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Implications of Switching Fossil Fuel Subsidies to Solar: A Case Study for the European Union

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Abstract: Fossil fuel subsidies (FFS) constitute one of the most obvious barriers to tackling climate change, as they encourage inefficient energy consumption and divert investment away from clean energy sources. According to the International Monetary Fund, FFS amounted globally to $233 billion in 2014, over four times the value of subsidies awarded to promote renewable energy. In this study an integrated assessment model is used to analyse the CO_2 implications in the European Union of eliminating FFS and recycling the revenues to promote rooftop PV. It is found that eliminating FFS would give rise to a small reduction in CO_2 due to fuel-switching from coal to gas. If the revenues were recycled to promote solar, then the CO_2 reduction would increase from 1.8% to 2.2% by 2030. Eliminating FFS is not a panacea from the mitigation point of view, even if the revenues are recycled, but other important objectives, such as those related to renewable energy promotion and the reduction of air pollution, are advanced at zero cost for the government.

Keywords: fossil fuel subsidies; renewable energy; mitigation; air pollution

1. Introduction

The main goal of the Paris Climate Agreement (UNFCC) is to ensure that the average global temperature increase does not exceed the threshold of 2 °C or 1.5 °C above preindustrial levels. To that end, greenhouse gas (GHG) emissions need to peak "as soon as possible", and then be reduced practically to zero in the second half of this century [1]. Currently, fossil sources account for 80% of the global total primary energy supply and 60% of global greenhouse gas (GHG) emissions [2]. Therefore, an urgent and far-reaching transformation in the energy system will be required, where fossil fuels are gradually phased out of the energy mix, especially coal, which is the most CO_2-emission-intensive fuel of all in terms of energy content.

There are many different regulatory and economic instruments that can be used to boost this transition towards a low-carbon economy. From the economic perspective, one of the most urgent measures should be the elimination of fossil fuel subsidies (FFS), since they encourage inefficient energy consumption and divert investment away from clean energy sources. According to the International Monetary Fund [3], FFS amounted globally to $233 billion in 2015. The elimination of FFS would not only be beneficial from the climate change perspective (these subsidies work in practice as a negative carbon price), but would also help to eliminate a significant market distortion that encourages inefficient consumption, and does not, as it is sometimes perceived to do, benefit the poorest. According to the International Monetary Fund, these subsidies tend to be regressive as only 7% of subsidies in developing countries actually reach the poorest 20% of households, while 43% end up in the hands of the richest 20%. For all of these reasons, the International Energy Agency has proposed a phase-out of

FFS as one of the key elements for enabling society to move to a low carbon economy. In this regard, at their recent meeting in Ishe-Shima [4], the G7 leaders recently pledged to phase out fossil fuel subsidies by 2025.

In this context, there is emerging interest among the scientific community in the potential environmental, economic, and social implications of phasing-out FFS. Ellis [5] provides a survey of the literature that has sought to quantify the economic and environmental consequences of fossil fuel subsidies at global level. These studies conclude that a phase-out of FFS would reduce world GHG emissions in the longer term, although the magnitude differs greatly from one study to another, ranging from 0.6% [6] to 10% [7,8]. In general, studies that are based on economic models (partial or general equilibrium models) tend to obtain higher emission reductions than integrated assessment models of the energy-system and the economy, as they tend to be more optimistic in terms of fuel-switching possibilities. (For example, computable general equilibrium (CGE) models typically use a highly aggregated constant elasticity of substitution (CES) function to capture the elasticity substitution between fossil fuels. Although some models include more detail in the electricity sector this is rarely the case in the transport sector.) Schwanitz et al. [6] use the REMIND integrated assessment model and show that in the long-term the removal of fossil fuel subsidies would only result in emission reductions of around 0.6%. Most remarkably, they show that if it is not supplemented by other policies, the removal of fossil fuel subsidies may actually increase emissions in some countries. The reason is that the induced change in global energy prices and the lack of alternatives in many countries may eventually lead to an increase of coal consumption and the use of coal-to-liquids conversion technologies. Therefore, the phase-out of fossil fuel subsidies needs to be designed and implemented carefully, and must take into consideration the substitution possibilities that are available in each specific region/country [8].

This study uses an integrated assessment model (IAM) (the Global Change Assessment Model, GCAM) to analyse the CO_2 reduction potential when the revenues from the elimination of FFS are used to promote renewables, and more specifically, solar technologies. Although there are some studies that suggest that IAMs are not the most accurate tool to analyse short-term changes or shocks [9], this work focuses on which would be the global (including energy, land use, or climate systems) situation in 2030, so to use such an integrated instrument provides insights to the framework.

