund these FiTs is collected through a surcharge that was around RMB 0.019/kWh in 2017,[18] suggesting a subsidy to renewable power generation of around USD 15 billion.[19] China's ethanol and biodiesel use in 2017 was modest, with around 3 billion litres of ethanol and 0.3 billion litres of biodiesel (USDA, 2017a and 2019), with subsidies of perhaps USD 0.4 billion per year, this number should be treated with caution given that there are indications production costs have been falling in recent years as the industry scales (IEA Bioenergy, 2016; USDA, 2019; and IISD, 2008).[20]

Japan, in an effort to reduce its reliance on fossil fuel imports, has supported renewable deployment (primarily solar PV) through FiTs. In 2017, the FiT scheme required a surcharge on electricity that amounted to USD 19 billion, including administrative costs and after deducting the saved fuel costs that resulted (METI, 2018). Ethanol consumption in Japan in 2017 was around 0.9 billion litres and biodiesel around 0.01 billion litres (USDA, 2017b), leading to subsidies from a price-gap analysis that may be in the order of USD 0.3 billion per year.[21]

The United States periodically reports on the level of federal tax breaks provided by specific policies and programmes, with an estimated USD 6.7 billion accruing to renewable power generation technologies in 2017. This includes a mixture of ongoing payments – notably through the Production Tax Credit (PTC) – and one-time investment tax breaks, including the Investment Tax Credit (ITC) for solar, but also through other policies. For 2015, these were estimated to be around USD 3.3 billion excluding American Recovery and Reinvestment Act payments, but rose in 2016 to USD 6.2 billion due to the almost doubling of new solar PV deployment in that year (CBO, 2016).[22] In addition to this, as part of the American Recovery and Reinvestment Act of 2009 (Recovery Act), certain qualifying projects were able to take cash grants in lieu of their ITC or PTC entitlement. The rules were such that construction completion could be spread out over a number of years and grants of USD 1.4–2 billion[23] were made to these qualifying projects in 2015, bringing the total federal tax support to USD 4.8-5.4 billion in 2015.

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[15] These policy tools are not automatically subsidies, but depend on the level at which they are set relative to a reference cost.

[16] Unless otherwise stated, all monetary values in this report are expressed in real 2017 USD, that is to say taking into account the effect of inflation.

[17] This is based on comparing wholesale prices for ethanol and biodiesel to those for conventional gasoline and diesel. The variation represents the different wholesale conventional gasoline and diesel price sources. Unfortunately, the most recent analysis for the EU28 (Trinomics, 2018) does not break down its biofuels support estimates. It does estimate renewable quota subsidies values at around USD 6.7 billion in 2016, however, and, given that most EU states only use renewable quotas for biofuels, the price-gap estimate range calculated by IRENA appears reasonable.

[18] https://www.in-en.com/article/html/energy-2275486.shtml

[19] The surcharge recovery rate is lower than this figure, so actual subsidy levels were some USD 2–3 billion lower in 2017, however, given the accumulated deficit in payments to renewable project developers the higher figure is used as a more realistic value for the subsidy level.

[20] This is an estimate based on the direct support levels for 2017 and an estimate of indirect support for 2017 based on a 2008 analysis by the Global Subsidies Initiative scaled-up to reflect production growth. Whether these indirect support measures remain in place is unclear; yet if they do, their impact on subsidy levels is modest.

[21] In the absence of specific data on Japanese ethanol prices/costs, European prices are assumed to provide a suitable proxy.

[22] These are best estimates of the tax benefits that accrue to renewables from Treasury analysis. Actual forgone revenues (*e.g.*, tax preferences actually claimed) are not available until the detailed individual tax claims are processed and reviewed. For instance, as of October 2018, the detailed tax record summaries are available for individuals tax returns for 2016, but the bulk of the tax credits are from corporate entities and line item estimates are only available for 2013. In some cases the line item estimates result in significant differences to the previous Treasury estimates, so these values must be treated with caution.

[23] CBO, 2016 and the Treasury grant data are not in agreement (https://home.treasury.gov/policy-issues/financial-markets-financial-institutions-and-fiscal-service/1603-program-payments-for accessed 11 October 2018). The lower value comes from the more recent Treasury data.

Complementary data on the value of state-level subsidies for renewables in the United States is not available. As an example, however, California estimates that its Renewable Portfolio Standards (RPS) had average costs slightly lower than their Market Price Referent, but slightly higher than the estimated fossil fuel procurement cost (CPUC, 2018). This is only part of the financial support that the State of California provides to support renewable deployment, though, as rebates have also been offered.

Systematic collection and analysis of state-level subsidies to renewables would be a useful addition to the understanding of overall subsidy levels in the United States, as many states provide support that will not be captured by a price-gap analysis. An examination of the net present value of all the states' RPS' against a counter-factual no-RPS policy for the period 2015–2050 yields net costs of around ±USD 31.7 billion, depending on input assumptions. The RPS is thus either competitive and reduces system costs, or it results in a net subsidy over the period 2015–2050 depending on the evolution of a wide range of electricity sector input variables (NREL and LBNL, 2016).

Federal tax preferences for biofuels in the United States were estimated at USD 1.8 billion in 2015, rising to USD 4.2 billion in 2016 (CBO, 2016 and CRS, 2017). In 2017 the tax preferences to biofuels were estimated to be around USD 2.6 billion.[24] Data for reference prices of fossil fuels, as well as ethanol and biodiesel prices, is available – allowing a price-gap analysis of the renewable fuel mandated level of subsidies.[25] In 2017, these added USD 11.5 billion to total subsidies for biofuels in the United States (USD 9.6 billion for ethanol and USD 2.0 billion for biodiesel), raising these to a total of USD 14.1 billion.

Elsewhere, India is rapidly expanding its deployment of solar and wind power generation technologies. At the end of 2017, the total cumulative deployment of wind power in India had reached 33 GW and that of solar PV 18 GW. Given India's low installed costs for wind power and the country's relatively late acceleration of solar PV deployment, after the significant cost reductions seen globally, total subsidies to renewable technologies in India were around USD 1 billion in 2015, increasing to USD 1.4 billion in 2016 and to USD 2.2 billion in 2017 (IISD, 2018). India's consumption of ethanol was around 2 billion litres in 2017, while for biodiesel it was in the order of 0.1 billion, with subsidies of perhaps USD 0.9 billion on a price-gap basis, although with a high degree of uncertainty.

Global renewable subsidy estimates for 2017

Table 4 represents a partial overview of global renewable energy subsidies in 2017. This section provides a more detailed discussion of the global renewable subsidies estimates of the IEA and IRENA, the only two institutions that have undertaken an analysis of global renewable energy subsidies to date.

The IEA has been discussing fossil fuel energy subsidies in its *World Energy Outlook* since 1999 (IEA, 1999), and started providing quantitative estimates of fossil fuel subsidies for a group of non-OECD countries in 2006, adding renewable energy subsidy estimates for biofuels (20 countries) and electricity (27 countries) from 2011 (IEA/OECD, 2011).

This report presents IRENA's first estimates of global renewable energy subsidies. The IRENA calculations are based on the WTO definition of subsidies to the energy sector and use a hybrid approach that captures tax expenditures (where possible), while using a price-gap analysis to capture other deployment policies, such as mandates or auctions.[26] Table 5 provides an overview of the approach, the key policies captured and uncertainties surrounding the final estimates, due to data constraints.

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[24] The tax credits for biodiesel, have however lapsed and do not apply beyond 2017.

[25] The United States Department of Energy – Energy Information Administration provides data on refiner's prices for resale, while Iowa State University provides data on weekly ethanol and biodiesel prices in different states.

[26] Where tax benefit policies are known to be planned to lapse, the analysis transitions to a price-gap approach to capture subsidy levels over time.

Table 5: Overview of IRENA coverage and calculation methods for country and regional estimates of renewable energy subsidies in 2017

COUNTRY/ REGION	POLICIES CAPTURED	CALCULATION METHOD	POLICIES NOT CAPTURED	UNCERTAINTIES
EU-28	Tax expenditures, direct transfers, and indirect transfers	Inventory method (for tax expenditures & direct transfers) & price-gap (for feed in premiums, FiTs, etc.)	Sub-national interventions, direct investments by development banks	Extent of sub-national subsidies
UNITED STATES	Federal tax expenditures, direct transfers, direct investment by federal government & indirect transfers	Inventory method (for tax expenditures & direct transfers) & price-gap (for feed in premiums, FiTs, etc.)	Sub-national interventions (with the exception of California), soft loans.	Extent of sub-national subsidies
CHINA	Indirect transfers	Price-gap		Extent of tax expenditures not captured in prices, soft loans and direct support costs not captured
JAPAN	Indirect transfers	Price-gap		Extent tax expenditures not captured in prices, soft loans and direct support costs are captured
INDIA	Indirect transfers	Price-gap		Extent tax expenditures not captured in prices, soft loans and direct support costs not captured
REST OF WORLD	Indirect transfers	Price-gap		Extent tax expenditures not captured in prices, soft loans and direct support costs not captured

The most significant gap in the analysis of renewable subsidies relates to the extent of the sub-national, or state-level, subsidies in the United States and the extent to which the price-gap approach accurately captures subsidies for renewable energy in non-OECD countries.

In the case of the United States, renewable subsidies are calculated by combining federal tax expenditure estimates (including direct transfers) with price-gap calculations, to estimate the balance of subsidies. This is done, however, using realised, after-subsidy market pricing for solar and wind projects, as this eliminates the uncertainty over what is the appropriate level for the cost of capital. For this to capture all subsidies, estimates of the state-level subsidy packages are required. This has been done for a sub-set of California policies, but the necessary compilation of the cost of some California state subsidies and other state support policies is not available. This results in the subsidy estimate for renewables in the United States in 2017 being an underestimate of the actual value, but to what extent is not clear. In 2010 or even 2012, this would have been a serious issue, but with the cost reductions experienced for solar and wind in the last decade, state-level support policy costs have undoubtedly reduced.[27]

The price-gap approach has the advantage of capturing the subsidy rate required to bridge the gap between a renewable technology and the incumbent. Its accuracy depends, however, on choosing the right reference price and in being able to accurately calculate the cost of energy or service delivered by the renewable technology. Neither of these tasks are trivial, particularly for renewables, given that site-specific factors can greatly impact costs. As a result, the price gap approach is at best an imperfect measure, but is a useful and efficient way of trying to capture policies that reduce the price required for a renewable project to be competitive.

The LCOE or cost of energy service delivered by renewables is derived from IRENA's REmap analysis of supply and demand-side technologies, and from the IRENA Renewable Cost Database of 17 000 renewable power generation projects and 9 000 auction/PPA results (IRENA, 2018, 2018c, and 2019b). The reference prices for fossil fuels are calculated based on the global and regional fossil fuel price assumptions in REmap, combined with equipment cost and performance data also from the REmap analysis (IRENA, 2018a and 2019a). Biofuels pricing data is taken from relevant national sources (*e.g.,* the United States Energy Information Administration) or from commercial pricing products (*e.g.,* Platts Weekly Global Ethanol Report).

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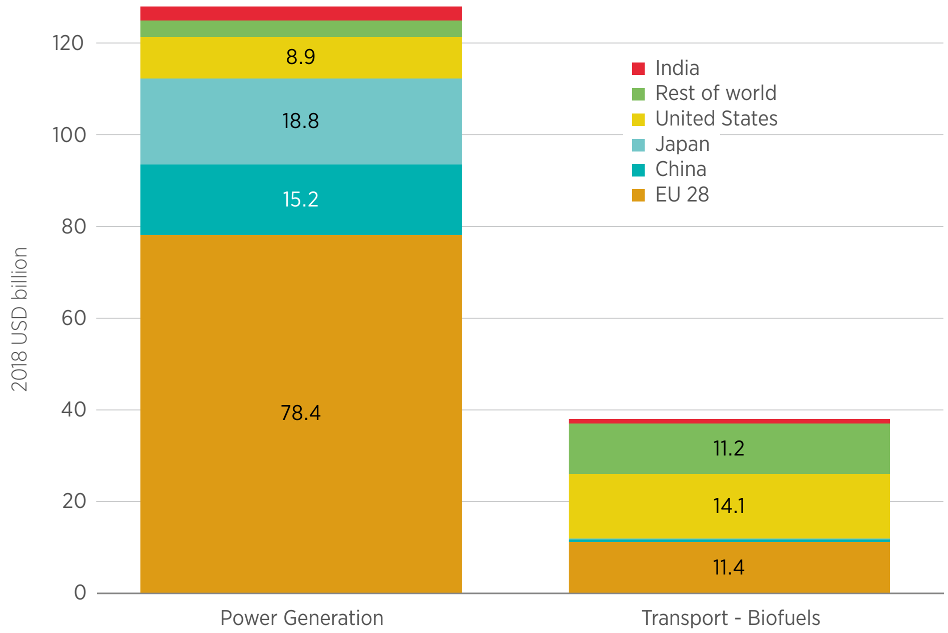
[27] For instance, by 2015 state-level rebates for solar PV systems had fallen from between USD 1 to USD 4/W by state in 2010 to between USD 0 to USD 0.8/W in 2015 (LBNL, 2018).

