Global Fossil-fuel Subsidy Reform and Paris Agreement

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1. Introduction

Global fossil-fuel consumption subsidies reform has been widely discussed as one of the key policies to combat climate change, reduce energy consumption and help achieving Paris Agreement targets within the context of the United Nations Framework Convention on Climate Change (UNFCCC, 2018a, Burniax and Chateau, 2014, IEA, 2015, Coady et al., 2015). At the same time following the downward trend in international energy prices (IEA, 2018) and some successful cases of the domestic energy markets reform (IEA, 2017b), their volumes have significantly decreased in recent years. While in 2014 economic value of global fossil-fuel consumption subsidies was around \$500 billion, in 2016 they amounted to \$260 billion (IEA, 2017a). Such sharp downward trend in subsidization, as well as high uncertainties around future development of international oil prices (IEA, 2018) could have a significant impact on the mitigation potential of the energy subsidies reform.

Some previous studies, though different in regional coverage, timeframe and modelling methodology, suggest that global fossil-fuel subsidies elimination may result in world greenhouse gas (GHG) or CO_2 emissions reductions between 6.5% and 10% relative to the reference scenario (OECD, 2009, Magne et al., 2014, Burniax and Chateau, 2014, IEA, 2015). More recent estimates (Jewel et al., 2018) argue that if current era of low oil prices would continue, environmental impacts of the global fossil-fuel subsidies reform could be as low as 1% decrease in world CO_2 emissions and even under high oil prices, global CO_2 emissions reductions would not exceed 4%.

At the same time, even under low international energy prices, some countries could significantly benefit from the fossil-fuel consumption subsidies elimination and achieve their Paris Agreement targets solely by implementing corresponding policy. While fossil-fuel subsidies reform is explicitly included into the Nationally Determined Contributions (NDC) of 13 countries, concrete impact on emissions reductions is often missing in the provided contributions (Terton et al., 2015). In this paper, we focus on 25 countries with large fossil-fuel consumption subsidies and estimate the impacts of global fossil-fuel subsidy reform on achieving country-specific emissions reductions targets defined by NDC. We provide an assessment of these policies under different assumptions about future international energy prices. Through our assessment, we use the Global Trade Analysis Project (GTAP) Data Base (Aguiar et al., 2016) with included fossil-fuel consumption subsidies

(Chepeliev et al., 2018b) and dynamic computable general equilibrium ENVISAGE model (van der Mensbrugghe, 2018).

The rest of the paper is organized as follows. Section 2 provides an overview of the NDC by countries and outlines an approach used to convert all pledges to the emissions reductions targets relative to baseline scenario. Section 3 discusses development of the baseline scenarios used for policy simulations. Section 4 provides assessment of the environmental and economic effects of global fossil-fuel consumption subsidies elimination with particular focus on meeting NDC targets. Finally, Section 5 concludes.

2. Energy subsidies and nationally determined contributions

As of March 2017, 175 countries have ratified the Paris Agreement within the context of the United Nations Framework Convention on Climate Change (UNFCCC, 2018a). At the same time, depending on the contributing country, NDC submissions use different approaches, timeframes and benchmarks towards the definition of emissions reductions targets, e.g. relative to a historical year, Business as Usual (BaU[1]) scenario, in terms of GDP carbon intensity changes, etc. For the purpose of this study, we harmonize all targets by converting them to emissions reductions relative to a country-specific BaU scenario.

We focus on the countries with largest fossil-fuel consumption subsidies and represent rest of countries as aggregate regions. We consider a country to be a large fossil-fuel subsidy supplier if total energy subsidies value is larger than $5 billion in 2011 or corresponding value relative to GDP is over 3%. Figure 1 reports fossil-fuel subsidy values and energy subsidies' share in GDP for selected countries that satisfy the aforementioned criteria. While in value terms, most fossil-fuel subsidies are associated with net energy exporters, over 40% of subsidization cases reported on Figure 1 take place in net energy importing regions (underlined red).

[1] We use expressions business as usual (BaU) and baseline as synonyms in this paper.

