Limited emission reductions from fuel subsidy removal except in energy exporting regions

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Hopes are high that removing fossil fuel subsidies could help to mitigate climate change by discouraging inefficient energy consumption and levelling the playing field for renewables[1–3]. In September 2016, the G20 countries re-affirmed their 2009 commitment (at the G20 Leaders' Summit) to phase out fossil fuel subsidies[4,5] and many national governments are using today's low oil prices as an opportunity to do so[6–9]. In practical terms, this means abandoning policies that decrease the price of fossil fuels and electricity generated from fossil fuels to below normal market prices[10,11]. However, whether the removal of subsidies, even if implemented worldwide, would have a large impact on climate change mitigation has not been systematically explored. Here we show that fossil fuel subsidy removal would have a small impact on global energy demand and carbon dioxide emissions and would not increase renewable energy use by 2030. Subsidy removal would reduce the carbon price necessary to stabilize greenhouse gas concentration at 550 parts per million by only 2–12 per cent under low oil prices. Removing subsidies in most regions would deliver smaller emission reductions than the Paris Agreement (2015) climate pledges and in some regions global subsidy removal may actually lead to an increase in emissions, owing to either coal replacing subsidized oil and natural gas or natural-gas use shifting from subsidizing, energy-exporting regions to non-subsidizing, importing regions. Our results show that subsidy removal would result in the largest CO_2 emission reductions in oil- and gas-exporting regions, where reductions would exceed their climate pledges and where subsidy removal would also affect fewer people below the poverty line than in lower-income regions.

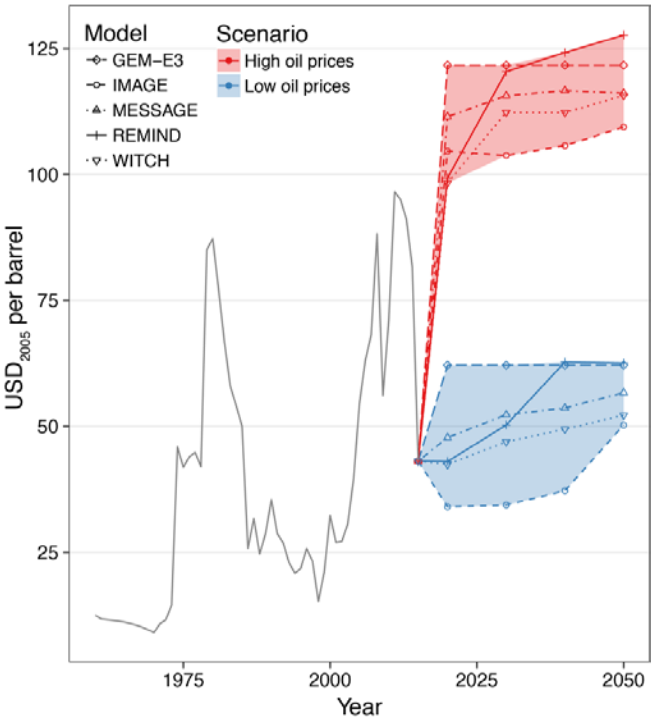
Fossil fuel subsidies amounted to about $330 billion worldwide in 2015 (referring to the US dollar in 2005, throughout) after having reached about $570 billion in 2013. This fall in subsidies could be partly a sign of reform or simply a reflection of today's lower oil prices, given that historically subsidies have followed the oil price[11] (Supplementary Figure 1). It is therefore too early to say whether subsidies will continue to fall, stabilize, or increase if oil prices rise again. Earlier work found that global subsidy removal by 2020 would reduce greenhouse gas emissions by 5% (ref. 12) -6% (ref. 13) by 2035 and 6% (ref. 12) -8% (refs

14, 15) by 2050. However, all of these studies were done using a single model and none of them explored variations in the oil price which greatly affects the size of subsidies.

We use five Integrated Assessment Models (IAMs) to evaluate the global and regional effects of fossil fuel subsidy removal on emissions, energy mix and energy demand under both low and high oil prices. In the high oil price scenarios, oil prices exceed $100/barrel and in the low oil price scenarios they drop below $60/barrel by 2020 (Figure 1).