Figure 4: IRENA's global subsidy estimates for renewable power generation and biofuels by country/region, 2017



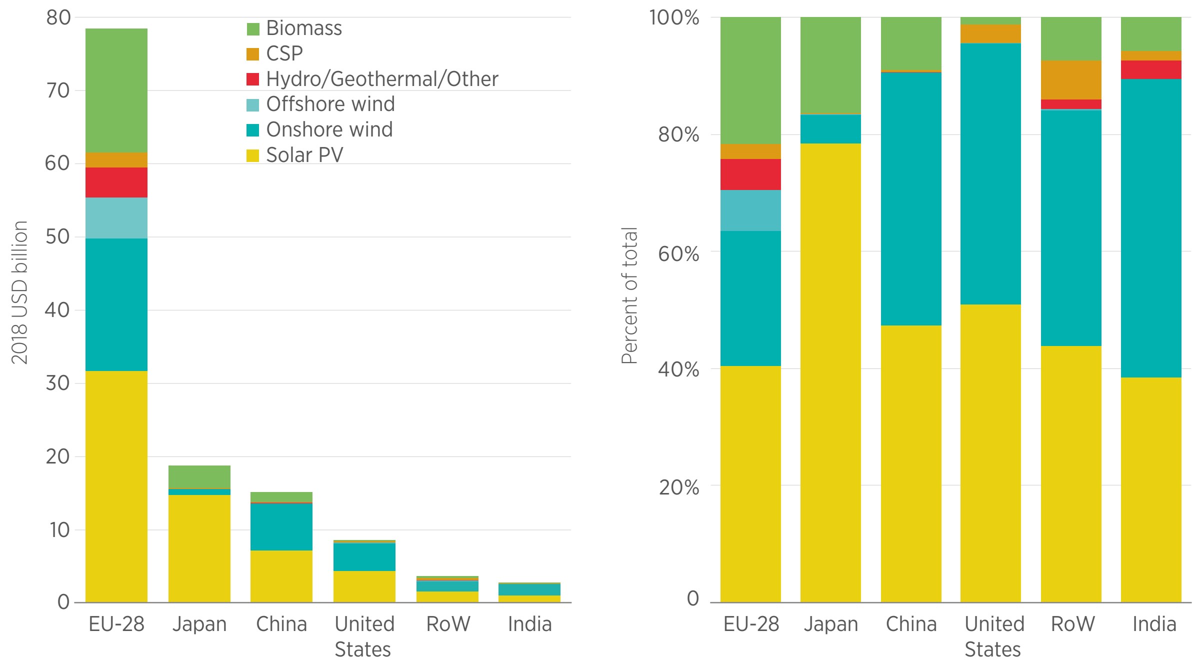
On this basis IRENA has estimated the supply-side subsidies for renewable energy to have been around USD 167 billion in 2017, with total subsidies to renewable power generation of around USD 128 billion in 2015 and transport sector subsidies of USD 38 billion (Figure 4).

The EU accounts for around 54 % (USD 90 billion) of total estimated renewable subsidies in 2017, followed by the United States with 14 % (USD 23.7 billion), Japan with 11% (USD 19 billion), China with 9 % (USD 15.6 billion), India with 2 % (USD 3.8 billion) and the rest of the world accounts for 9 % (USD 14.8 billion). Subsidies for renewable power generation are dominant in Japan (99 %), China (97 %), the EU (87 %) and India (76 %). Subsidies for biofuels dominate in the United States (62 %) and the rest of the world (75 %).

In 2017, the EU had the largest share of renewable energy subsidies, due to its USD 78 billion subsidy for power generation (Figure 5). This saw the EU account for 62 % of total renewable power generation subsidies in 2017, while Japan and China accounted for 15 % and 12 %, respectively. The EU accounted for an estimated 86 % of offshore wind power subsidies in 2017, 52 % of solar PV subsidies and 57 % of onshore wind subsidies.

Globally, solar PV is estimated to have received the largest share (48 %) of renewable power generation support, with USD 60.8 billion in 2017. The next largest recipient was onshore wind which received USD 31.6 billion (25 %), followed by biomass with USD 21.9 billion (17 %) and with offshore wind receiving USD 6.6 billion (5 %).

Figure 5: IRENA subsidy estimates for renewable power generation by country/region and technology, 2017

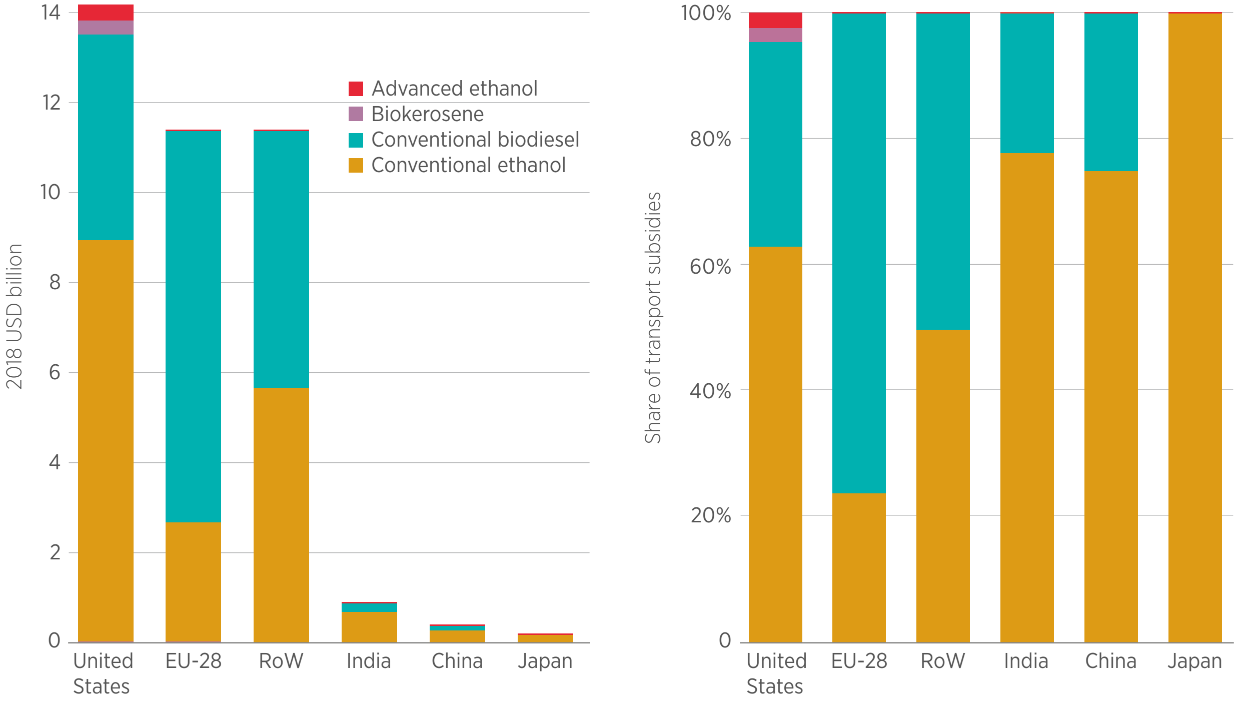


Note: RoW = Rest of World

Focusing on the renewable power generation technologies receiving support by country/region (Figure 5) reveals that in 2017, Japan had the highest share (77 %) of support going to solar PV (which is also the highest share for one technology). This reflects the overwhelming dominance of solar PV in recent deployment (IRENA, 2018b). Of the EU's USD 78 billion subsidies for renewable power generation in 2017, 40 % supported solar PV, 23 % supported onshore wind, 22 % went to bioenergy power generation, 7 % to offshore wind, 5 % to "hydropower, geothermal and others" and 3 % to CSP.

In China, India and the rest of the world, onshore wind received large shares of the total renewable power generation subsidy. Some 43 % of China's renewable power generation subsidies went to onshore wind in 2017, while the figure was 51% for India and 40% for the rest of the world. Subsidies to bioenergy for power generation are an important share of total renewable power generation subsidies in the EU and Japan, where they accounted for 22 % and 16 %, respectively, that year.

Figure 6: IRENA subsidy estimates for biofuels for transport by country/region and fuel, 2017



Note: RoW = Rest of World

Subsidies for biofuels are less concentrated in one region than those for power generation. The United States, with an estimated USD 14.1 billion in subsidies for biofuels, accounted for 37% of total biofuels subsidies in 2017. As the EU accounted for around 30% (USD 11.4 billion), the United States and the EU combined therefore accounted for around two-thirds of the total, while India accounted for 2% (USD 0.9 billion) and China and Japan for 1% each. The rest of the world accounted for 30% (USD 11.4 billion).

At USD 19 billion in 2017, subsidies for conventional biodiesel accounted for 50% of total global subsidies for biofuels, while conventional ethanol took just under USD 18 billion in subsidies, which accounts for just under half of the total. In 2017, estimated subsidies to advanced biofuels remained modest and accounted for less than 1% of the global total.

BOX 1: IRENA AND IEA RENEWABLE ENERGY SUBSIDIES COMPARED

Using a price-gap approach, the IEA estimates that global subsidies for renewable power generation technologies stood at USD 123 billion in 2015, which is around USD 13 billion higher than IRENA (IEA/OECD, 2016 and 2017a). The IEA estimates that solar and wind power combined accounted for around 80 % of all renewables subsidies in 2016, with China, Germany, Italy, Japan and the United States accounting for nearly two-thirds of the total.

IRENA, however, has arrived at different numbers for renewable power generation subsidies. Although IRENA has a lower estimate of subsidies for renewable power generation in 2015, there are countries/regions with numbers above and below the IEA value. For the EU, IRENA estimates total subsidies that are around USD 12.6 billion (20 %) higher in 2015 than the IEA's estimate.[28] Yet, IRENA's estimates for the United States are USD 10.3 billion lower, while those for China are USD 4.5 billion lower. IRENA's figures for India are USD 0.9 billion lower, while for the rest of the world, they are USD 6.7 billion lower.

The key difference in the treatment of the United States is that, for 2015, IRENA took the federal tax subsidy values and, after using PPA and auction results for solar and wind corrected for federal tax subsidies, undertook a price-gap analysis to capture state-level subsidies for utility-scale projects.[29] The value of subsidies for distributed solar PV systems may explain the lower IRENA total, however.[30]

The IEA estimated subsidies for biofuels in 2015 to have been USD 27 billion, taking total subsidies for renewables to USD 149 billion, that year.[31] IRENA's estimates of the global biofuel subsidy in 2015 are around USD 0.8 billion lower than the IEA subsidy value for that year. How IRENA's country estimates compare to IEA values is unclear, as no country or region breakdown is provided by the IEA for 2015, but the share of subsidies at a global level between conventional biodiesel and ethanol appears to be similar in both the IEA and IRENA data.[32]

Recent IEA analysis has provided less commentary on renewable energy subsidies, making comparisons for more recent years less comprehensive. For 2017, the IEA estimated subsidies to renewable power generation to be USD 146 billion (IEA/OECD, 2018), USD 18 billion higher than IRENA.

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[28] IRENAs numbers are in line, however, with the Council of European Regulators (CEER, 2017) and the European Commission estimates (Trinomics, 2018).

[29] With the exception of California, where the state-level solar PV rebate values have been included.

[30] In practical terms, this may be due to the difference in the subsidy value from net metering for distributed solar PV by the IEA. IRENA has calculated this based on the difference between average retail prices and average generation costs. If the IEA is estimating based on an LCOE for solar PV, then the difference between this and the IRENA estimate will be the missing state tax expenditures not captured by IRENA. The gap, however, remains large between the two estimates and without access to the IEA analysis, the reasons for this remain unquantifiable.

[31] The *World Energy Outlook 2017* (IEA, 2017) does *not app*ear to include an estimate of biofuels subsidies in 2016, unlike the previous year's edition.

[32] See Figure 11.24 from the World Energy Outlook 2016 (IEA, 2016).

2.2 FOSSIL-FUEL SUBSIDY LEVELS: DEFINITIONS AND CALCULATION METHODOLOGIES MATTER

The broad definitions of energy subsidies used by the EC, IEA, IMF, OECD, WB and WTO discussed in the previous sections have the advantage of spreading the net widely, encompassing a broad range of potential subsidies. There is also a practical challenge with these definitions, however, given the difficulty of cataloging and calculating subsidy levels in a comparable manner amid the wide range of ways that energy can be subsidised.

As previously discussed, there are three commonly used approaches to calculating subsidy levels (Sovacool, 2017). This leads to two key challenges that mean different energy sector subsidy numbers are sometimes not directly comparable. These challenges are:

- The broad scope of energy subsidy definitions means there is significant variation in what measures or policies are considered subsidies by different stakeholders.

- Calculation methodologies for assessing the absolute level of the subsidy programmes included in the analysis can yield different results and are sometimes not directly comparable.

These two sources of divergence in subsidy level results introduce uncertainty in the minds of policy makers and other stakeholders. They are also a drain on scarce analytical resources, when understanding the reasons for divergence between numbers is important. This can limit the usefulness of these definitions and their different energy subsidy estimates (IEA, *et al.*; 2010) and can distract from the vital efforts to reduce inefficient and harmful fossil-fuel subsidies, especially when slightly different country approaches make comparability between countries even more difficult.[33]

Agreeing on more detailed approaches that would yield comparable data can be difficult, however. Indeed, for the G20, defining subsidies has proved contentious, with the Group unable to reach agreement on a common definition. Instead, each country has chosen its own definition and is encouraged to undertake a self-assessment of their own subsidy levels (IEA, *et al.*; 2010). This has been accompanied by agreement on a peer-review process for each country's self-assessment analysis. As of 2019, though, only China, Germany, Indonesia, Italy, Mexico and the United States had completed an assessment of their inefficient fossil fuel energy subsidies.

Significant variations can arise from different definitions of what is a subsidy, the programmes or policies that are deemed to meet the criteria laid out in these definitions (or simply inferred from them) and the calculation methods. This has led to a wide range of estimates of fossil-fuel subsidies. The IMF, for example, calculated fossil-fuel subsidies of USD 4.9 trillion[34] (6.3% of global GDP) for 2015 and USD 5.3 trillion in 2017, based on an externalities approach that includes climate and health impacts (Coady *et al.*, 2019). In contrast, the IEA uses a price-gap approach and estimates fossil-fuel subsidies of USD 317 billion in 2015[35], USD 276 billion in 2016, USD 319 billion in 2017 and USD 427 billion in 2018 (IEA, 2019). The yearly variations are primarily driven by changes in fossil fuel prices, but are also due to some structural reforms (IEA, 2016, 2017a and 2019). The OECD, meanwhile, takes a different approach to the IEA, by examining the impact of individual programmes that support fossil fuels – from tax exemptions to financial support to fossil fuel companies to compensate for below market pricing. The OECD thus estimated fossil-fuel subsidies at USD 143 billion in 2017 (OECD, 2019). None of these three sources have the same geographical coverage or calculation methodology. Despite a wide range of estimates for environmentally harmful subsidies, their value is clearly very large, with the potential to distort individual markets significantly.

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[33] See Koplow, 2012 for a discussion of how G20 definitions vary slightly by country and can create gaps in comparability and overall coverage.

[34] Unless otherwise stated, all monetary values are expressed in real 2018 USD, that is to say taking into account the effect of inflation.

[35] For 2015, the IMF had higher estimates of "pre-tax" fossil-fuel subsidies – those that are broadly equivalent to the IEA definition of subsidies – of USD 341 billion, but some of the tax items captured by the IEA and OECD estimates are likely to appear in the IMF post-tax estimates, to some extent balancing this out.