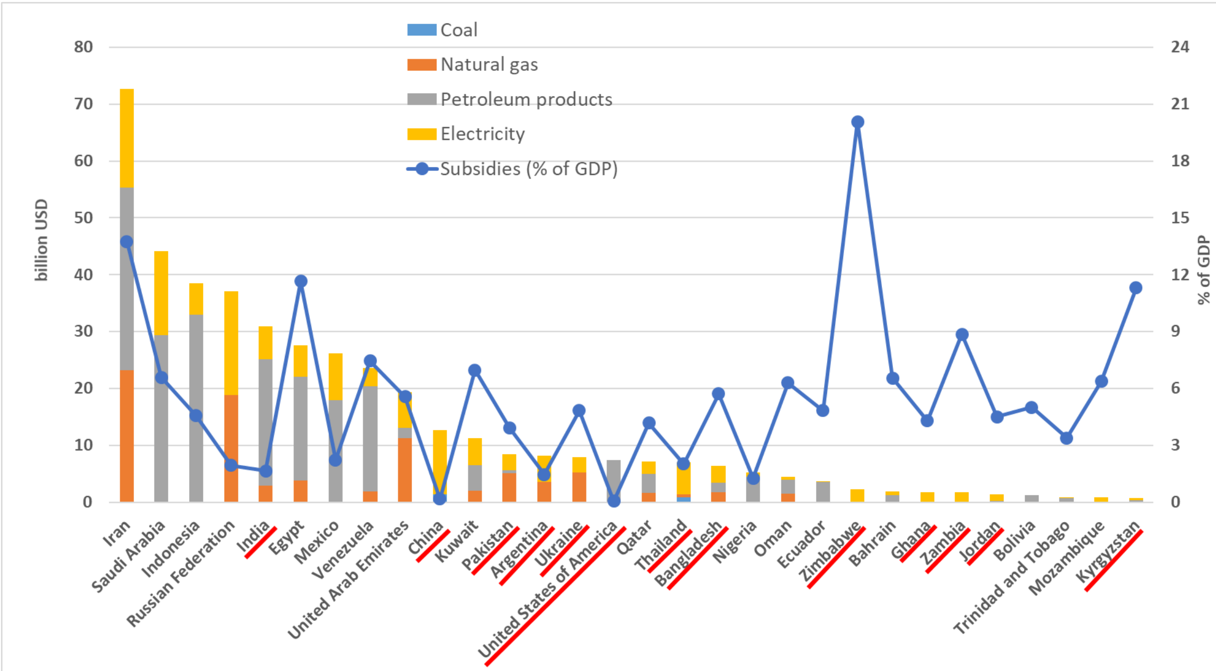

Figure 1. Magnitude of the fossil-fuel consumption subsidies in selected countries in 2011

Notes: Regions underlined red are net energy importers. Appendix A provides mapping between GTAP 9.2 Data Base regions and aggregation used in this study. Appendix B provides information on fossil-fuel subsidies for regions not reported on Figure 1.

Source: Estimated by authors based on IMF (2015), Coady et al. (2015), Aguiar et al. (2016).

We further identify levels of the BaU GHG emissions by countries in 2030 and convert these values to emissions changes w.r.t. 2011 levels. NDC targets are estimated as changes w.r.t. 2030 BaU emissions levels. Within the NDC, countries apply different approaches in developing their BaU paths. In some cases, GHG emissions under the BaU scenario are assumed to grow at the same pace or even faster than GDP growth rates. In particular, such cases include Pakistan, Ghana and Zimbabwe (Appendix C). Furthermore, for instance, in case of Pakistan, conditional NDC target (Appendix D) leads to the 2030 GHG emissions to be 3.5 times higher than 2011 levels (an average annual 6.9% emissions growth rate). This significantly exceeds existing forecasts of the GDP growth rates (Appendix C), thus assuming an increase of the GDP carbon intensity in Pakistan within the conditional NDC target.

While reference pathways (BaU) should provide information on how emissions would develop in the absence of climate policy (CAT, 2018), it does not mean that there should be no efficiency improvements and carbon intensity reductions in the baseline. To this extent, NDC that assume very moderate or even no GDP carbon intensity reductions under the BaU path seem to be infeasible and contradict historical trends. On the other hand, some developing countries assume relatively stringent BaU paths. For instance, Zambia assumes that GHG emissions under the BaU path would grow 1.33 times by 2030 w.r.t. 2011 levels.