The IAMs we use vary in their modelling approaches and solution mechanisms (Supplementary Table 1, Supplementary Text 1 and 2), which improves the robustness of the results in the face of structural model uncertainties. They include four technology-detailed energy-economy models and one multi-sectoral computable general equilibrium model. An important difference across models, which affects the modelled effects of subsidy removal, is the responsiveness of energy supply and demand to changes in energy prices (Supplementary Tables 1 and 2, Supplementary Texts 2 and 3).

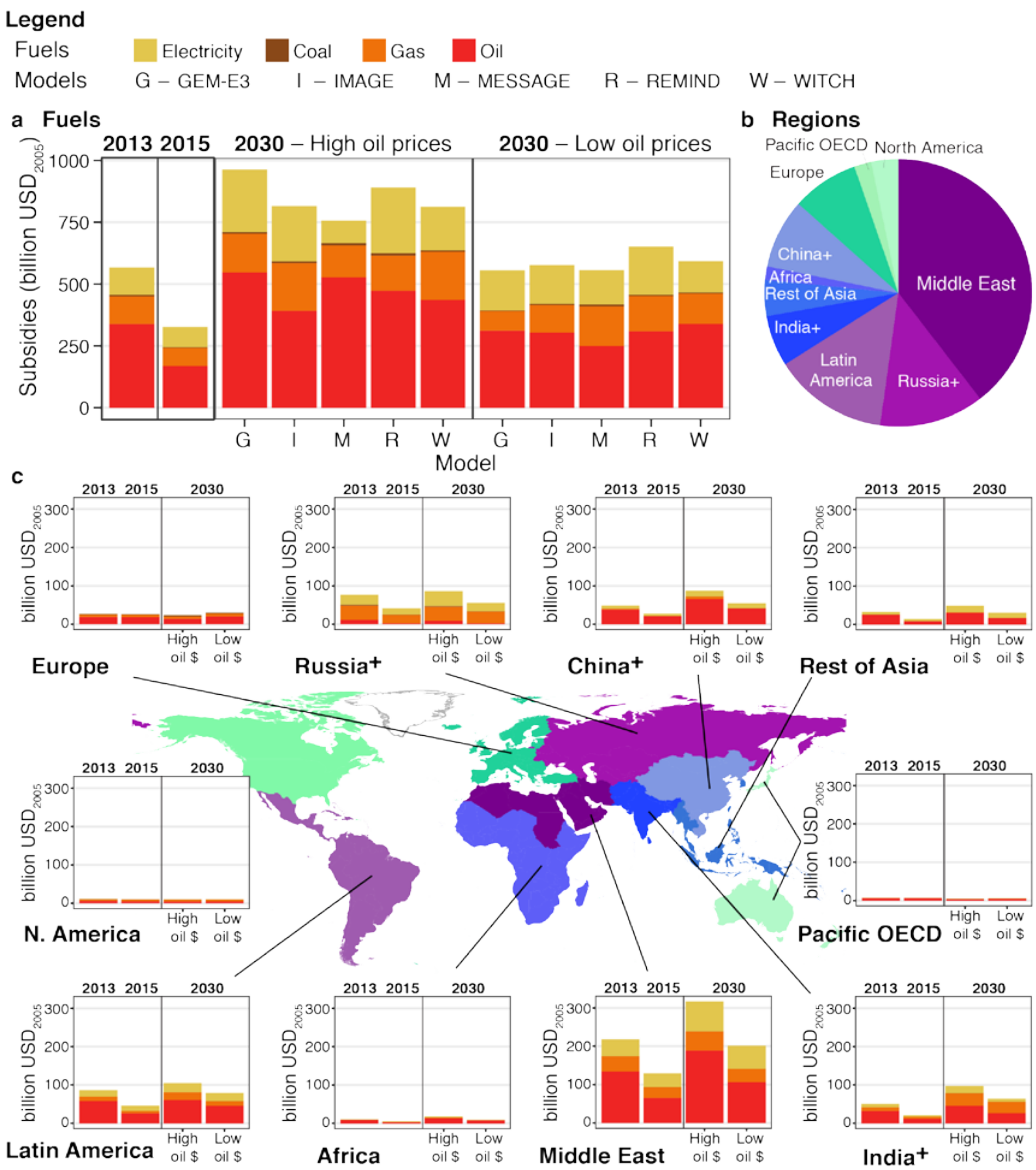
Figure 1: Modeled high and low oil price scenarios. Historical prices represent crude oil prices from ref. [16] and are shown through 2015. Modeled prices start in 2020.