Table 6: Comparison of the level and scope of comprehensive multi-country fossil-fuel subsidy estimates

	IEA	OECD	IMF	IEA/OECD
PRE-TAX SUBSIDY (USD BILLIONS/YEAR)	319	143	302	347
POST-TAX SUBSIDY (USD BILLIONS/YEAR)			5 039	
COUNTRIES COVERED	42 (predominantly non-OECD)	36 OECD countries plus Argentina, Brazil, Colombia, China, India, Indonesia, The Russian Federation & South Africa	191	67
FUELS COVERED	Coal, oil, gas and electricity support	Coal, oil and gas	Coal, oil, gas and electricity support	Coal, oil and gas
YEAR FOR SUBSIDY ESTIMATE	2017	2017	2017	2017

Source: Based on IEA, 2019; OECD, 2019; and Coady, , 2019

The OECD and IEA have also completed an analysis blending their subsidy inventories, but only for fossil fuels, therefore excluding the IEA estimates of fossil fuel subsidies in the electricity sector. With this, they have arrived at a more comprehensive value. Their estimate of the total subsidy from their two, different approaches, but avoiding overlaps, is USD 347 billion in 2017. This, however, still appears to be missing some tax expenditures, notably in the United States (CRS, 2017), and although the OECD has discussed how these might be calculated, subsidised loans, loan guarantees and other policies that reduce financing costs are still excluded. Crucially, however, the combined estimate does not include the IEA's subsidy estimates for electricity support that directly benefits fossil fuels, and thus they likely underestimate total subsidy levels. Table 6 presents a comparison of the scope and geographical coverage of these major subsidy estimates.

Methodology matters: Fossil-fuel subsidies in Germany

The latitude for interpretation in some subsidy definitions, in combination with the different possible calculation methodologies, can have a large impact on country-level subsidy estimates. Subsidy estimates must therefore be clearly documented to allow comparisons to be made.

The importance of this can be demonstrated by examining different subsidy estimates for fossil fuels in Germany. Germany is a useful example, because it is quite transparent in its subsidy inventory and there is a healthy debate about the impact of envrionmentally harmful subsidies supported by a number of other subsidy estimates from various non-governmental sources. Each of these estimates differ in material ways, but can be compared due to the effort that has been taken to separately report the individual value of individual policies. As a starting point, as part of their G20 engagement, Germany estimated their inefficient fossil-fuel subsidies at USD 9.9 billion in 2015 and 2016, rising to an estimated USD 11 billion in 2017 and USD 11.3 billion in 2018 (Bundesministerium der Finanzen, 2017). The calculations are based on an inventory of programme specific tax concessions and budgetary transfers. This differs significantly, however, from the OECD estimate of USD 5.5 billion, despite their very similar, at face value, inventory-based approach. The difference is largely due to the two datasets having different boundary conditions (*e. g.,* the German inventory only represents Federal subsidies, not those of the states), but most significantly, because of a number of differences in the programmes included in the two datasets.

The higher German federal government subsidy estimate stems from the inclusion of some direct budgetary transfers and the electricity tax relief omitted from the OECD data. The arguments for including or excluding some of these elements is sometimes discussed in the reports and sometimes a result of the boundaries set (*e. g.,* the German inventory only includes federal assistance). Adding the direct budgetary transfers from the OECD programme inventory at the state level to the Federal subsidy analysis would increase the fossil-fuel subsidy estimates to USD 11.9 billion in 2015 and USD 12.2 billion in 2016.

Yet, an analysis by the Overseas Development Institute (ODI) and Climate Action Network Europe (CAN Europe) arrives at a higher total when applying the WTO definition of energy subsidies (Gençsü and Zerzawy, 2017). Their analysis suggests total fossil-fuel subsidies in Germany averaged USD 41 billion per year for the period 2014–2016.[36] The difference comes partly from their definition and partly from methodological decisions.

In addition to the German self-reporting inventory, the ODI and CAN Europe estimate of fossil-fuel subsidies includes subsidy estimates for:

- The lower tax for diesel compared to petrol, which added around USD 9.8 billion in 2014-2016, while the tax relief for commercial aviation added USD 9.2 billion as inefficient subsidies in transport.[37]

- Tax exemptions for company cars, which are almost exclusively fossil-fuel powered, added another USD 4.4 billion.[38]

- The "Special Compensation" provision of the Renewable Energy Sources Act, which results in partial exemption of the surcharge for renewable energy for energy intensive industries. Between 2014 and 2016, this was worth an average USD 3.1 billion per year to qualifying companies.[39]

- The exemption from the renewable energy surcharge available to self-generating electricity producers, which represented a benefit of USD 1.5 billion per year, over the period 2015–2016.

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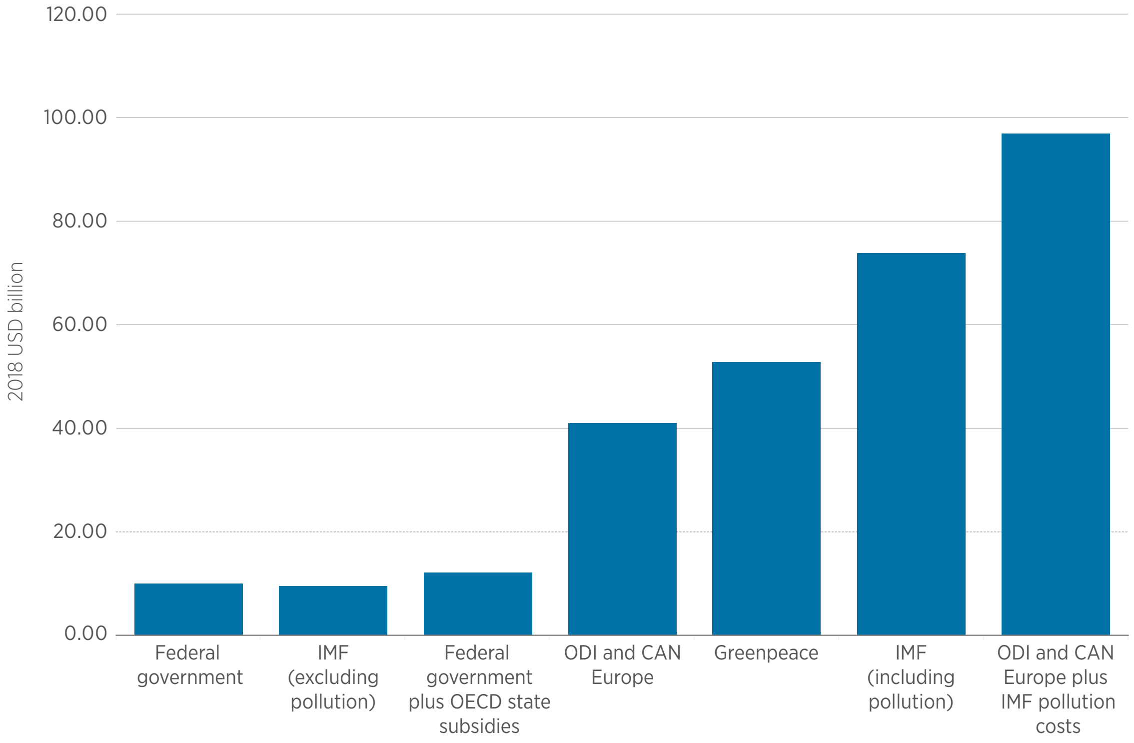
[36] They report USD 42.9 billion per year, including USD 2.9 billion per year for gross public finance volumes (93% of which was international) for fossil fuels. Normally, these are not all considered to be subsidies. The value of the subsidy would be in terms of better terms and conditions, longer tenures, reduced rates charged and the value of any loan guarantees relative to what the financing costs would have been, if sourced from the market.

[37] The German self-assessment identifies around USD 670 million in 2016 in tax relief to the domestic aviation. The ODI and CAN Europe estimates are taken from Zerzawy (2017) and include the tax exemption of aviation kerosene sold in Germany for international flights.

[38] The estimate for company car tax deductions is, however, for the year 2014 and is taken from Zerzawy, 2017. Although this could be seen as a transport or corporate subsidy, there are certainly grounds for including this figure, as the German federal self-assessment often states, "This measure is not targeted at particular fuels and, in so far as this is the case, does not intervene selectively in competition in the fuel market. In view of fossil fuels' large share of the market at present, they profit from this measure." This is to justify the inclusion of the measure as a subsidy.

[39] Interestingly, the G20 peer review report on Germany's self-assessment includes a total value for these two mechanisms, as well as one for CHP, placing the value of the two at EUR 5.293 billion in 2016 – although no value is given for these schemes in the self-assessment. This measure clearly provides a competitive boost to the industries that benefit, but it could be argued this is not a subsidy in the strictest sense of the term, as the survey acts like a tax.

Figure 7: Subsidies to fossil fuels in Germany from different sources, 2014/2016



Based on: Bundesministeriums der Finanzen, 2017; Coady, *et al.*, 2019; Gençsü and Zerzawy, 2017; OECD, 2019; Zerzawy, 2017.

This is not the largest estimated of fossil-fuel subsidies in Germany, however. Separate analysis conducted for Greenpeace identified the even higher 2016 level of USD 53 billion (Zerzawy, 2017). Most of the difference results from the inclusion of value added tax exemptions for international flights and tax deductions possible by individuals for travel to work by vehicle. Finally, the IMF estimates Germany's "pre-tax subsidies and forgone tax revenue" at USD 10.8 billion in 2015, similar to the German self-assessment, but with total subsidies of USD 74 billion. The vast majority of these subsidies come from externalities, with global warming accounting for USD 22 billion and local air pollution for USD 34 billion.

Germany and other countries have notably seen a healthy debate in the public and private sectors around the costs and benefits of energy subsidies. The German Federal Environment Agency (Umweltbundesamt) has also analysed environmentally harmful subsidies and with boundary conditions closer to those used by Greenpeace (Umweltbundesamt, 2016).

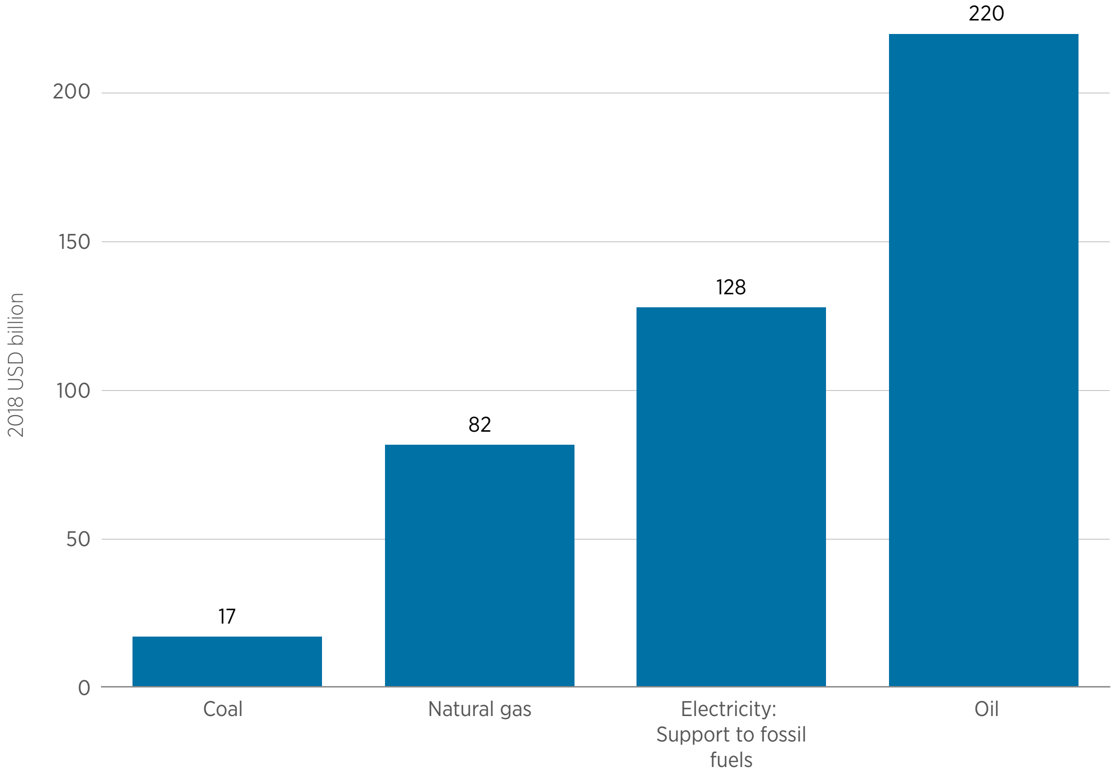
Combining the externality-based fossil-fuel subsidies from the IMF and the ODI and CAN Europe budgetary and taxation subsidies would yield a figure of around USD 97 billion in fossil-fuel subsidies in Germany in 2015/2016 (Figure 7). Notably, this could be considered a more complete estimate than any one of the individual studies, but it is around 30 % higher than the largest single study's estimate for Germany and almost ten times larger than Germany's self-assessed fossil fuel subsidy estimate. Germany is to be commended for its transparency, as this kind of comparison is not possible for most countries. This comparison does serve, however, to highlight the challenges to the wider debate within society about the importance of reducing harmful subsidies in the energy sector when subsidy estimates vary widely.

2.3 TOTAL FOSSIL-FUEL SUBSIDIES

IRENA has calculated an estimate of global total fossil-fuel subsidies in 2017[40] by examining the IEA and OECD fossil-fuel subsidy estimates and supplementing them with additional tax subsidies estimates, available in the public domain but omitted from the OECD database. This analysis includes the value of fossil-fuel subsidies coming from the underpricing of electricity where, in the IEA analysis, the benefit accrues predominantly to fossil fuels.

Similarly to the OECD, IRENA looked at the subsidy programmes catalogued in the OECD inventory of fossil-fuel subsidies and compared them to the IEA price-gap estimates (OECD, 2019) for the country overlaps (*e.g.,* Argentina, Colombia, China, India, Indonesia, Republic of Korea, Mexico and the Russian Federation). The highest value by fuel is chosen in these cases from the two sources.[41] The combined fossil-fuel subsidy inventory therefore covers 67 countries and includes estimates of fossil-fuel subsidies for coal, oil, natural gas and electricity support measures. This results in a more comprehensive estimate of total fossil-fuel subsidies globally, excluding negative externalities, but is still likely to be missing some important implicit fossil-fuel subsidies (*e.g.,* through bankruptcy laws, weak enforcement of environmental regulations, environmental remediation liabilities transferred to the taxpayer, etc.).

Figure 8: Total global fossil-fuel subsidies by fuel/energy carrier, 2017



Source: IRENA, based on OECD, 2019 and IEA/OECD, 2019.