The analysis focuses on the European Union (EU), which is a relevant case study for two reasons. First, the EU has already committed (see Council Decision, 2010/787/EU) to eliminating coal subsidies in all Member States by 2018 (Although there are some doubts whether all of the Member States will implement this directive (for example, some countries, such as Germany or Spain, are introducing new mechanisms that provide payment to coal-fired plants to provide a supply of electricity with domestic coal), this directive focuses on the elimination of "inefficient coal mine" subsidies.). In fact, coal subsidies are large in the EU, accounting for around 81% of global subsidies. Second, the EU has also set a specific target for renewables (at least 27% of final energy should come from renewable sources by 2030 [10], which also justifies the "recycling" of the revenues from FFS to renewables).

The paper is organised as follows: Section 2 presents the methods that were used in the study (including the data on FFS (Section 2.1), an overview of the GCAM model (Section 2.2) and the scenarios (Section 2.3)); Section 3 shows the results; Section 4 discusses the results; and, Section 5 concludes.

2. Materials and Methods

2.1. Data

This section presents an overview of FFS at global level and for the EU, as estimated by the IMF [11]. The estimations by the IMF follow a price-gap approach (The International Energy Agency follows the same approach (IEA 2015) and obtains similar results. However, the Organization for Economic Co-operation and Development (OECD) follows the so-called "inventory approach", which captures the direct budgetary support and tax expenditures on fossil fuel production or consumption. The OECD database applies only to 34 OECD countries) [3,12], which calculates subsidies by multiplying fuel consumption by the difference between end-user prices and supply costs (The IMF methodology also includes shipping costs and margins, plus value added taxes. The IEA also includes some tax subsidies, which is one reason for the difference between IEA and IMF estimations for pre-tax subsidies.). This gives the so-called "pre-tax" subsidies or FFS, which have to be financed directly from government budgets. On the IMF database, there are two main approaches reported: on the one hand, the mentioned "pre-tax" or direct monetized subsidies that account for US$233 billion in 2015 for FFS. On the other hand, "post-tax" subsidies, which also include the negative externalities from energy consumption, would account for around $5 trillion. This work focuses on the pre-tax subsidies. The data reported here and used in the study are based on FFS estimated for coal, petroleum, and gas Subsidies for electricity consumption are not considered in this study. The IMF database does not break down subsidies for electricity into different sources, so it is not possible to allocate those subsidies to fossil or non-fossil fuel sources, such as renewables or nuclear.

In 2015, FFS amounted globally to US$233 billion, which is 37% down on the figure for 2011. This reduction in FFS reflects the fall in international energy prices and the reduction in FFS already undertaken in some countries, such as Saudi Arabia, the United Arab Emirates, and Indonesia [13,14]. It should be mentioned that the historical trend in FFS might not be a suitable indicator for showing government attitudes towards promoting fossil fuels, as it is also affected by changes in energy prices and other macroeconomic conditions. However, FFS accounted for 0.41% of global GDP, which is still an economically significant figure, and in many countries, they represent a major share of the government budget.

Figure 1 shows the breakdown of FFS by regions and fuels. Most subsidies are concentrated in energy-exporting countries. The OPEC (Algeria, Angola, Ecuador, Gabon, Indonesia, Iran, Iraq, Kuwait, Libya, Nigeria, Qatar, Saudi Arabia, the United Arab Emirates, and Venezuela). (Organization of the Petroleum Exporting Countries) and CIS (The CIS (Commonwealth of Independent States) comprises Russia, Armenia, Azerbaijan, Belarus, Kazakhstan, Kyrgyzstan, Moldova, Tajikistan and Uzbekistan, with Turkmenistan, and Ukraine as associate members.) countries account for 73% of the world's FFS. Adding the USA, India, and the EU, the proportion of world FFS accounted for rises to 87%. As far as fuel sources are concerned, by far the most heavily subsidised fuel is oil (US$127 billion), followed by natural gas (US$89 billion) and coal (US$5.09 billion). In terms of FFS relative to GDP, the highest average absolute figure is that of OPEC countries, with 3.17%, followed by the CIS countries (1.3%) and India (0.6%).