We follow the IEA and OECD definition of fossil fuel subsidies as government support to consumption or production of oil, gas, or coal which lowers their prices below normal market prices (Methods). This definition excludes un-priced environmental and social externalities such as air pollution and related health effects which are included in some other estimations[17] but are not appropriate for the purpose of this paper (Methods). We compiled a global comprehensive dataset of fossil fuel subsidies[8,10,11,18,19] under both high and low oil prices

(Supplementary Tables 3 and 4, Supplementary Text 4 and 5). In 2013, when oil prices were relatively high, subsidies amounted to approximately $570 billion (Supplementary Table 5), including $340 billion for oil, $110 billion for natural gas and electricity (each), and $5 billion for coal (Figure 2). Only $22 billion (less than 4%) were production subsidies (Supplementary Table 3). Following the decline in oil prices, subsidies fell to about $330 billion in 2015, which amounted to about 10% of energy-related market transactions (Supplementary Table 6).

Figure 2. Current and projected fossil fuel subsidies without reform. (a) global subsidies in 2013 (high oil prices), in 2015 (low oil prices), and in 2030 under high and low oil prices projected in different models. (b) the regional distribution of subsidies in 2015 (Supplementary Table 5). (c) subsidies in 2013 and 2015 (Supplementary Table 5) and in 2030 under high and low oil prices in each region (model median). For model ranges and additional years see Supplementary Table 5, 7 and 8. The map presents a stylistic representation of regions. For regional definitions see Supplementary Tables 9-14.



In our scenarios, we model subsidy rates in a way consistent with historical patterns (Methods). Under high oil prices, by 2030, global subsidies would grow to between $750 and $970 billion; under low oil prices, subsidies would be between $550 and $700 billion through 2030 (Supplementary Table 5). In the subsidy removal scenarios, their phase-out starts in 2020 and is fully completed by 2030.

The three oil and gas exporting regions, Middle East and North Africa (MENA), Russia$^+$ (the $^+$ is used to refer to regions which constitute more than the named country – see Supplementary Table 9 for region definitions) and Latin America accounted for about two-thirds of all fossil fuel subsidies worldwide in 2015 (Figure 2). In Latin America and MENA, about half of total subsidies goes to oil. In Russia$^+$, about half of total subsidies goes to natural gas and the remainder to electricity (mostly generated from natural gas). Of these three regions, subsidy expenditures would grow the most in MENA which would experience the largest growth in energy use (Figure 2).

Developing and emerging economies (India$^+$, Rest of Asia, Africa, and China$^+$) currently have lower subsidies than the oil and gas exporters, but their subsidies may grow faster in the future (Figure 2). Without reform, subsidies in India under high oil prices could become comparable to those in Latin America and Russia$^+$ by 2030. In these regions, over half of all subsidies go to oil e.g. through depressed road fuel prices (in countries in the Rest of Asia region), tax breaks on road fuels (in China), or kerosene subsidies (in India and Africa)