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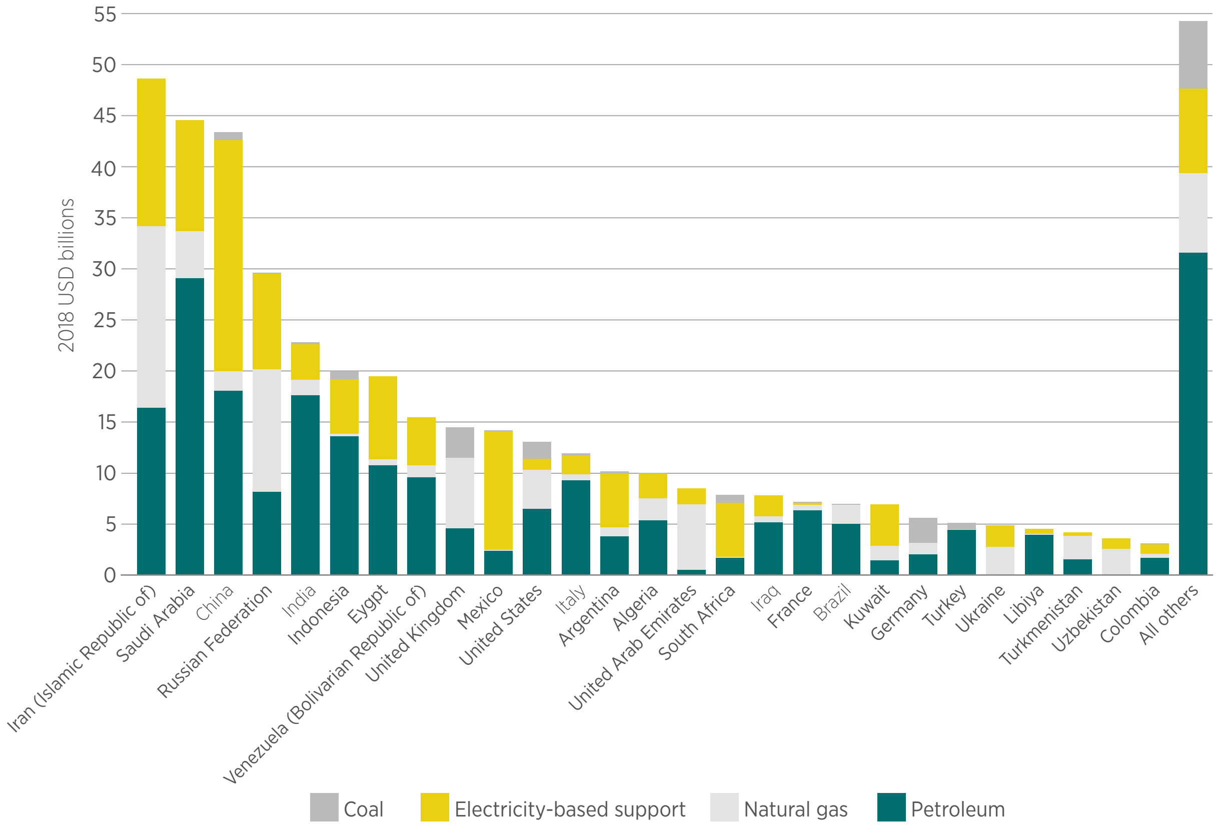
[40] For the rest of the presentation of subsidy values, data is presented using 2017 as a base year in the main body of the text to align with IRENAs *Global Energy Transformation: A Roadmap to 2050* analysis.

[41] This requires the removal of individual programmes in the OECD inventory, by fuel, that are related to electricity sector support and impact consumer or producer prices. This is necessary to avoid double counting, given that the IEA price-gap total for all subsidies to fossil fuels via electricity support should already capture these price-affecting measures in the OECD inventory.

Figure 8 presents the results of this analysis. The total direct fossil-fuel subsidies in 2017 were estimated to be around USD 447 billion,[42] with subsidies to petroleum products dominating, at USD 220 billion, followed by electricity-based support to fossil fuels at USD 128 billion. Subsidies to natural gas and coal in 2017 were estimated to be USD 82 billion and USD 17 billion, respectively.

Figure 9 presents these fossil-fuel subsidy levels by country and fuel. Of the top 10 countries by fossil-fuel subsidy in 2017, 47% of their total fossil-fuel subsidies were for petroleum fuels. The top five countries for fossil-fuel subsidies in 2017 had total subsidies of USD 189 billion, or 42% of the global total. The top ten countries accounted for 61% (USD 272 billion) of total fossil-fuel subsidies in 2017.

Figure 9: Fossil-fuel subsidies by country and fuel/energy carrier, 2017



Source: IRENA, based on OECD, 2019 and IEA/OECD, 2019.

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[42] The estimate for 2016 falls to USD 394 billion because of oil and gas price declines that year that reduced total petroleum subsidies by USD 39.7 billion and natural gas subsidies by USD 25.4 billion. Conversely, between 2015 and 2016, electricity-based support to fossil fuels grew by USD 8.5 billion.

2.4 NUCLEAR POWER SUBSIDIES

Comprehensive global estimates of the subsidies received by the nuclear power sector are currently missing from the total energy sector subsidies debate for incumbent technologies. Indeed, if the situation in terms of cataloguing global fossil-fuel subsidies still leaves much to be desired, the state of knowledge about nuclear is even worse. In part, this is because many nuclear power subsidies are more obscure and indirect than for renewables and fossil fuels and the absence of direct cash transfers makes it harder to estimate their value (Koplow, 2011; Blyth, 2013; and Koplow, 2017).

In the United States, the Congressional Research Service provides irregular updates of the estimated[43] federal tax subsidies to the energy sector (CRS, 2017), but these are very narrowly defined to include only federal tax preferences. In 2016, the federal tax benefits for nuclear were therefore estimated at USD 200 million. More detailed analysis (Koplow, 2011) that aimed to catalogue all of the means by which nuclear power benefits financially from public policy arrived at much higher values, however. Table 7 presents the categories of subsidy that were examined.

Calculating the monetary value of many of these subsidy sources is challenging, leading to a wide range of subsidy estimates and, in some cases, an incomplete picture. This is because not enough data is available to even attempt an estimate for some subsidy sources. The analysis for the United States (Koplow, 2011) reveals, however, that subsidies to the nuclear power sector in the US may have historically been very high and that ongoing subsidies to operating nuclear reactors probably remain significant. The analysis suggests that support for operating reactors in the United States in 2011 could have ranged from USD 0.008 to USD 0.064/kWh. The largest contributors to these values are the benefit derived from liability caps, which are generally very low for individual nuclear power plants relative to the potential economic losses from accidents,[44] and the direct and indirect subsidies for decommissioning and waste management.

In the EU, the EC has estimated the total subsidies to exisitng nuclear from government interventions related to decomissioning and waste management at USD 6 billion per year in 2016. This is not an estimate of the total subsidies to exisitng nuclear in the EU, but further work is planned to broaden the scope of the analysis to include the subsidy implicit in current liability caps (Trinomics, 2018).

For new-build nuclear, the absence of a comprehensive inventory of nuclear subsidies remains a challenge to calculation, although in some cases the main source of subsidies is clearer. In the United Kingdom, the Hinkley Point C reactors will receive around USD 0.13/kWh indexed against inflation for 35 years,[45] compared to average wholesale prices in Q1 2018 of around USD 0.07/kWh. Assuming a capacity factor of 85%, this would imply an annual subsidy of around USD 1.4 billion per year, subject to change as the wholesale price varies, just for the electricity produced by Hinkley Point C. At the same time, the project will receive loan guarantees and a government deal on limiting waste handling costs.

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[43] These are estimates of the tax subsidies, not actual lost revenue, as provided to the Congressional Research Service by the Joint Committee on Taxation. There is a significant lag in the availability of the actual values for the subsidy cost in terms of lost revenue, as there is a significant delay in the availability of line item summaries of tax forms that reveal what was actually claimed. For instance, in late 2018, the latest line item estimates for corporate tax returns related to the 2013 fiscal year.

[44] For instance, individual plants have liability coverage of just USD 5 million in Brazil, while in Germany that figure is USD 2.78 billion (OECD/NEA, 2018). The United States has the largest insurance scheme, with each plant required to have USD 450 million in private insurance, with a pool of coverage (second tier) available from accessing retrospective premium payments after an accident, if the costs exceed this level. The retrospective premiums can be levied from existing nuclear plants for a seven year period, raising the accident coverage in the United States to around USD 12.8 billion (with potentially another 5% of the second tier pool total coverage, raising the total to USD 13.4 billion).

[45] See https://www.lowcarboncontracts.uk/cfds/hinkley-point-c accessed 5 March 2019.

Table 7: Subsidy categories and sources for nuclear power

CATEGORY OF SUBSIDY	SUBSIDY SOURCE
FACTORS OF PRODUCTION (LABOUR, CAPITAL & LAND)	• Loan guarantees • Accelerated depreciation • Subsidised borrowing costs for public utilities • Cost recovery prior to project completion • Property tax abatements
INTERMEDIATE INPUTS	• Fuel costs • Uranium enrichment • Cooling water
OUTPUT-LINKED SUPPORT	• Production tax credits • Above market contracts for differences
SECURITY AND RISK MANAGEMENT	• Liability caps • Subsidised insurance • Proliferation
DECOMMISSIONING AND WASTE MANAGEMENT	• Nuclear waste management liabilities taken over by government • Plant decommissioning costs (effective government underwriting of fund shortfalls).

Source: Based on Koplow, 2011.

Comparable detailed analysis is not available for other countries, but if the figures for the United States are representative of the global experience, then subsidies to existing nuclear power in 2015 could have ranged from USD 21 billion to USD 169 billion.[46] This is an area where further additional research is warranted, given the absence of comparable cross-country data on subsidies in the nuclear power sector. In the analysis in the final section of this report, a subsidy figure of USD 21 billion for 2017 is assumed. This must be considered a placeholder, with the possibility that much higher values are realistic, but it is an acknowledgement that a value of zero is not a realistic assumption.

Summary

As is apparent, the process of deciding on a definition of subsidies, arriving at a methodology for their calculation and the decisions made about what measures qualify as a subsidy, or an “inefficient” subsidy in the case of the G20, can have a significant impact on what subsidy levels look like.

The methodological issues and challenges of calculating energy subsidies on a comparable basis, should, however, not detract from the efforts to progressively phase-out environmentally harmful subsidies that countries have signed up to in different forums.

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[46] The values could, however, be much larger. For example, an assessment of the likely economic costs of a nuclear accident in Germany based on existing studies suggests that a serious nuclear accident could incur costs in the order of trillions of dollars. Translating this into an insurance premium would yield a cost of at least USD 0.21/kWh, if premiums are assumed to go into a reserve fund over a 100-year duration (Versicherungsforen Leipzig, 2011).

This section has highlighted two important points:

- The calculation of energy sector subsidies can be a challenge. In some cases, subsidies are clear, transparent and well documented (*e. g.,* direct financial support to an industry), while in other cases, the mechanism by which subsidies are transmitted can make subsidy estimation difficult (*e. g.,* tax exemptions where applicability varies). In some cases, they are sufficiently opaque or difficult to calculate, that estimates can vary widely (*e. g.,* accident liability caps for nuclear power).

- In many cases, there is a subjective element in the categorisation and calculation of energy subsidies that is often framed by the goals to which the subsidy calculation will be put, as well as the perspectives of individuals or organisations that are involved in the definition and calculation.

This complexity and the conditions under which subsidy estimates are calculated contribute to the reasons why international standards for energy subsidy management have yet to be adopted (Jones & Steenblick, 2010). The duplication of effort that these varying approaches to energy sector subsidies and calculations create is unfortunate, as is the uncertainty around subsidy levels and their incidence that arise as a result, with these factors detracting from efforts to reform harmful energy sector subsidies. The World Bank (Kojima and Koplow, 2015) has already highlighted that:

"Multi-country calculations on fossil-fuel subsidies carried out in recent years have helped illuminate the strengths and limitations of different approaches and their usefulness. Efforts by various organisations to collect data and make them publicly available on a regular basis have facilitated subsidy measurement as well as benchmarking of pricing policies with one's peers. At the same time, the pursuit of different approaches has sown confusion among non-specialists."

Further progress clearly needs to be made in harmonising both definitions and accounting policies for subsidy calculations, as well as in their extension to the widest geographical coverage possible and a comprehensive coverage of all energy sector subsidies across fuels and technologies, on a comparable basis. In this respect, the ongoing efforts by the international community to advance common methodologies and metrics is to be applauded. Ongoing work to create a methodology for fossil-fuel subsidy metrics as part of Goal 12 of the Sustainable Development Goals (Sustainable Production and Consumption) by the London Group on Environmental Accounting - part of the UN System of Environmental Economic Accounting (UN SEEA) - could provide an important benchmark in this respect (UNEP, OECD and IISD, 2019).

3 TOTAL ENERGY SUBSIDIES IN 2017 AND THEIR EVOLUTION TO 2050: THE REMAP CASE

This section brings together the IRENA estimates for subsidies for renewables and the adjusted combined IEA/OECD fossil-fuel subsidies, as outlined in the previous sections. Combining the estimates of fossil fuel, renewable and nuclear power subsidies yields an estimate of total direct energy sector subsidies for 2017 of USD 634 billion (Figure 10). The total is dominated by the subsidies received by fossil fuels, which account for 70 % (USD 447 billion). Subsidies to renewable power generation technologies account for around 20 % of total energy sector subsidies (USD 128 billion), biofuels for 6 % (USD 38 billion) and nuclear for at least 3 % (USD 21 billion), but potentially more, as already noted.

Crucially, the value of USD 634 billion for 2017 is, in all probability, an underestimate of total energy sector subsidies. Coverage of sub-national incentives for both fossil fuel and renewables subsidies is likely not comprehensive, while the subsidy value added here for nuclear is a placeholder value, showing what the lowest level of subsidies might look like for existing nuclear. Thus, although this estimate of the total energy sector subsidies provides a useful order of magnitude estimate to help inform policy makers, further work is clearly needed to arrive at a more definitive value for total energy sector subsidies.