There are some countries, whose NDC are non-binding, meaning that reference scenario (BaU path) gives lower emissions than the contributed NDC target. In some cases, like Russia and Ukraine (Appendix D), it happens due to the unambitious NDC targets. In other cases, to some extent in China and India (Appendix D), it is due to the relatively stringent baselines. In general, it is not always straightforward to identify whether the BaU path is realistic enough and whether contributed NDC targets are fair in terms of international efforts. In the latter case, judgement significantly depends on the criteria for fair distribution of emission allowances (Robiou du Pont et al., 2017, CAT, 2018).

In some cases, NDC set targets for CO_2 emissions only (contrary to all GHG emissions) or focus on the emissions in specific sectors (e.g. energy and transportation). In this paper we assume that emissions targets apply to four gases (groups of gases) – CO_2, CH_4, N_2O and F-gases. At this point, if only CO_2 emissions reductions target is reported (e.g. 30% w.r.t. BaU in 2030), we assume the same reductions target (30%) for CH_4, N_2O and F-gases. Furthermore, if reductions target covers only energy sector (e.g. 25% GHG emissions cut in energy sectors w.r.t. BaU in 2030), we assume that this target holds for all GHG emissions sources reported in our model (e.g. 25% reductions w.r.t. BaU in 2030).[2]

Not all countries report their BaU emissions and/or emissions reductions targets in the NDC. In some cases, when NDC targets are reported, but BaU emissions are not (e.g. China and India), we estimate baseline emissions based on additional sources (Appendix D). In some cases, NDC do not report any quantitative reductions targets (e.g. Bolivia, Bahrain, Kuwait, Qatar), but only describe measures that would implement to combat climate change. In such cases, we do not estimate any GHG emissions reductions targets.

Figure 2 provides BaU GHG emissions pathways, as well as unconditional and conditional (in most cases, depending on the international financial support) NDC targets for selected countries (largest providers of fossil fuel subsidies). It also

[2] In the current version of the ENVISAGE model (van der Mensbrugghe, 2018) emissions are generated by three sources: a) direct consumption of a commodity; b) factor-based emissions (e.g. capital, i.e. herds, in the livestock sectors); and c) output or processed based emissions (e.g. methane from landfills). Carbon emissions in the current model version are only generated by the combustion of fossil fuels – coal, oil (crude and refined) and natural gas. Emissions of other GHGs can be a combination of all three sources of emissions.

provides estimates of the GDP growth-based GHG emissions, assuming that emissions would grow in line with the real GDP growth rates (consistent with the OECD-based SSP2 scenario) and there would be a 1% annual GDP carbon intensity improvement. The latter assumption is consistent with historical global GDP carbon intensity reduction with an average of 1.5-1.6% for 1990-2016 period (Enerdata, 2017, US EIA, 2016b).

Although GDP growth-based estimates are used for qualitative comparisons, in general such estimates (with uniform efficiency improvements) can favor developed economies and undermine future efficiency improvements and structural transformations in developing countries. While such comparison has significant shortcomings, large gap between GDP growth-based and NDC-reported BaU provides an additional indication of the unrealistically high BaU paths in some countries.