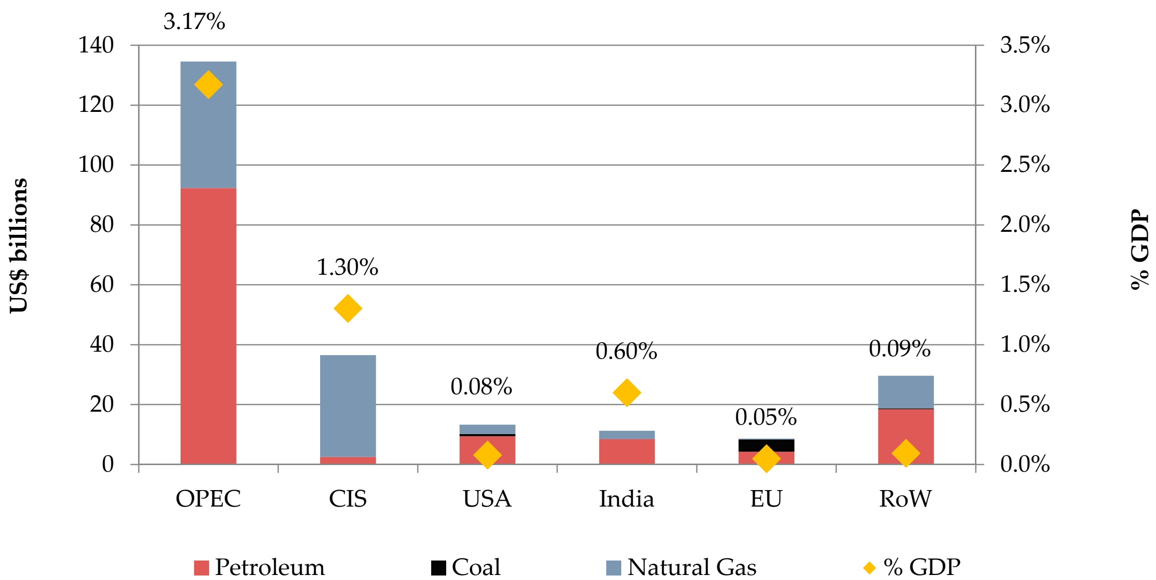

Figure 1. 2015 World fossil fuel subsidies by regions and fuels (billion $ 2015 and % GDP). Source: IMF.

In the EU, FFS are not as high as elsewhere. In 2015, FFS in the EU amounted to US$8.63 billion (3.69% of global subsidies). The EU has comparatively low subsidies on oil (US$4.3 billion) and gas (US$0.3 billions), but its subsidies on coal (the most intensive fuel in terms of CO_2) are very high (US$4.1 billions) and account for a striking 81% of world coal subsidies. According to European legislation, subsidies on coal must be eliminated by 2018 in all of the Member States. Also, the EU, as a member of the G7 group, has agreed to eliminate all forms of support for fossil fuels by 2025.

2.2. Model

The model used in this study is the Global Change Assessment Model (GCAM), developed by the Joint Global Change Research Institute (JGCRI), affiliated to the University of Maryland and the Pacific Northwest National Laboratory (PNNL). GCAM is an integrated assessment model that links economic, energy, land use, and climate systems. It is one of the four models chosen to develop the Representative Concentration Pathways (RCPs) of the IPCC's 5th Assessment Report. In this study, the standard release of GCAM 4.2 is used.

GCAM is a global dynamic-recursive partial equilibrium model disaggregated into 32 geopolitical regions and operating in five-year time steps from 1990 to 2100. The GCAM energy system includes primary energy resource production, energy transformation to final fuels, and the use of final energy forms to deliver energy services. The model distinguishes between two different types of resource: depletable and renewable. Depletable resources include fossil fuels and uranium; renewable resources include biomass, wind, hydropower, geothermal energy, municipal, and industrial waste (for waste-to-energy) and solar technologies (including both concentrated solar power (CSP) and solar photovoltaic equipment). All resources are characterised by cumulative supply curves, i.e., upward-sloping supply-cost curves that represent the idea that the marginal monetary cost of resource utilisation increases with deployment. Competition between technologies is modelled by a logic probabilistic model that allocates a share weight to each technology and each level. Full documentation on all the technologies in the energy system is provided in Clarke et al. 2008 [15].

Indeed, for the purpose of the study, it is interesting to remark that the model takes into consideration the flexibility of the electricity sector: the increase of an intermittent technology, such as solar or wind without storage, means that complementary "backup technologies" (i.e., gas) would also be expanded in order to be able to satisfy the demand in every situation, including the "peak loads".

GCAM tracks all the GHG emissions from energy and land-use systems. It provides the mitigation cost of different energy and climate policies for each specific region. The mitigation costs are calculated by the model as the area below the calculated marginal abatement cost curves [16]. GCAM also reports the emissions of main air pollutants (including NO_x, VOCs, CO, and SO_2), and can be used to analyse the co-benefits/trade-offs of mitigation in terms of air pollution. Emissions of air pollutants depend on the activity levels in each region, such as fuel consumption, and on the level of pollution controls, which are assumed to increase over time [17,18].