Figure 10: Total energy sector subsidies by fuel/source, 2017

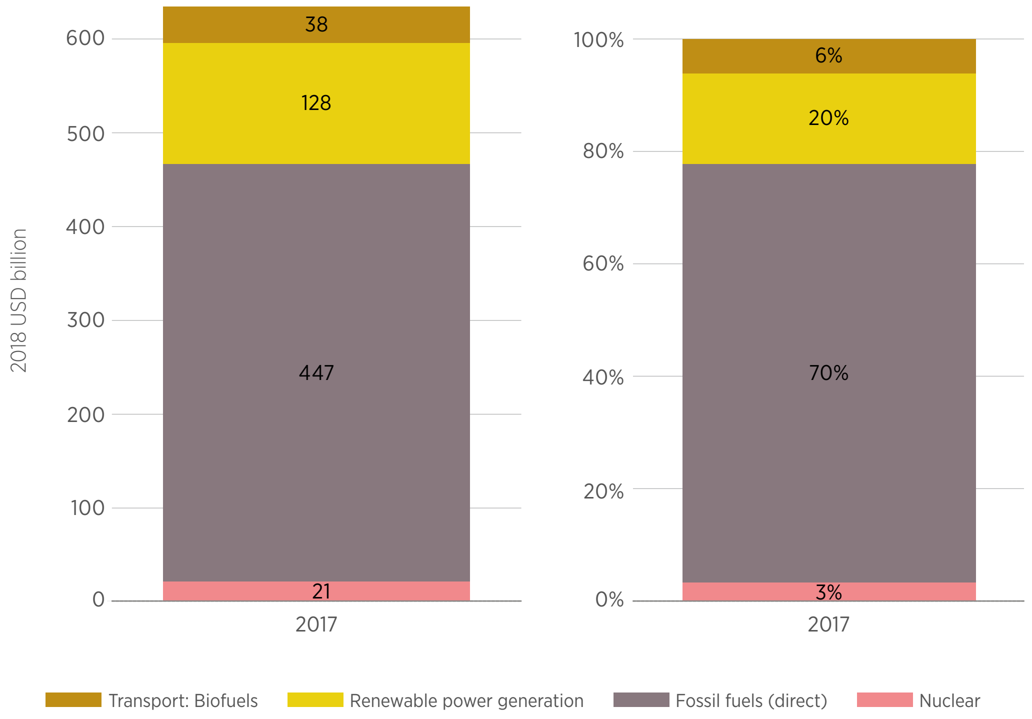
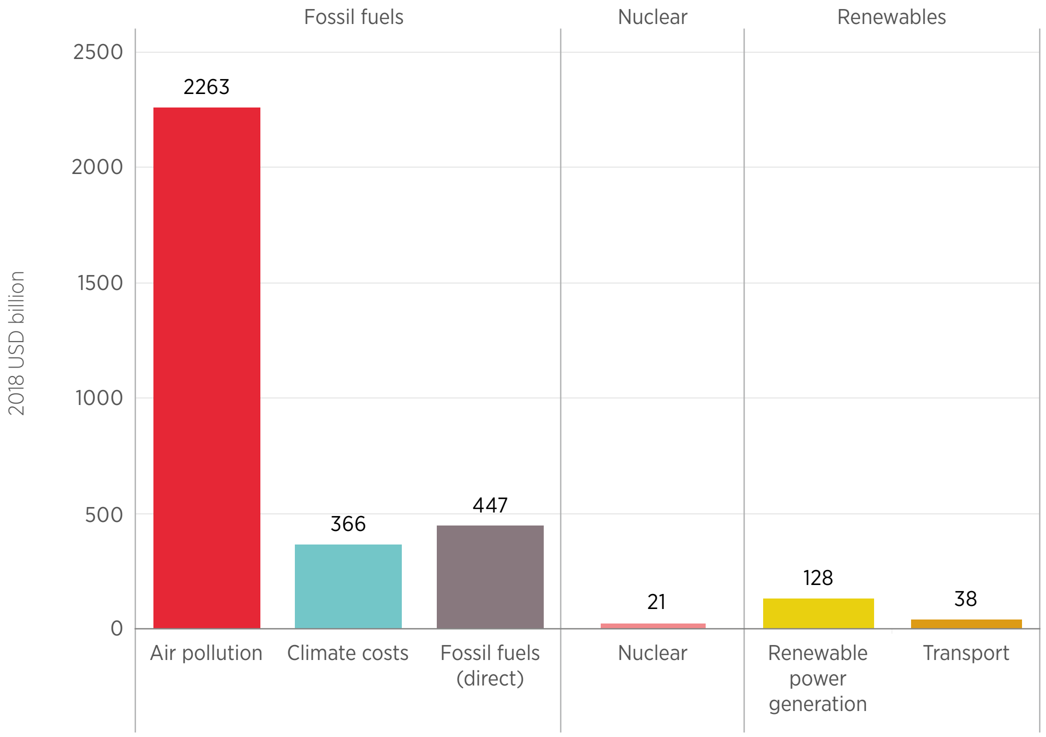


Figure 11: Total energy sector subsidies by fuel/source and the climate and health costs, 2017



Source: IRENA analysis and IRENA, 2019a.

These numbers, notably, exclude the climate and health costs of the local air pollutants emitted by fossil fuels. The IRENA analysis to 2050 includes estimates of these unpriced externalities, however (IRENA, 2019a). In 2017, the costs of outdoor air pollution from fossil fuels were estimated to be in the order of USD 2.3 trillion in 2017,[47] with climate change costs adding around USD 370 billion[48] (Figure 11). The inclusion of these costs, if added to total energy sector subsidies, would raise total energy sector subsidies to USD 3.1 trillion, or 6.9 times larger than the pre-tax subsidy estimate alone (Figure 11). The costs of unpriced externalities and the direct subsidies for fossil fuels (USD 3.1 trillion) exceed subsidies for renewable energy by a factor of sixteen.

3.1 TOTAL ENERGY SECTOR SUBSIDIES TO 2050

IRENA has used the analysis in the REmap Case (IRENA, 2019a), in conjunction with the current estimates of total energy sector subsidies in 2017, to analyse how total energy sector subsidies out to 2050 might evolve if the world is to stay on track to achieve the Paris Agreement climate goal of restricting global warming to 2 °C or less.

The REmap Case projections include data on energy production and consumption for the entire energy sector globally and examine in detail the different energy service demands (*e. g.*, space and water heating in buildings, process energy needs in industry, etc)

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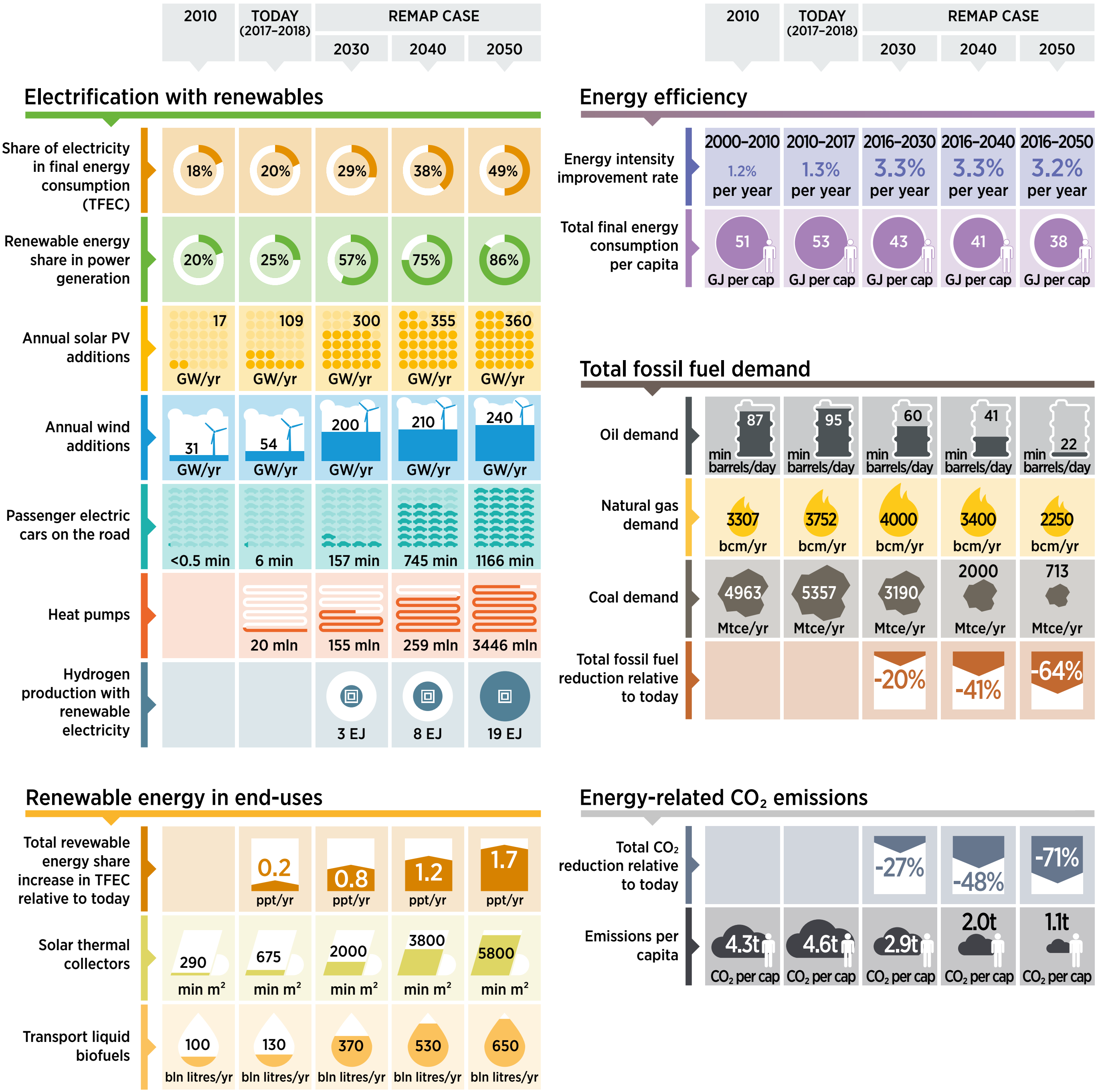
[47] This is a central estimate of the value in 2015. It is lower than the IMF estimate for 2015 of around USD 2.8 trillion.

[48] There is significant uncertainty about the actual level of costs stemming from both climate change and local air pollution. This calculation assumes a value of USD 11/tonne of CO_2 and is based on the lower bound of the societal cost of carbon (Interagency Working Group on Social Cost of Greenhouse Gases, 2016).

Figure 12: Key energy sector indicators in the REmap Case to 2050



	2010	TODAY (2017–2018)	REMAP CASE 2030	REMAP CASE 2040	REMAP CASE 2050
Electrification with renewables					
Share of electricity in final energy consumption (TFEC)	18%	20%	29%	38%	49%
Renewable energy share in power generation	20%	25%	57%	75%	86%
Annual solar PV additions	17 GW/yr	109 GW/yr	300 GW/yr	355 GW/yr	360 GW/yr
Annual wind additions	31 GW/yr	54 GW/yr	200 GW/yr	210 GW/yr	240 GW/yr
Passenger electric cars on the road	<0.5 mln	6 mln	157 mln	745 mln	1166 mln
Heat pumps		20 mln	155 mln	259 mln	3446 mln
Hydrogen production with renewable electricity			3 EJ	8 EJ	19 EJ
Renewable energy in end-uses					
Total revewable energy share increase in TFEC relative to today		0.2 ppt/yr	0.8 ppt/yr	1.2 ppt/yr	1.7 ppt/yr
Solar thermal collectors	290 mln m²	675 mln m²	2000 mln m²	3800 mln m²	5800 mln m²
Transport liquid biofuels	100 bln litres/yr	130 bln litres/yr	370 bln litres/yr	530 bln litres/yr	650 bln litres/yr

	2010	TODAY (2017–2018)	REMAP CASE 2030	REMAP CASE 2040	REMAP CASE 2050
Energy efficiency					
Energy intensity improvement rate	2000–2010 1.2% per year	2010–2017 1.3% per year	2016–2030 3.3% per year	2016–2040 3.3% per year	2016–2050 3.2% per year
Total final energy consumption per capita	51 GJ per cap	53 GJ per cap	43 GJ per cap	41 GJ per cap	38 GJ per cap
Total fossil fuel demand					
Oil demand	87 mln barrels/day	95 mln barrels/day	60 mln barrels/day	41 mln barrels/day	22 mln barrels/day
Natural gas demand	3307 bcm/yr	3752 bcm/yr	4000 bcm/yr	3400 bcm/yr	2250 bcm/yr
Coal demand	4963 Mtce/yr	5357 Mtce/yr	3190 Mtce/yr	2000 Mtce/yr	713 Mtce/yr
Total fossil fuel reduction relative to today			-20%	-41%	-64%
Energy-related CO_2 emissions					
Total CO_2 reduction relative to today			-27%	-48%	-71%
Emissions per capita	4.3t CO_2 per cap	4.6t CO_2 per cap	2.9t CO_2 per cap	2.0t CO_2 per cap	1.1t CO_2 per cap

and modes for transportation (*e. g.*, light-duty vehicles, road and rail freight, and aviation) in the end-use sectors. Importantly for this analysis, the REmap Case also includes data on the stock of energy sector assets (including electricity generating technologies, but also end-use technologies), that is needed in order to assess gross capacity additions per year.

Figure 12 provides an overview of the evolution of some of the key energy sector indicators out to 2050 in the REmap Case that are part of the underlying drivers of the evolution in energy sector subsidies outlined below. Further details of the IRENA REmap tool can be found in various IRENA publications (IRENA, 2014; IRENA, 2017; IRENA, 2018a; and IRENA, 2019a).

Although subsidies may provide only one metric by which the transition can be measured, policy makers could benefit from understanding how subsidy needs in the energy sector could evolve over the period until 2050.

Marginal abatement cost curves and changes in overall energy system costs help policy makers understand, in broad terms, relative abatement costs and overall abatement costs respectively. They do not, however, reveal to policy makers the likely incidence of the overall burden. The order of magnitude of the evolution of subsidies in different sectors and over time must of course be balanced by the benefits unlocked, but examining this issue does provide useful information to policy makers about the challenges ahead. As deployment of specific technology solutions grow, costs fall and their performance improves. Thus, in individual sectors, subsidy needs will start to plateau and then fall, but sectors that are otherwise difficult to decarbonise will still need to be addressed. There will thus be a rebalancing through time of subsidies from sectors and applications/end-uses where deployment, economies of scale and innovation have already unlocked competitive solutions, to sectors where this process is only just beginning.

For the analysis to 2050 in this report, subsidy programmes that have sunset clauses, or that are only available for fixed periods, are assumed to expire when currently anticipated to end. Programmes and policies that are open-ended that lead to subsidies in the energy sector are assumed to continue. The exception to this is that countries are assumed to phase out their fossil fuel subsidies over time, as these would be inconsistent with their climate goals. Per unit of energy subsidies for fossil fuels are assumed to decline rapidly to 2030 and thereafter decline at a slower rate to 2050.[49]

Some small level of fossil-fuel subsidy is assumed to remain in 2050. As a result, in the REmap case, the decline in the level of fossil-fuel subsidies in the energy sector is being driven by the reduction in the rate of subsidy to fossil-fuels *and* the reduction in fossil fuel consumption over time, as the energy sector transitions to a sustainable future. New fossil-fuel subsidies will however emerge, even in the REmap case, concentrated where carbon capture and storage (CCS) in some energy intensive industrial sectors is required to address process emissions.