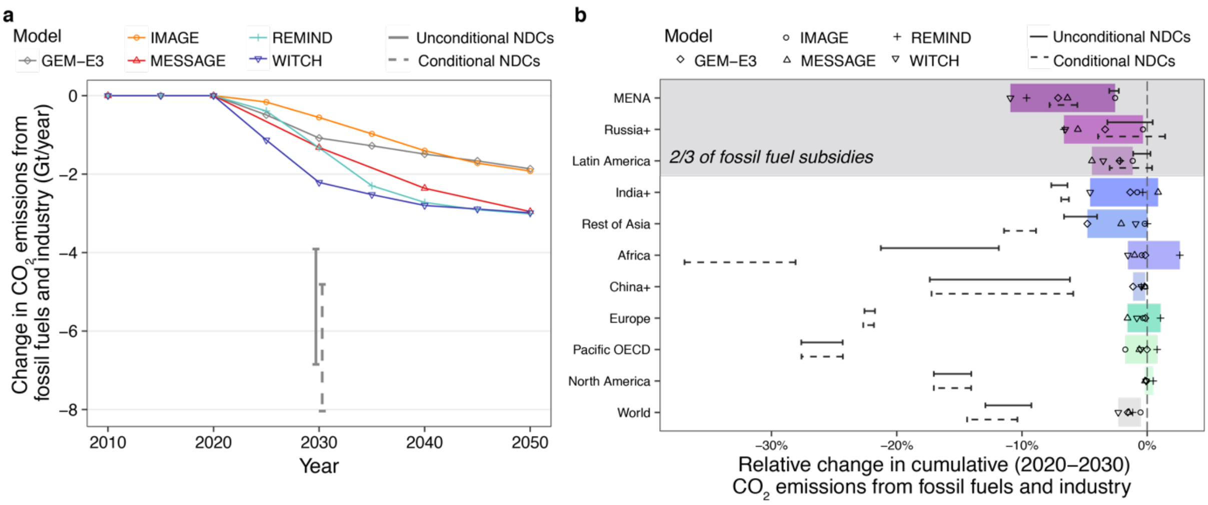
Subsidies in the developed regions (Europe, North America and Pacific OECD) accounted for about 13% of subsidies worldwide in 2015, and are not projected to grow very much in the future.

Subsidy removal would lead to a small decrease in global CO_2 emissions: 0.5-2 Gt CO_2 or 1-4% by 2030 under both low (Figure 3, Supplementary Figure 5) and high (Supplementary Figure 5 and 6) oil prices. This is much less than the Nationally Determined Contributions (NDCs) from the Paris climate agreement, which add up to a decrease of between 4-8 Gt from fossil fuels and industry. Subsidy removal would reduce the average global carbon price in 2020-2050 required to achieve modest climate goals (an atmospheric concentration target of 550 parts per million CO_2 equivalent by 2100 or a probable 2-2.3°C temperature increase in 2100[20]) by an average of 2-12% or $0.7-2.1 per ton CO_2 under low oil prices (Supplementary Text 6 and Supplementary Tables 16 and 17).

Even though the oil price has an impact on the absolute level of subsidies, it does not greatly affect the impact of subsidy removal on emissions because the latter depends on the ration between subsidies and energy prices, which is similar in the low- and high-oil-price scenarios. Figures 3 and 4 illustrate the low-oil-price scenarios; the high-oil-price scenarios are illustrated in the Supplementary Information and described in the text wherever they are very different.

The impacts of subsidy removal are distinctly different in two groups of regions. In oil and gas exporting regions (MENA, Russia+ and Latin America), subsidy removal leads to the largest emission reductions, equivalent to or greater than their relatively modest NDCs. In all other regions, emission reductions from subsidy removal are generally less than their NDCs (Figure 3 and Supplementary Figure 6).

Figure 3 Global and regional impact of subsidy removal and NDCs on CO_2 emissions from fossil fuels and industry under low oil prices. (a) The impact of subsidy removal on global annual emissions compared to each model's Baseline. (b) The impact of subsidy removal on cumulative change emissions from 2020 to 2030 at the regional level (colored bars). Solid lines represent emission effects of unconditional NDCs and dashed lines of conditional NDCs – both modeled in MESSAGE[21]. The uncertainty ranges for these effects arise from different historical emission inventories, alternative accounting, attribution of non-commercial biomass and uncertainties in formulations of NDCs (Methods, Supplementary Table 15, ref. 21). See Supplementary Figure 6 for high oil prices Supplementary Figure 5 for global relative changes and regional absolute changes.



In Russia+, where most subsidies are for natural gas (including electricity generation), subsidy removal would reduce the use of natural gas and generally lead to higher emission reductions than the modest NDC. In MENA and Latin America, subsidy removal would decrease oil and natural gas use leading to emission reductions generally comparable to the so-called 'conditional' NDCs (i.e. commitments dependent on international action) but generally larger than the unconditional NDCs.