2.3. Scenario Schemes

The main purpose of the paper is to explore the impacts of removing FFS in the EU and "recycling" the savings to subsidise solar energy. This subsection presents the scenarios of the different fossil fuel subsidy reforms. The three scenarios are summarized as follows:

- Baseline: This is the reference scenario in which there is no climate policy in place. In this scenario, subsidies on fossil fuel (see Section 2.1) are included in the base year (2015) as a negative cost in unitary terms ($ per GJ). Unitary subsidies are assumed to remain constant throughout the simulation period. The amount of money spent on subsidies can then be obtained in each period by multiplying by the consumption of fossil fuel.
- Phase-out: This scenario phases out subsidies on fossil fuels in the EU. However, the revenues are not reinvested in promoting low carbon technologies.

- Recycling: This scenario phases out FFS and reinvests them in renewables, more specifically, in solar rooftop photovoltaic (The subsidized rooftop PV technology is an off-grid electricity system, which is directly competing with grid-based electricity. The industrial photovoltaics are not taken into consideration in these results.) (hereinafter, rooftop PV). The rooftop PV option is selected for three main reasons. First, the government can directly promote this technology without interfering in other policies, such as in the new renewable energy capacity auction-based system [19] or the EU emission trading system (EU-ETS) [20]. On the other hand, investments in rooftop PV also enable small actors to participate, such as municipalities, small business and individuals (Although there are more technological options that allow small participants (micro-wind installations), rooftop PV presents the highest level of development.) Finally, the other main renewable alternative, wind energy, is starting to bid at zero (In a recent auction of 500 MW of wind energy in Spain all the capacity was acquired at bids of zero—meaning that no financial support is required.) subsidy cost, which means that some renewable technologies are closer to competing with other technologies at market prices. In any case, a sensitivity analysis is shown to demonstrate the CO_2 mitigation potential of using other renewable technology options.

As the renewable energy system has been supported by different financing mechanisms over the last years, it is important to reflect the important magnitude of this mentioned "recycling" process. The latest estimation on subsidies to renewable power sector [1] accounts for US$120 billion, so taking into account that the used number for FFS subsidies is US$233 billion, it would almost double that amount.

3. Results

This section presents implications of eliminating FFS in the different scenarios by 2030 for the energy system (Section 3.1), CO_2 emissions and mitigation costs (Section 3.2) and air pollution (Section 3.3). The results include a sensitivity analysis for different FFS recycling options.

3.1. Energy and Electricity System

This subsection shows the changes in the energy system for the scenarios with and without the recycling of revenues from subsidies. Figure 2 shows the absolute variations in primary energy consumption of the scenarios, with respect to the baseline.

Figure 2. Differences in primary energy consumption in 2030 in EU (EJ) with respect to the baseline scenario.

The most important reduction observed in both scenarios is in coal consumption, with drops of 6.3% and 7% by 2030, respectively. This is because coal, which is mainly used in electricity generation and industrial processes, can easily be replaced by other fuel sources. Indeed, natural gas consumption increases by 1.5% and 1.3% by 2030, with the elimination of the subsidies. This happens because the subsidies for natural gas are relatively smaller than the ones for coal, so, according to the model assumptions, gas would become comparatively more competitive and may replace coal in some sectors.

The effect on oil consumption is however very limited, with reductions of 0.16% and 0.19%. Oil is mainly used in the transport sector, and, according to the model, the use of alternatives, such as biofuels and electric vehicles, due to the elimination of oil subsidies is limited, given the high costs for these alternatives. Another interesting consequence is that in the recycling scenario, where rooftop PV penetrates the market strongly, other technologies, such as nuclear and wind energy, decrease.

In order to provide a better understanding of the changes in the energy system, Figure 3 shows the change in the electricity mix with respect to the baseline scenario. The results are consistent with those already explained for the primary energy mix. However, there are some aspects that deserve closer attention. First, the use of biomass in the electricity sector is not substantially modified. Similarly, the electricity that is generated from gas-fired plants does not increase despite the major deployment of gas as an energy source (see Figure 2). This is because the subsidized rooftop PV replaces fossil fuels (mostly coal) in the electricity sector, whereas biomass and gas replace coal and oil in other sectors (such as industry, buildings or to a lesser extent transport). Additionally, as explained in a previous Section 2.2, wind and solar are considered as intermittent technologies, so to ensure that electricity demand can be met at any time (including "peak loads") the expansion of solar would replace some use of wind energy. This effect would be ameliorated if the cost of storage batteries were lower. Finally, there is a decrease of nuclear power that can be explained with the need for backup support that solar energy requires (due to the intermittency). Since the recycling scenario presents an energy mix with a higher share of renewable energy, and nuclear energy cannot be used as backup for the increased solar power (nuclear power stations cannot be switched on-off easily), it is less extended than in the baseline scenario. The deployment of rooftop PV is quite limited in both the baseline and FFS phase-out scenarios. However, in the scenario where all FFS are switched to rooftop PV the production of rooftop solar electricity increases with 0.17 EJ by 2030, which represents a doubling of rooftop solar electricity production when compared to production in 2015.