The evolution of subsidies for renewable energy is based on detailed input assumptions for the technology costs contained within the REmap Case, when compared to fossil fuels, combined with the deployment outputs of the REmap case (see IRENA, 2019a). These input assumptions vary by technology, year and country and are multiplied by the deployment rates in the REmap Case to calculate subsidy levels based on the amount of energy consumed and/or the stock of energy using or generating equipment, if subsidies are available to investments. Given the uncertainty over the long-run trajectory of tax expenditures, by 2030 the renewable subsidy analysis transitions to a price-gap methodology for all renewable technologies and end-use sectors.[50] Given the uncertainty around the level of subsidies to nuclear, the analysis assumes that the minimum value of USD 0.008/kWh identified for the United States is applied to the output of entire stock of existing nuclear reactors and to the output of new reactors built out to 2050 to replace retiring reactors.[51]

The present technical paper, notably, adheres to quite a strict definition of subsidies. This is essentially the additional incremental LCOE for the renewable, efficiency or other decarbonisation solution for that year, netted out at the level of an individual solution

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[49] The average subsidy rate (USD/MJ) is assumed to be reduced to 20 % of 2017 levels for coal, oil and natural gas by 2030, and by 50 % for fossil-fuel support, channelled through the electricity sector. By 2050, coal subsidy rates are assumed to be eliminated and those for oil, natural gas and fossil-fuels through electricity support are at 5 % of their 2015 levels.

[50] One implication of this is that subsidy levels in 2030 and 2050 are effectively assumed to be set at efficient levels for the level of deployment based on perfect information. In reality, support programmes are rarely 100 % efficient, as there are administrative costs, while policies may not be designed efficiently. The subsidy levels estimated here exclude these future administrative costs and any other policy inefficiencies.

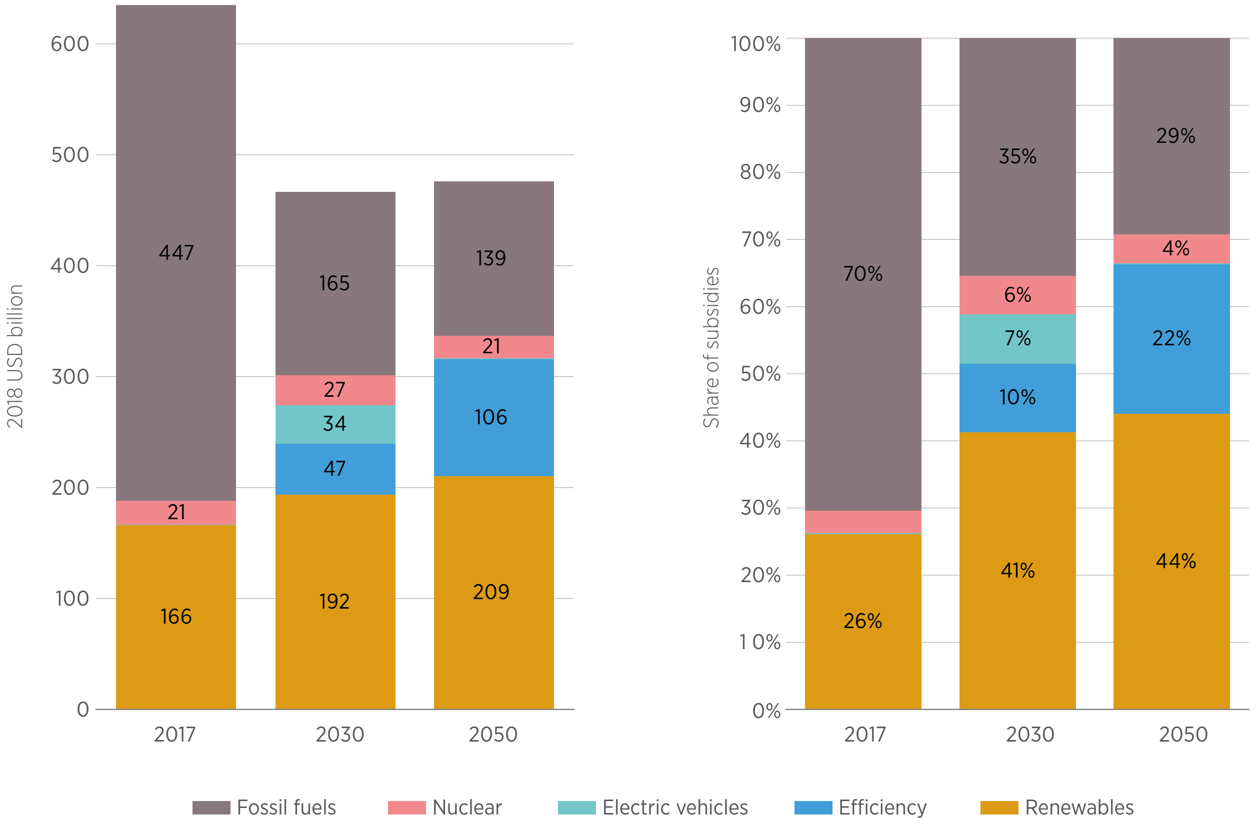
[51] Each kWh of nuclear generation is therefore assumed to receive USD 0.008/kWh in subsidies (Koplow, 2011). The actual level of subsidies out to 2050 for nuclear will be higher than this, given subsidies to new nuclear construction will be required in most markets. This requires additional analysis, though. Future work by IRENA will look at incorporating better estimates of the ongoing subsidies to existing nuclear power and, crucially, estimates for the subsidies for new-build that are not covered here.

by country. Higher levels of aggregation would see lower subsidy estimates, as would the presence of a price for CO_2. If increased efforts are made to price the externalities generated by fossil fuels in the form of local and global pollutant emissions, then subsidy levels would be lower than presented here. With a more cost-reflective pricing of externalities, energy markets and agents in end-use sectors would then increasingly be factoring in the costs of these externalities into their investment and operational decisions.

Between 2017 and 2030, total, annual energy sector subsidies in the REmap Case are projected to decline from USD 634 billion to USD 466 billion, a 27% reduction (Figure 13). Compared to what may occur, however, under the Reference Case – where oil demand in 2030 is around a tenth higher than in 2017 and natural gas demand is around 50% higher, with little progress in the reduction of per unit subsidies to fossil fuels – this represents a reduction of USD 341 billion, or 42%. The REmap Case sees a rebalancing of the distribution of energy sector subsidies away from fossil fuels and towards renewables and energy efficiency. By 2050, total energy sector subsidies have fallen to USD 475 billion per year (25% lower than in 2017), which is USD 390 billion (45%) lower than they might have been in the Reference Case.

In 2017 the total energy sector subsidies of USD 634 billion represented around 0.8% of global Gross Domestic Product (GDP). Given that global GDP is projected to grow by around 58% between 2017 and 2030 at the same time that total energy sector subsidies are expected to decline to USD 466 billion in the REmap case, subsidies decline to 0.4% of global GDP in 2030. By 2050, global GDP is projected to be

Figure 13: Energy sector subsidies by source excluding climate and health costs in the REmap Case, 2015, 2030 and 2050



almost three times higher than in 2017, which would imply that the total energy sector subsidies would fall to 0.2% of global GDP.

Direct subsidies for fossil fuels fall from USD 447 billion in 2017 to USD 165 billion in 2030 in the REmap Case, as per unit subsidies are reduced and coal demand is around 40% lower than in 2017 and oil demand around 27% lower. The share of fossil fuels in total energy sector subsidies falls from around 70% in 2017 to 35% in 2030. In that year, USD 76 billion of the total fossil-fuel subsidies is required to support CCS in industrial sectors, predominantly in order to address process emissions. Around half of the subsidies to CCS are concentrated in the iron and steel sector, 32% in the cement sector and 13% in the chemicals sector. By 2050, fossil-fuel subsidies have fallen to USD 139 billion (29% of the total in 2050), with support for CCS dominating at USD 126 billion, or 27% of total energy sector subsidies, and 91% of the remaining fossil-fuel subsidies.

As the deployment of renewable energy accelerates, notably in the end-use sectors, the total subsidies for renewables grow and reach USD 192 billion in 2030. This is driven by an increase in subsidies for renewable energy in transport, industry and buildings, as subsidies for renewable power generation fall. Total annual subsidies for renewable energy increase by around 10% between 2030 and 2050 as deployment of renewable solutions in the hard to decarbonise industry and transport sectors increase. Energy efficiency is typically a cost-effective solution to reduce energy consumption and emissions. However, as ever more stringent reductions in fossil fuel use are required, more expensive energy efficiency options become an attractive solution to minimising overall costs in the energy transition. As a result, subsidies to energy efficiency over and above the Reference Case, notably in industry, start to rise and reach USD 106 billion per year in 2050. The drivers for this evolution in total energy sector subsidy levels are outlined in more detail below.

Power generation subsidy costs will decline rapidly in many countries in the coming 10–15 years, as cost-competitiveness has already been achieved in many countries, or will be in the near future (IRENA, 2018c and 2019b). As a result, subsidies for renewable power generation will start to decline by 2030 (Figure 14). Total subsidies for renewable power generation fall from USD 128 billion in 2017 to USD 53 billion by 2030, despite the rapid growth in renewable power generation deployment. Between 2017 and 2030, the total installed capacity of solar PV increases from around 223 GW to around 3 150 GW, that of onshore wind from around 496 GW to around 2 300 GW, offshore wind from 19 GW to 216 GW and CSP from 5 GW to 76 GW.

This reduction in subsidies for renewable power generation by 2030 is driven by most new deployment in the period out to 2030 not requiring subsidies, and indeed, even reducing electricity costs, as well as the expiration of an increasing share of the relatively expensive support given to renewables (notably in Europe) from pre-2015 deployment. For countries with long-duration support policies, or very low fossil fuel costs, the peak in power generation support is usually in the late 2020s.[52]

Japan is the only country examined where overall subsidies to the power generation sector increase up to 2030. This is due to three factors: Japan deploys a relatively high share of solar PV in the REmap Case; solar PV costs in Japan remain higher than in virtually all other markets, except California (IRENA, 2019b); and deployment is concentrated in the more expensive residential and commercial solar PV sectors, that are proportionately more expensive than utility-scale projects (IRENA, 2019b).

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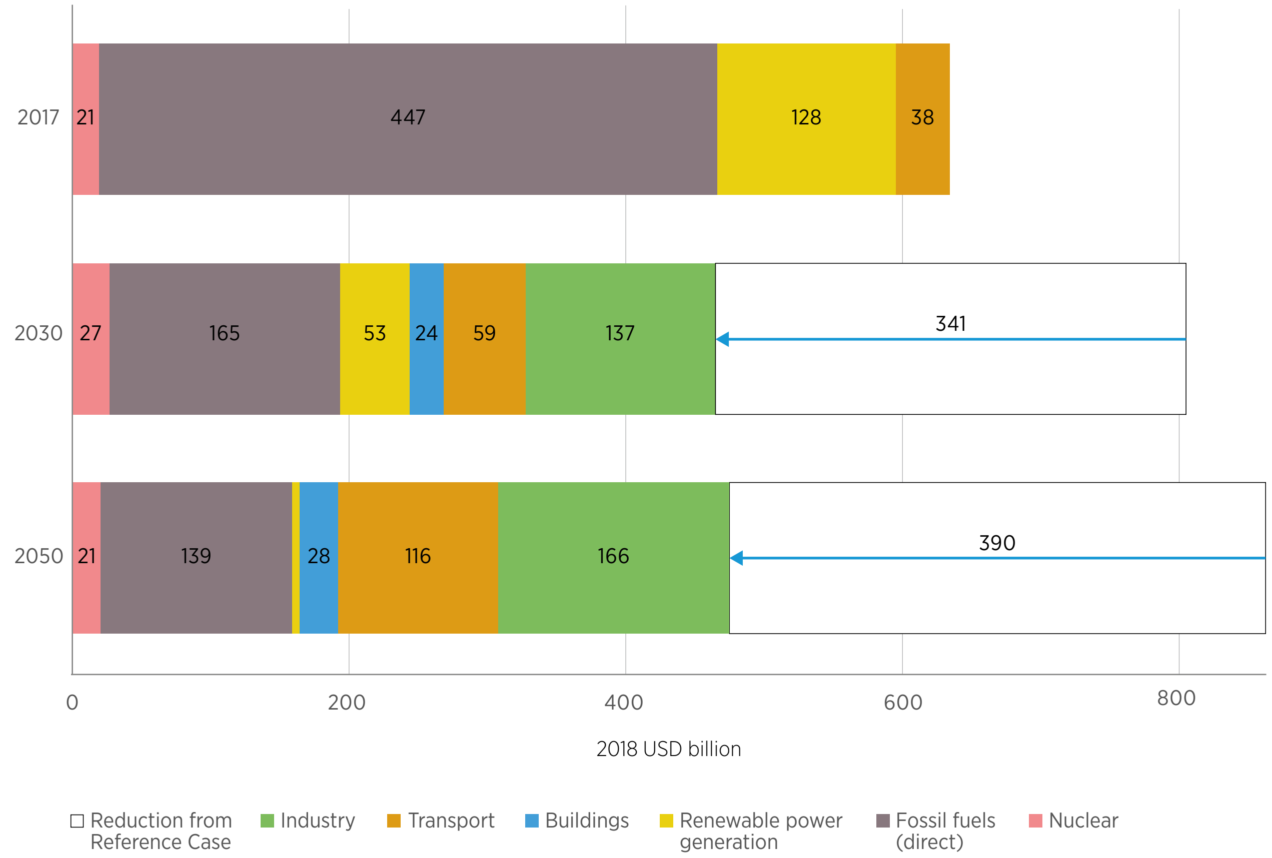
[52] See for example, Agora Energiewende (2016), “Projected EEG Costs up to 2035” for a detailed analysis of the renewable electricity surcharge evolution in Germany.

Figure 14: Energy sector subsidies by fuel or sector excluding climate and health costs in the REmap case, 2017, 2030 and 2050



Note: The subsidy totals in this figure to Industry, Transport and Buildings include subsidies from the deployment of renewable and energy efficiency measures in those sectors.