Developing and emerging economies which are not major oil and gas exporters would generally experience smaller emission impacts (both in absolute terms and in relation to their NDCs) from subsidy removal due to lower subsidy levels. The main effect of subsidy removal in India+, would be reduced use of oil and natural gas, and in the Rest of Asia – slightly reduced use of coal and oil. In both regions, the decline in emissions would be generally smaller than the NDCs. In China+ subsidies are lower and the impact of their removal would also be small in comparison with the NDCs. In Africa, subsidy removal would also have a much smaller effect than the NDCs (and in one model would even lead to an increase in emissions due to the substitution of oil with coal).

In the three developed regions (Europe, North America and Pacific OECD) with low subsidies, the main impact of global subsidy removal is driven by the change of the price of fossil fuels on the global market. As oil and gas exporters reduce domestic demand by removing subsidies, they make more resources available for the global market. This can for example lead to increased use of natural gas in Europe (Figure 4). This effect is more pronounced in models with more flexible energy trade. The resulting change in emissions can either be negative or positive depending on whether the cheaper natural gas substitutes oil and coal or leads to an increase of consumption. All in all, subsidy removal would lead to much smaller emission reductions than the NDCs.

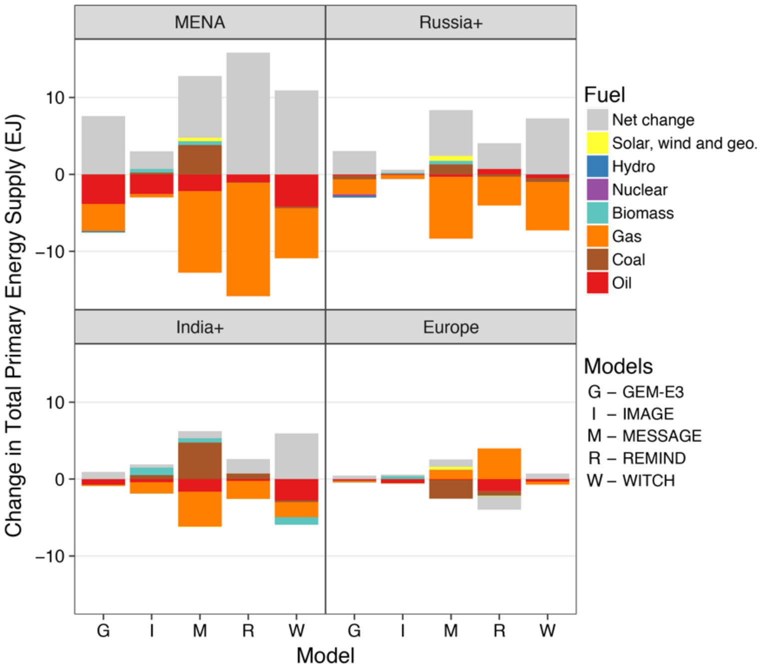
Although the above results are robust for all models, there are certain variations, due to different features and assumptions of particular models. The most notable difference is that in some regions, subsidy removals can unexpectedly lead to an increase in emissions. In India^{+} (MESSAGE) and Africa (REMIND) this occurs because these models assume more flexibility in fuel substitution. As a result, removing subsidies leads to substitution of oil or natural gas with more carbon-intensive coal resulting in either increase or smaller reductions of emissions. In addition, REMIND assumes the most flexible international energy trade which means that energy importing regions (Europe, Pacific OECD and North America) increase the use of natural gas (and therefore greenhouse gas emissions - Figure 3) after it stops being subsidized in energy exporting regions. Other less notable differences are discussed in Supplementary Text 2.

Our results show that removing fossil fuel subsidies would somewhat lower global energy demand. The decrease in energy demand is caused by increasing energy prices and ranges between 5 and 26 EJ/year or 1%-4% in 2030 (Supplementary Figure 7 and 8). Under high oil prices, the decrease in demand is somewhat larger, reaching up to 30 EJ/year or 7% in 2030 (Supplementary Figures 7 and 8). The decrease in demand is largest in oil and gas exporting regions (MENA, Russia+, and Latin America) whereas in some energy-importing regions energy use could even increase following subsidy removal due to larger availability of natural gas on international markets as discussed above.