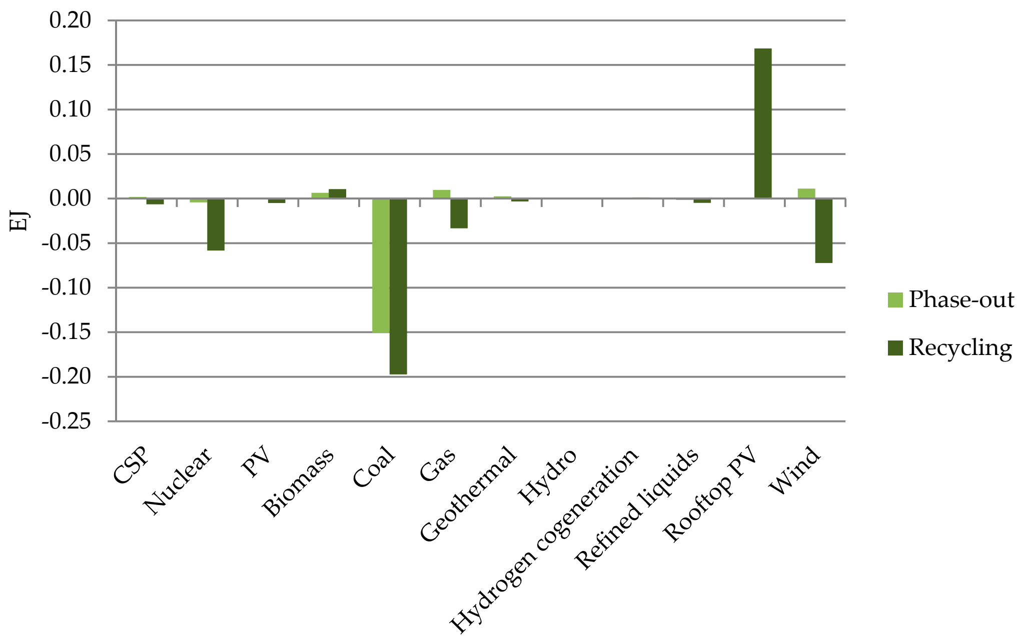

Figure 3. Differences in electricity mix in EU in 2030 (EJ) with respect to baseline scenario.

Due to the reallocation of subsidies and the implicit inefficiency that they promote, it is also interesting to analyse the impacts of eliminating FFS in all electricity consumption. It is clear that when FFS are established (baseline scenario), overall energy consumption is higher, because of the relatively lower prices. Therefore, electricity consumption decreases when FFS are removed and reinvested, as can be seen in Figure 4. These reductions amount to between 0.68% and 1.02% when FFS are removed and 1.02% and 1.18% when they are reinvested in rooftop PV.

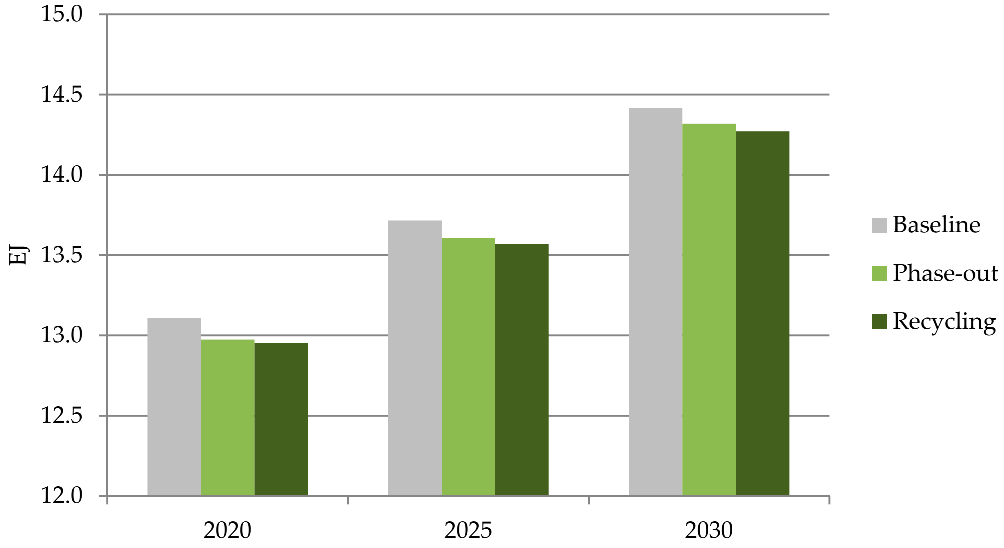

Figure 4. EU27 total electricity consumption per period (EJ).