Globally, by 2050, solar PV capacity reaches over 8 500 GW, onshore wind surpasses 5 000 GW, offshore wind surpasses 1 000 GW and CSP 300 GW. With continued technology improvements, large and ongoing economies of scale, and highly competitive manufacturing and global supply chains, renewable power generation technologies are commercially competitive without subsidies. Any remaining legacy subsidies have by then expired or been compensated for by lower costs than incumbent technologies from new and replacement investment in renewable power. No net subsidies will therefore be paid out directly to renewable power generation in 2050.

As significant efforts are made beyond the electricity sector, the growth of subsidies relative to the Reference Case for the end-use sectors also grows. The subsidies needed over and above the Reference Case[53] in the Industry and Buildings end-uses for energy efficiency and renewables are USD 137 billion and USD 24 billion, respectively in 2030, before growing to USD 166 billion and USD 28 billion, respectively in 2050.

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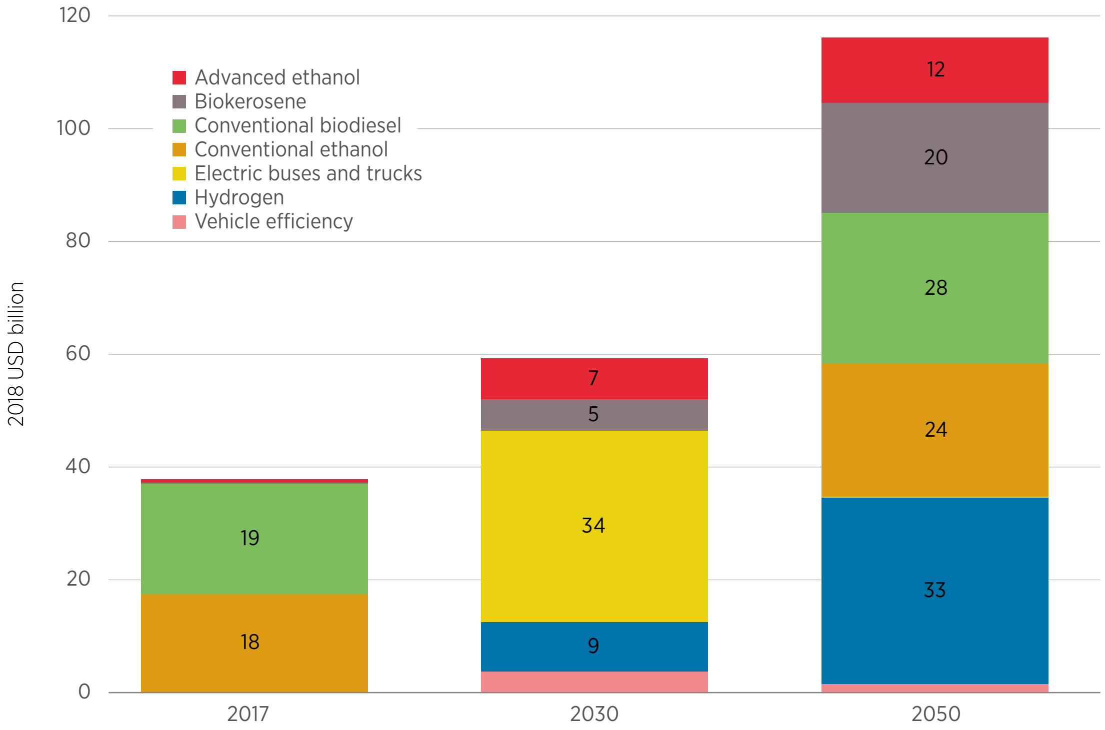
[53] The IRENA analysis effectively assumes that the energy efficiency actions taken in the Reference Case are economically attractive at the time they are implemented, so no subsidy is required. The highly variable level of detail in country's Nationally Determined Contributions (which heavily influence the Reference Case) mean that the REmap analysis has not been able to evaluate to what extent this assumption is correct. The subsidy values here for Industry and Buildings should therefore be considered minimum expected values, as there may be some subsidy elements in the Reference Case trajectory.

Figure 15: Transport sector energy subsidies by fuel/source excluding climate and health costs in the REmap Case, 2017, 2030 and 2050



In the transport sector, subsidies increase from USD 38 billion in 2017 to USD 59 billion by 2030 (Figure 15). By then, higher oil prices will make conventional biofuels largely economic. With the necessity of growing sustainable biofuels use, subsidies for advanced biofuels from lignocellulosic feedstocks for ethanol and the use of biokerosene for the aviation sector enter the early phases of commercial deployment. By 2030, advanced ethanol use requires around USD 7 billion in support and biokerosene around USD 5 billion. Hydrogen derived from renewable electricity also starts to contribute to decarbonising freight transport, with around 540 PJ requiring subsidies of around USD 9 billion in 2030. While in the short-to-medium haul freight segment, electric trucks in the smaller and medium-size categories will start to contribute in larger numbers. These small- and medium-size trucks will initially be more expensive than their fossil fuel counterparts in terms of total cost of ownership and account for USD 34 billion in subsidies by 2030. Efforts to improve vehicle efficiency also start to rely on more expensive options, raising costs by that date.

In the transport sector, by 2050, subsidy needs double compared to 2030, reaching around USD 120 billion. Several factors will drive this development between 2030 and 2050:

- Oil prices will fall between 2030 and 2050, as oil demand is reduced, from USD 85/barrel to just over USD 60/barrel. This increases the economic hurdle rate for alternatives to fossil fuels.

- Deployment of renewable fuels increase, with significant growth in hydrogen and advanced ethanol use for freight transport and biokerosene for aviation occurring.

- Production costs for renewable fuels fall. This is driven by learning-by-doing, economies of scale, efficiency improvements in production, and cost declines for inputs (notably for renewable electricity for hydrogen).

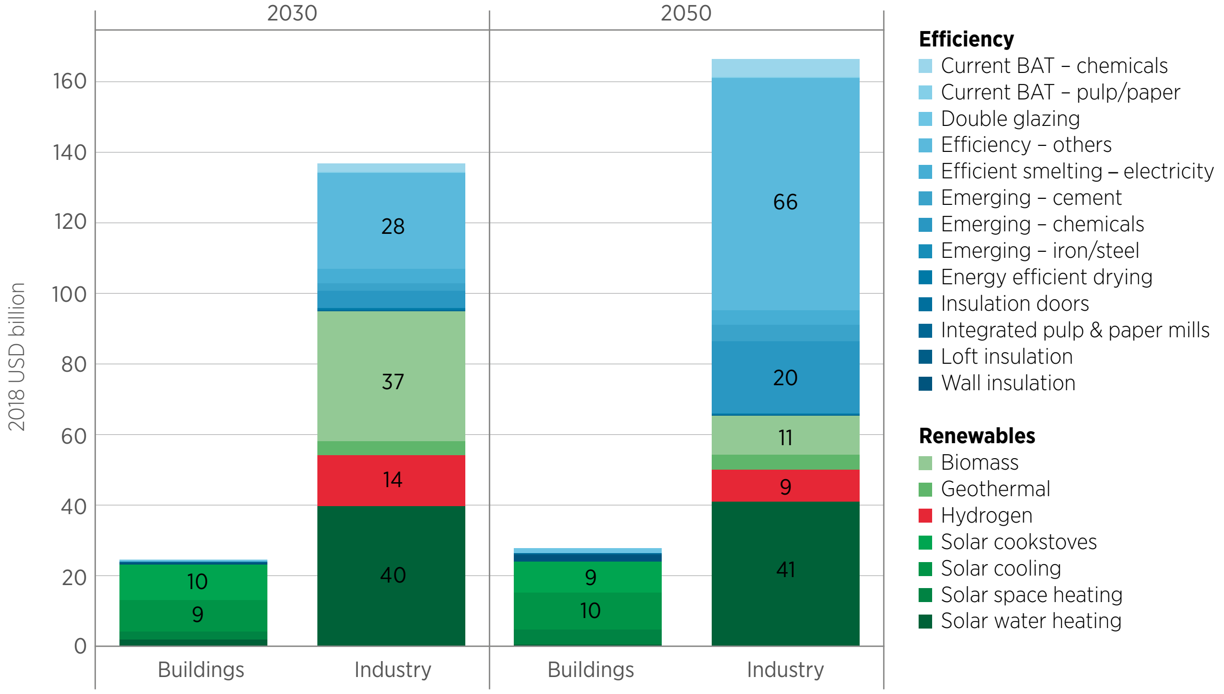
While the growth in deployment of advanced biofuels and hydrogen sees subsidies rise, a major offset for these renewable fuels compared to 2030 is their production cost decline. For example, hydrogen becomes the largest source of subsidies in the transport sector as hydrogen use rises eight-fold between 2030 and 2050 (to over 4 400 PJ in 2050), but subsidies grow less than four-fold, to USD 33 billion, or 29% of the total of USD 116 billion. The lower oil price in 2050 results in subsidies being needed for the production of some conventional ethanol and biodiesel. For conventional ethanol, this is predominantly in regions with higher feedstock costs (*e.g.,* the OECD), whereas the subsidy need is more generalised for conventional biodiesel. Advanced ethanol use rises to over 2 000 PJ in 2050 and biokerosene to over 2 600 PJ, resulting in subsidies of USD 12 billion and USD 20 billion, respectively, in 2050.

In the Industry and Buildings sectors, a three-pronged strategy is at work. In these, increased electrification combines with energy efficiency measures and renewable options – notably for heat – in order to reduce emissions. The subsidies required for these solutions vary significantly between the two sectors, however.

In Buildings, many of the energy efficiency options are economic and do not require subsidies, although there remain significant barriers to their uptake. As a result, 95% of the subsidies required in the Buildings sector in 2030 and 87% in 2050 come from the deployment of renewable sources for heating and cooling, notably solar.

In Industry, the energy efficiency measures deployed become progressively more expensive, out to 2050, and the subsidies required to make these measures economic increases from USD 42 billion in 2030 to USD 101 billion in 2050 (Figure 16), with the largest component (USD 66 billion) coming from a myriad of energy efficiency measures in the less energy intensive industrial sub-sectors (*e.g.,* light manufacturing, food, textiles, ceramics, etc.).

Figure 16: Industry and Buildings sectors: Energy subsidies by fuel/source excluding climate and health costs in the REmap Case, 2030 and 2050



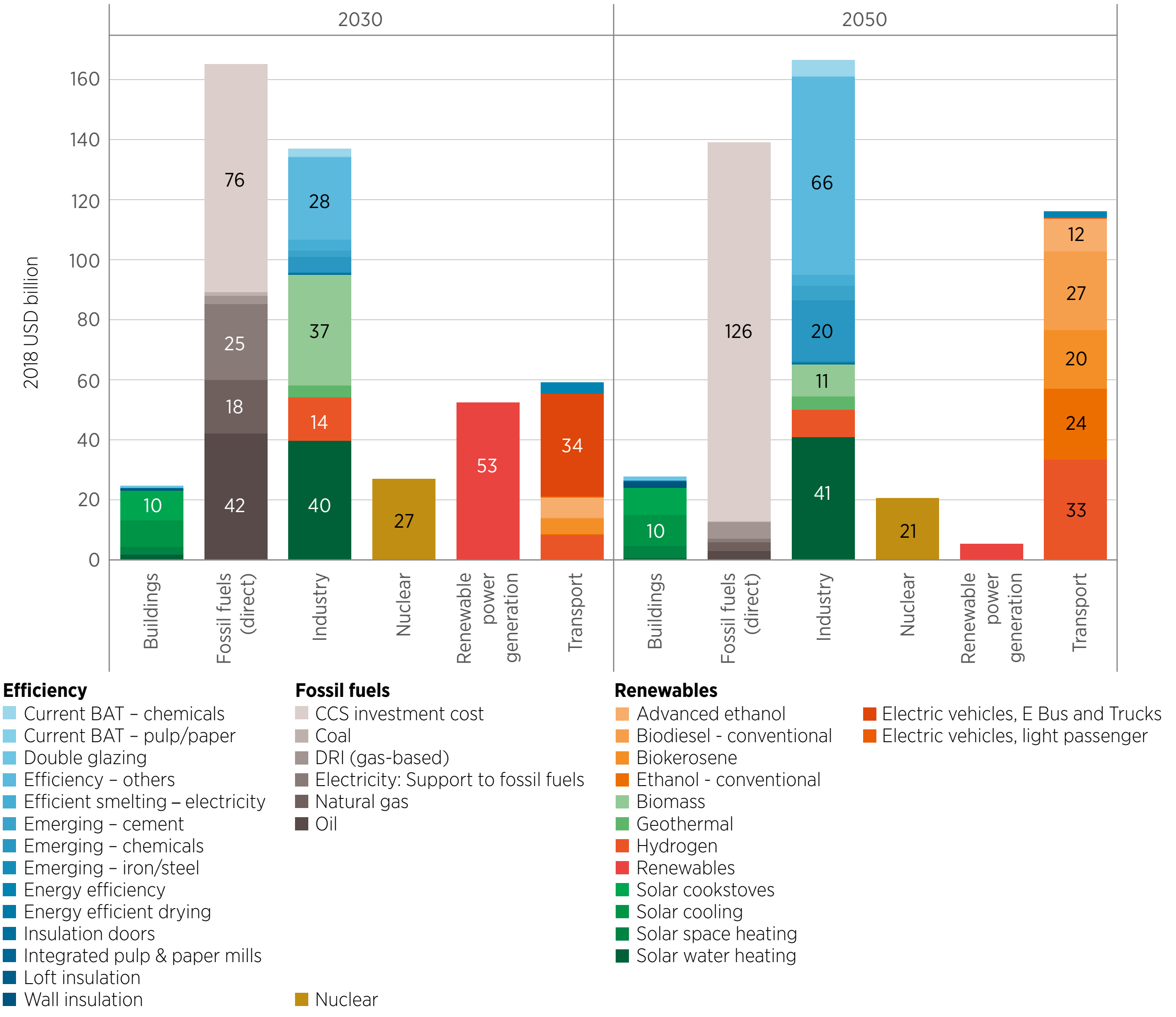
Note: BAT = Best available technology

In the REmap Case, between now and 2050, the composition of energy sector subsidies (excluding climate and air pollution) continues to shift towards the end-use sectors, as these more difficult and expensive to transform end-uses are addressed.

In 2030, subsidies to fossil fuels remain the largest single component of total energy sector subsidies (Figure 17), but subsidy levels in industry become the second largest source, as increased energy efficiency measures and switching to renewable solutions is required.