In addition, removing fossil fuel subsidies would not strongly stimulate the growth of renewable energy by 2030 (Figure 4). In general, fossil fuel subsidy removal leads to an increase in the share of renewables in regional energy mixes by less than 2 percentage points (Supplementary Figure 13). A slightly larger increase may occur under high oil prices in bioenergy in Russia^{+}, MENA and Latin America or solar energy in MENA and Russia^{+} (Supplementary Figures 10-12). Beyond 2030, subsidy removal could stimulate more noticeable growth of renewable energy, in particular bioenergy under certain modeling assumptions.

A more pronounced effect of fossil subsidy removal is the switch from one fossil fuel to another, for example from subsidized natural gas and oil to coal in MENA, Russia^{+} and India^{+} as well as from coal and oil to natural gas in Europe (Figure 4) which highlights the need to consider systemic effects of subsidy reform policies. The switch between fossil fuels is more pronounced in models with higher flexibility of supply and lower flexibility of demand as well as higher flexibility of international trade (Supplementary Text 2). Another more granular effect is the slow-down of the switch from solid fuels (coal and firewood) to natural gas and kerosene amongst the poor, as shown by IMAGE (a model representing different income groups – Supplementary Figure 9). This is in line with earlier findings: as modern fuels become more expensive, lower income groups are unable to avoid traditional fuels, unless supportive policies are implemented in parallel[22,23].

Figure 4 Change in supply of different fuels resulting from subsidy removal in 2030 in four regions under low oil prices. MENA and Russia⁺ illustrate exporting regions, India⁺ - developing importing countries, Europe - developed countries (Supplementary Figure 10 shows the other six regions). "Solar, wind and geo." indicates the aggregate change in solar, wind and geothermal power. Positive values of "Net change" indicate a decrease in the total primary energy supply, negative values – an increase. Supplementary Figures 11 and 12 show results under high oil prices. The regional definitions (Supplementary Tables 9 – 14) can influence the size of energy system changes.



We tested the sensitivity of our findings against baseline assumptions (Supplementary Text 7, Supplementary Figures 14-17), oil and gas price de-coupling (Supplementary Text 8, Supplementary Figures 18-21) and higher production subsidies assumptions from ref. [24,25] (Supplementary Text 9, Supplementary Table 18, Supplementary Figures 22-25). The emissions and energy systems impacts are generally robust across these uncertainties but changing socio-economic baseline assumptions changes the projected emission reductions from some regional NDCs, which in turn changes the relationship between the NDCs and the effects of subsidy removal (Supplementary Text 7).

Our finding that subsidy removal would have the largest impact on CO_2 emissions in Russia⁺, MENA and Latin America is especially meaningful considering two features of the political economy of subsidies. The first is that subsidy removal could disproportionately harm the poor in some countries[26,27]. The second is that today's low oil prices pressure energy exporting states to reduce spending as government revenues shrink[26]. This provides a unique political opportunity to remove subsidies precisely where it would have the largest effect on emissions and impact a comparatively small number of people living below $3.10/day (Supplementary Table 19 and Supplementary Text 10). Conversely, in low-income regions subsidy removal would lead to smaller emission reductions and likely impact more people living below this poverty line. The frequently-voiced suggestion to couple subsidy removal with other emission reduction policies like carbon pricing[12,15] or clean energy support schemes[28,29] would not necessarily reduce the impact of subsidy removal on the poor unless specifically designed with this objective in mind.

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Contributions statement
J.J., D.M., V.K. and K.R. designed the experiment with input from C.B. and M.T. J.J. compiled the fossil fuel subsidies and energy price data. D.M. and V.K. provided the MESSAGE data. J.E. and L.B. provided the WITCH data. D.G. and D.v.V. provided the IMAGE data. K.F. and L.P. provided the GEM-E3 data. C.B. provided the REMIND data. J.J. made all the figures with assistance from V.V. and D.G. J.J. led the analysis of the modeling results and writing of the paper with input from all authors.

Data availability
All data for the subsidy scenarios and sensitivities are available at

https://tntcat.iiasa.ac.at/ADVANCEWP3DB. The NDC data used in this paper are from ref. 21 and are available upon request. The sources and compilation method for the input data on subsidies and prices are described in detail in the section “Energy price and subsidy data” in the Methods section.

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