Finally, the elimination of FFS would also help to meet the EU's targets on renewables. Figure 5 shows what the share of renewable sources would be in each scenario. In the baseline scenario, the projected share of renewables in the electricity mix in the EU by 2030 is 20.23%. This share is greater in both the Phase-out (20.51%) and Recycling (21.11%) scenarios. These results are still far from the target for renewable energy (27% of the energy mix), but it is worth mentioning that the increase is being achieved at zero extra cost for the government.

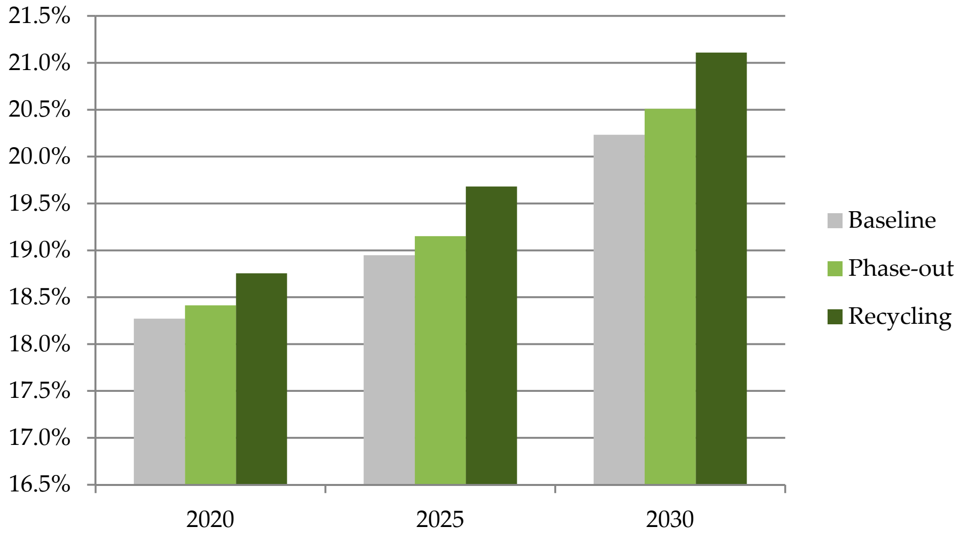

Figure 5. Share of renewable energy sources in the EU electricity mix per period.

3.2. CO_2 Emissions and Mitigation Costs

This section shows the implications of the different scenarios in terms of CO_2 emissions, taking into consideration both emission reduction and mitigation costs. A sensitivity analysis is also presented here to assess the effect of recycling FFS to promote other renewable technologies.

Figure 6 analyses CO_2 emissions per period in each scenario up to 2030 as percentage variations, with respect to the baseline scenario. If FFS are merely eliminated ("Phase-out" scenario), emissions decrease by up to 1.8% by 2030. However, when the subsidies are taken and reinvested in rooftop PV emissions decrease by 2.2% by 2030, a relative increase of 21%.

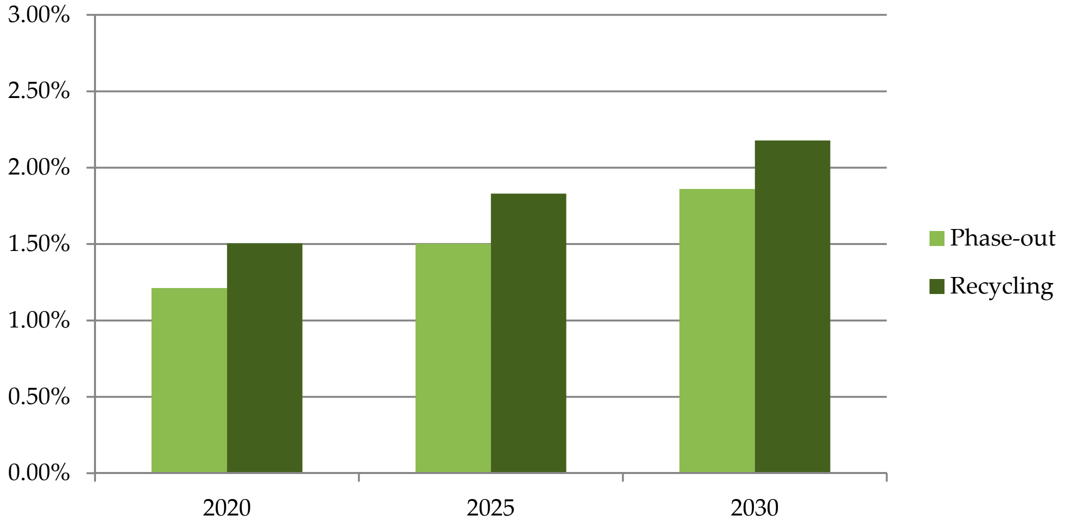

Figure 6. Percentage reduction of CO_2 emissions per period (%).