By 2050, the remaining fossil-fuel subsidies predominantly support CCS in industry, with this becoming the second largest source of subsidy needs. The decarbonisation effort in that sector becomes significantly more expensive by 2050, as emissions reductions become increasingly expensive to unlock. At the same time, despite cost reductions, the expense of providing renewable fuels for transport at significant shares of demand (beyond the light-duty vehicle sector) in the long-distance road, sea and air segments begins to increase subsidy levels for the transport sector overall.

Figure 17: Energy sector subsidies by fuel/source and sector/end-use (excluding climate and health costs) in the REmap Case, 2030 and 2050



The subsidies required for the solutions deployed in the REmap Case result in significant economic benefits to the economy, given the reductions in externalities that accrue (IRENA, 2019a). By 2030, the REmap Case results in reduced outdoor pollution and climate costs of USD 620 billion to USD 2 160 billion relative to the Reference case (Figure 18).[54] By 2050, as fossil fuel use is reduced more substantially, the annual benefit increases to between USD 2.5 trillion and USD 6.3 trillion. The savings dwarf the ongoing energy sector subsidies to renewables and energy efficiency. In 2050, the USD 316 billion in subsidies to renewable and energy efficiency save eight to twenty times more in reduced externalities.

Figure 18: Total energy sector subsidies compared to climate and health cost savings in the REmap Case, 2015, 2030 and 2050

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[54] The cost range for 2030 is from USD 17-80/tonne of CO_2, rising to USD 50-110/tonne of CO_2 in 2050.

CONCLUSIONS

As countries around the world grapple with the realities of how to deliver on the goals of the Paris Agreement, the multi-facetted nature of the energy transition is increasingly apparent. Alongside the need to cut energy-related CO_2 emissions, the transition by countries around the world to high shares of renewables and energy efficiency is being driven by increasingly inter-linked economic, environmental and social-development policy goals. One area that deserves more attention in this respect is the role of energy subsidies, and more specifically the role of environmentally beneficial or harmful subsidy types, in the steadily expanding energy transition.

Subsidies to fossil fuels prove especially damaging, because they exacerbate the already serious issue of fossil fuels negative externalities (*e.g.*, health and climate costs resulting from fossil-fuel combustion) which are rarely, if ever, fully priced.

The present technical paper finds that:

- Relatively few estimates exist at the global level for environmentally harmful subsidies to fossil fuels, and even fewer for support to renewable energy.

- Many more studies are available at the country or regional levels. These mainly address fossil-fuel subsidy levels – and to a lesser extent support to renewables. Still, data comparability remains a challenge.

- No commonly agreed definition exists for energy sector subsidies. Instead, different organisations and forums have adopted different definitions, which can result in confusion among interested stakeholders over subsidy data.

- Accounting methods for energy sector subsidies also vary widely. In some cases, this reflects the constraints of data availability. In other cases, the boundaries of what constitutes a subsidy can have a meaningful impact, even with functionally equivalent subsidy definitions.

- Significant gaps remain in the coverage of estimated subsidy levels in the energy sector. This is because subsidies that may be difficult to estimate in the first place (*e.g.*, exemptions from pollution regulations, lax of enforcement of end-of life environmental clean-up regulations, insufficient nuclear liability insurance, etc.) are often excluded from official subsidy estimates.

- The author of this technical paper is not aware of any previous, systematic effort made to assess the total value of energy sector subsidies. Yet for the reasons mentioned above, even the estimates in this technical paper are likely to underestimate total energy sector subsidies.

Much of the analysis of energy sector subsidies has, in the past, focused primarily on fossil fuels. Furthermore, relatively few institutions examining global subsidies to particular fuels or technologies have used a consistent methodology and accounting approach in their calculations. This makes comparisons of subsidy levels between fuels and technologies from different sources problematic.

To provide greater clarity about all kinds of energy subsidies, greater emphasis could be placed on:

- Fostering dialogue among academics, research institutes, think-tanks and international organisations on definitional and accounting methodologies for energy-subsidy analysis.

- Identifying opportunities to establish common subsidy definitions and accounting methodologies, or at least some key components of these, to increase the comparability of different subsidy estimates.

- Improving the analysis of global subsidy levels for the entire energy sector, not just fossil fuels.

- Determining whether greater co-ordination of analysis at the country and regional levels could also yield better, more systematic global estimates, rooted in the detailed insights of stakeholders with knowledge of conditions "on the ground".

Progress on these issues would reduce the uncertainty around the comparability of subsidy estimates and potentially help to avoid unnecessary duplications of effort. This would facilitate a more robust, fact-based debate around the reform of environmentally harmful energy subsidies.

This technical paper has presented a range of estimates for energy sector subsidy levels in one recent year, 2017. These include a new estimate of the environmentally harmful subsidies provided directly to fossil fuels in that year, based on data from the IEA and OECD for 2017, supplemented with IRENA's analysis of massive indirect subsidies to fossil fuels through the under-pricing of negative externalities (*e.g.*, costs of climate damage, health costs from pollution). This technical paper also attempts to provide a comprehensive first estimate of total energy sector subsidies in 2017.

Accordingly, it finds that:

- Direct environmentally harmful subsidies to fossil fuels in 2017 amounted to at least USD 447 billion.

- Indirect subsidies to fossil fuels stemming from their negative externalities in 2017 were in the order of at least USD 2.6 trillion and possibly much higher. This total comprised an estimated USD 2 263 billion for increased health costs due to outdoor pollution caused by fossil-fuel combustion, combined with USD 366 billion for climate costs.

- Support to renewable energy, at USD 166 billion in 2017, was almost 19 times smaller than the environmentally harmful, both direct and indirect, subsidies to fossil fuels in the same year.

- Support to renewable power generation, reaching USD 128 billion in 2017, retained the largest portion of renewable energy subsidies, while support for biofuels accounted for USD 38 billion.

- Robust global estimates are unavailable for subsidies to nuclear power, but such subsidies are likely to have reached at least USD 21 billion globally in 2017.

- Total direct subsidies for all energy sources reached at least USD 634 billion in 2017, with 70% of those being for fossil fuels.

This technical paper combines the prior analysis in IRENA's REmap Case (IRENA, 2019a) with the best possible estimates of total energy sector subsidies in 2017. Viewing these estimates in conjunction with various paths for energy sector development helps to see how total energy sector subsidies might evolve over the next three decades (until 2050), particularly if the world follows the necessary path to achieve the Paris Agreement climate goal of restricting global warming to well below 2°C.

In the envisaged transformation of the world's energy system, the analysis finds:

- Total energy subsidies would fall sharply – from USD 634 billion annually in 2017 to USD 466 billion in 2030 and USD 475 billion in 2050.

- Phasing out environmentally harmful subsidies means that the remaining subsidies for fossil fuels (USD 139 billion in 2050) would be dominated by subsidies to CCS in industrial applications, which would also capture process emissions.

- Support for renewables would increase from USD 166 billion annually in 2017 to USD 192 billion in 2030 and USD 209 billion in 2050. Support to renewable power generation falls to USD 53 billion in 2030 – a 60% decline between 2017 and 2030.

- Subsidies to energy efficiency and renewables are set to grow in hard-to-decarbonise transport and industry sectors.

- Subsidies to renewable-based transport solutions would grow to USD 116 billion in 2050, dominated (70%) by biofuels, with most of the balance made up by renewable-based "green hydrogen".

- The support required to decarbonise industry rises to USD 166 billion in 2050, amid rising costs to reduce industrial emissions, given the need for deeper cuts that necessitate costlier energy efficiency options and renewable heat to ensure abatement.

- The REmap Case results in the costs associated with outdoor pollution and climate damage by 2050 *falling* by between USD 2.5 billion and USD 6.3 trillion dollars per year compared to what they otherwise would have been. The benefits, just from these two sources, therefore, would greatly exceed the annual subsidies needed to achieve the transition.

The analysis in this technical paper, however, leaves further questions to be answered for a comprehensive understanding of energy sector subsidies. Future work could attempt to refine and expand upon certain aspects of the data and analysis.

Potential areas for further research include:

- Expansion of the coverage of environmentally harmful subsidies to include harder-to-calculate sources. These would include subsidised loans, export-credit guarantees, key exemptions from environmental regulations, the systematic transfer of remediation costs for abandoned production sites to public authorities, and other instances.

- Comprehensive global analysis of existing subsidies to nuclear power.

- Incorporation of more supply-side subsidies, such as those related to facilitating infrastructure (*e.g.*, rail links, ports, etc.).

- Estimates of current subsidies to certain end-use technologies (*e.g.*, solar thermal) and energy efficiency.

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ANNEX A: DIFFERENT DEFINITIONS OF ENERGY SUBSIDIES

THE WORLD TRADE ORGANIZATION

The World Trade Organization (WTO) definition of a subsidy – one that is in theory accepted by all participating members, if not actually used for energy sector subsidy analysis – comes from the "Agreement on Subsidies and Countervailing Measures" [55] and is presented in Table 1.

Table 1: Subsidy text from the WTO "Agreement on Subsidies and Countervailing Measures"

ARTICLE I

DEFINITION OF A SUBSIDY

1.1 For the purpose of this Agreement, a subsidy shall be deemed to exist if:

(a)(1) there is a financial contribution by a government or any public body within the territory of a Member (referred to in this Agreement as "gobernment"), i. e. where:

(i) a government practice involves a direct transfer of funds (*e. g.* grants, loans, and equity infusion), potential direct transfers of funds or liabilities (*e. g.* loan guarantees);

(ii) government revenue that is otherwise due is foregone or not collected (*e. g.* fiscal incentives such as tax credits);

(iii) a government provides goods or services other than general infrastructure, or purchases goods;

(iv) a government makes payments to a funding mechanism, or entrusts, or directs a private body to carry out one or more of the type of functions illustrated in (i) to (iii) above which would normally be vested in the government and the practice, in no real sense, differs from practices normally followed by governments;

or

(a)(2) there is any form of income or price support in the sense of Article XVI or GATT 1994;

and

(b) a benefit is thereby conferred.

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[55] The full text can be found on the WTO website (accessed on 4 July 2018). https://www.wto.org/english/docs_e/legal_e/24-scm.pdf

THE EUROPEAN UNION (EU)

The European Commission (EC) defines state aid as "an advantage in any form whatsoever conferred on a selective basis to undertakings by national public authorities".[56] It also includes a number of other stipulations for a measure to qualify as state aid, including:

- There has been an intervention by the state or through state resources, which can take a variety of forms (*e. g.* grants, interest and tax relief, guarantees, government holdings of all or part of a company, or providing goods and services on preferential terms, etc.).
- The intervention gives the recipient an advantage on a selective basis – for example, to specific companies or industry sectors, or to companies located in specific regions.
- Competition has been or may be distorted.
- The intervention is likely to affect trade between member states.

When necessary, the EC reviews any state aid construed as a subsidy, to ensure that it does not compromise the principles of the single market. Specific consideration is given to renewable energy, however, given that it contributes to the EU's climate and energy goals.[57]

The EC's 2018 inventory of energy sector subsidies adopted the OECD definition (Trinomics, 2018), while acknowledging its drawbacks. This inventory has adopted some measures to try and mitigate these, in order to come up with comprehensive estimates. In practice, the EC definition of energy sector subsidies is now broader than its definition of state aid.

THE INTERNATIONAL ENERGY AGENCY (IEA)

The IEA definition of energy subsidies has the merit of being simple in conception, although it is still not easy to apply systematically.

The definition is: "Any government action directed primarily at the energy sector that lowers the cost of energy production, raises the price received by energy producers, or lowers the price paid by energy consumers. It can be applied to fossil and non-fossil energy in the same way." (IEA, 2014).

The IEA uses a price-gap analysis (*e. g.*, where consumer prices are compared to reference prices that are designed to represent a market price equivalent without support) to compare actual prices to a reference price for what would be an unsubsidised product.[58] This approach is not likely to capture all types of subsidy and may underestimate some, depending on their design and whether or not all of the subsidy is actually passed through to consumers, or part of the subsidy is captured by producers, wholesalers or retailers.

THE ORGANISATION FOR ECONOMIC CO-OPERATION AND DEVELOPMENT (OECD)

The OECD definition of subsidy support to fossil fuels is: "Both direct budgetary transfers and tax expenditures that in some way provide a benefit or preference for fossil fuel production or consumption relative to alternatives," (OECD, 2015).

Crucially, the OECD uses a different approach to the IEA in terms of calculating the level of subsidies. The OECD has created an inventory of specific measures that calculates the direct government transfers and

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[56] http://ec.europa.eu/competition/state_aid/overview/index_en.html accessed on 14 August 2018.

[57] This is not a blanket exemption and specific conditions are in place to ensure support is provided in a way that minimises distortions to competition. See https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52014XC0628%2801%29&from=EN

[58] See their methodology paper (accessed on 4 July 2018). http://www.iea.org/media/weowebsite/energymodel/documentation/Methodology_FossilFuelSubsidies.pdf

tax expenditures of different programmes. They note that this means that the IEA and OECD approaches are not directly comparable, despite similar definitions, but have recently started to try and integrate the two approaches (OECD, 2018).

THE WORLD BANK (WB)

The WB has also written about fossil fuel subsidies and defines them as: "A deliberate policy action by the government that specifically targets fossil fuels, or electricity or heat generated from fossil fuels" that has one or more of the following effects:

- It reduces the net cost of energy purchased.
- It reduces the cost of production or delivery of fuels, electricity, or heat.
- It increases the revenues retained by resource owners, or suppliers of fuel, electricity, or heat.

The definition excludes policy actions that achieve these effects through promotion of efficiency improvement along the supply chain, greater competition in the market, or other improvements in market conditions (Kojima and Koplow, 2015).

THE INTERNATIONAL MONETARY FUND (IMF)

The IMF has also looked at identifying and quantifying energy sector subsidies and defines fossil fuel subsidies as:

"Consumer subsidies (that) arise when the prices paid by consumers, including both firms (intermediate consumption) and households (final consumption), are below supply costs, including transport and distribution costs. Producer subsidies arise when prices are above this level," (Clements, *et al.*, 2013).

The important distinction made by the IMF is between pre-tax subsidies (those that are similar to the IEA's definition and can be examined with a price-gap analysis) and post-tax subsidies. For post-tax subsidies, they take a wider view than the OECD, by covering any divergence from efficient tax levels. The implications of this are significant, as it means that un-taxed negative externalities are also counted as subsidies (including, depending on the fuel costs from greenhouse gas emissions, local air pollution, accidents, traffic congestion and road damage by heavy trucks). This inclusion changes the order of magnitude of energy sector subsidies, compared to estimates that exclude these.

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