Due to variations in the penetration of the technologies, the abatement cost differs from one scenario to another. To put the numbers in context, the abatement cost of the recycling scenario is compared with the current EU policy, which is to achieve a 40% CO_2 reduction by 2030. Indeed, it is estimated that the FFS reform would cover 3% of the mitigation cost that is needed to meet the European target of a 40% CO_2 emission reduction by 2030 The cost of the EU policy is also calculated by setting the mitigation target in GCAM. As detailed in Section 2.2, the model provides the cost of the simulated policy. According to the model assumptions, the average abatement cost ($\$/tCO_2$) increases with the stringency of the policy that is established. In the recycling scenario, the cost is around 96.7 $\$/tCO_2$ in 2030, while when simulating the mentioned EU policy, it is 419 $\$/tCO_2$.

Lastly, to show the mitigation potential of recycling the revenues to promote other renewable options, and following the same methodology and assumptions, Table 1 shows the CO_2 mitigation achieved with different technologies relative to the baseline scenario. It can be seen that reinvesting FFS to promote other renewable sources can increase CO_2 mitigation by 3–3.5%. These figures result from the lower costs of other renewable technologies when compared to rooftop PV. However, our focus on rooftop PV is based on the advantages that this technology has for implementation reasons. As shown in Section 2, direct investments in rooftop PV help to avoid certain regulatory problems, such as market distortions (EU-ETS), and facilitate the entry of other, smaller participants (municipalities or individuals).

Table 1. Sensitivity analysis on CO_2 mitigation potential using different renewable technologies (%).

TOTAL PROJECTED REDUCTIONS (%)	2020	2025	2030
Rooftop PV	1.5%	1.8%	2.2%
Other solar (CSP and utility-scale PV)	1.9%	2.2%	2.6%
Wind	2.6%	3.1%	3.4%

3.3. Air Pollution

The implications of other air pollutants have become a key element in the analysis of climate policies [21,22]. In this study, some of the main air pollutants have been considered: black carbon (BC) (Although BC has a demonstrated greenhouse effect [23] it is also a $PM_{2.5}$ precursor, so it is considered an air pollutant.) carbon monoxide (CO), ammonia (NH_3), nitrogen oxides (NO_x), organic carbon (OC) and sulfur dioxide (SO_2).

Figure 7 shows the variation with respect to the baseline in some of the main pollutants for the different scenarios. In the "Phase-out" scenario, SO_2 emissions show the biggest reduction (−2.8%). In Recycling, SO_2 emissions show an additional effect and drop by 3.1%. More and more studies are analysing the implications of climate and energy policies for SO_2 [24], as it is one of the main contributors to the damage associated with air pollution. On the one hand, exposure to SO_2 has implications for health due to its effect on circulatory and respiratory systems, especially among children and older people. On the other hand, BC and SO_2 have both direct and indirect effects: after being emitted, they are among the main precursors for the formation of both PM_{10} and $PM_{2.5}$. Exposure to high concentrations of PM is considered as a major risk factor in terms of health impacts.

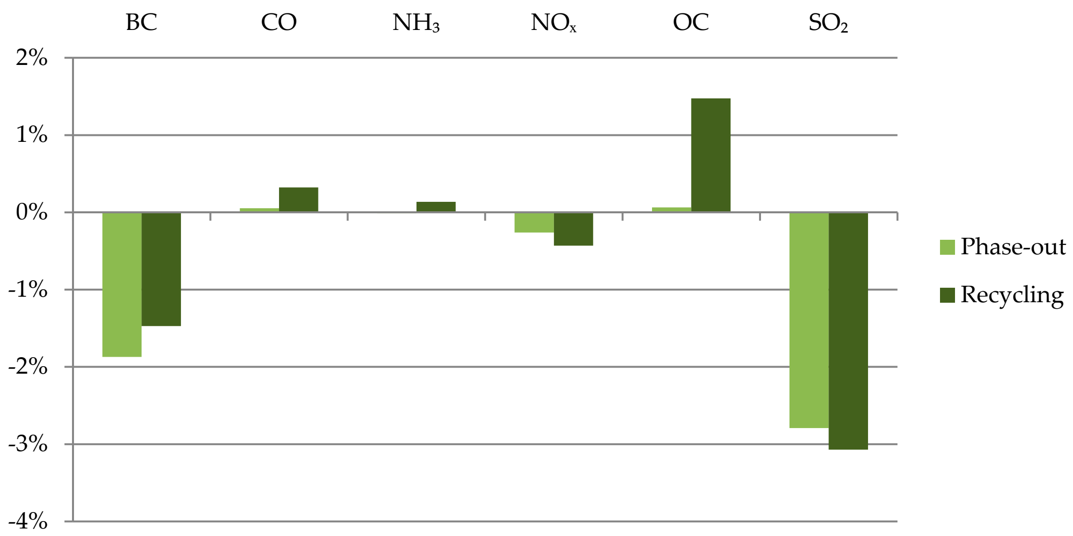

Figure 7. Differences in air pollutants in EU-27 in 2030 (%).

However, when FFS are reinvested the increase in biomass consumption (Section 3.1) results in an increment of CO and OC. Although the figures are not very high (0.32% and 1.47%, respectively), it is important to realize that they could entail some indirect damage. For instance, CO is a precursor for the formation of tropospheric ozone (O_3), which has been proven to have impacts on health [25,26] and agricultural systems [27]. Moreover, OC emissions are also a key element for the deposition of $PM_{2.5}$ in the atmosphere.

4. Discussion

This paper has certain limitations, but it also opens up further research questions, which are discussed in this section. The most important one is that the results depend on the projections of the baseline scenario. As shown, CO_2 emission reduction could be between 1.5% and 3.5% if there is no other climate policy in place in the region, but this result could change if there is a climate policy already in place. In any event, it has been shown that FFS recycling always has a positive impact in terms of renewable energy penetration and emission reduction.

Another important issue is that in Europe there are sectors where there is already a mechanism in place to reduce CO_2 emissions. The "EU-ETS" cap and trade system is the most important such mechanism, covering around 45% of all the GHG emissions in the region. FFS recycling could therefore lead to overlapping regulation problems. However, as presented, this limitation could be reduced by switching subsidies to renewable technologies that do not affect this system, such as directly subsidising rooftop photovoltaic facilities.

On the other hand, as mentioned briefly in the introduction, most previous studies in this field have used General Equilibrium Models [13,28]. Such models focus on welfare or distributional analysis or the price implications of removing FFS. Among their results, it can be highlighted that FFS are inefficient as a policy instrument for protecting poor households from fuel price increases. It would be interesting to see if removing FFS proves to be a regressive policy due to the possible increase in electricity prices. Additionally, using GCAM instead of another type of model makes it impossible to analyse macroeconomic indicators, such as possible industrial losses, employment effects, or welfare variations.

Work has also been done in relation to investing FFS savings [29], and some authors suggest creating an international fund in order to reallocate possible revenues. According to these authors, if the global savings (of oil importers) were reinvested, a positive economic transformation would be achieved. This paper analyses only the case of the EU: the amount of money that is saved from subsidies is directly reinvested in cleaner energy sources with the EU. However, an interesting line for further research would be to check the implications of using that money to promote mitigation options outside the EU.

Finally, there could be several barriers to applying the policy that is proposed in this study. The study focuses on reinvesting Member State subsidies at the EU region level, but the differences between the 27 European countries would make such an agreement complicated, given the concentration of subsidies in specific countries (such as Germany and Poland).

5. Conclusions

In this paper, we analyse the impacts of removing fossil fuel subsidies (FFS) in the EU and "recycling" the savings to subsidise solar energy directly (rooftop PV). We find that although removing FFS in EU does not suffice in itself to achieve major emission reductions—which is also an important result—the recycling of these subsidies to promote low-carbon technologies can generate additional positive effects. The most interesting is related to the additional penetration of renewable technologies: it is shown that if FFS is reinvested in rooftop PV, then the installed capacity of this technology could present a significant increase, according to the assumptions of the model.

As shown, if no additional climate policy is established FFS recycling could result in a CO_2 emission reduction of between 1.5% and 3.5%. Therefore, taking into consideration that this is only a first step towards meeting European CO_2 targets, FFS recycling should be considered as a valuable policy. Even though there are other climate policies that may entail higher CO_2 decreases, they could require substantial investments and long implementation periods, while the elimination and recycling of FFS is budget neutral and can be implemented very fast and at zero-cost.

It is also clear that deploying such a policy around the world would need hard cooperation and negotiation processes. Nevertheless, many countries have started taking measures in this area [12], so existing results and experiences could help in the implementation processes.

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