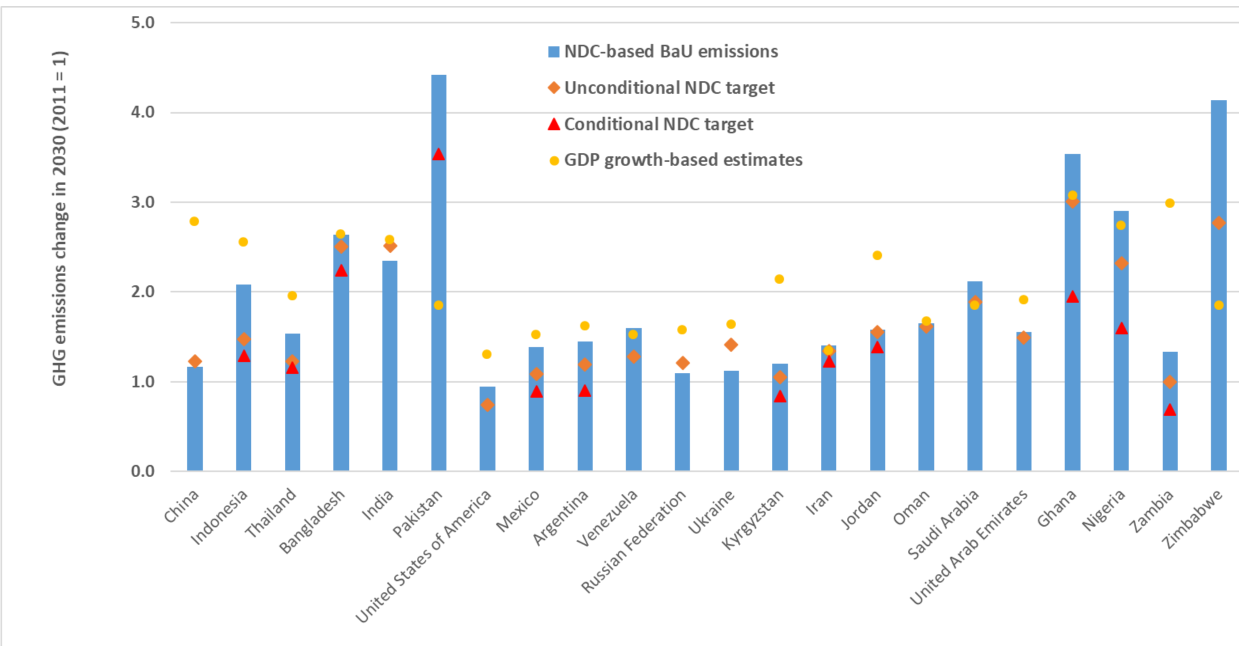

Figure 2. Baseline emissions, unconditional and conditional reduction targets associated with NDC in 2030, (2011=1)

Notes: 2030 emissions levels are expressed relative to 2011 levels (2011 = 1). GDP growth-based estimate assumes that GHG emissions would be growing in line with SSP2 scenario GDP growth rates (IIASA, 2016) and GDP carbon intensity would be reducing 1% per year.

Source: Estimated by authors based on IIASA (2016), UNFCCC (2018b), CAT (2018), CW (2018), WB (2017), US EPA (2018), Chepeliev et al. (2018a).

3. NDC targets and baseline scenarios

To provide an assessment of the fossil-fuel subsidies elimination pathways, we use a global dynamic computable general equilibrium model ENVISAGE (van der Mensbrugghe, 2018). The core database, which includes energy volumes and CO_2 emissions, is the Global Trade Analysis Project (GTAP) version 9 (Aguiar et al., 2016). To complement an input database with other GHGs, we also use the GTAP non-CO_2 GHG emissions database (Irfanoglu and van der Mensbrugghe, 2015). In this paper, we are using a 9.2 version of the GTAP database with 2011 benchmark year.[3] We use a GTAP-Power extension of the GTAP Data Base (Peters, 2016) with electricity sector disaggregated into 12 sub sectors. We further include pre-tax fossil-fuel consumption subsidies to the GTAP Data Base following Chepeliev et al. (2018b).

Our baseline scenario uses macroeconomic and demographic assumptions of the OECD-developed SSP2 scenario from the SSP database (IIASA, 2016) that represents "middle of the road" pathway with intermediate socio-economic challenges for mitigation and adaptation. With quantified macroeconomic and demographic assumptions, SSP database does not provide detailed outline of energy profiles. Therefore, we make additional assumptions regarding long-term regional energy-environmental development. Appendixes E and F summarize our assumptions regarding production cost changes, shares of renewable technologies, electrification rates, energy efficiency changes, etc. To account for different options of the evolution of international energy prices and fossil-fuel subsidy values, we consider three scenarios:

- global oil price is fixed at the 2011 level[4] w.r.t. to the manufactures unit value (MUV) index ("Oil_const"); fossil-fuel subsidy values are calibrated using 2011 data;[5]

[3] Comparing to the GTAP 9 database, 9.2 release includes updated Input-Output tables for 28 EU countries, Switzerland, Venezuela, Thailand, Uganda, Philippines, Costa Rica, Tunisia, New Zealand, China, India and Ukraine. It also adds one new IO table for Tajikistan.

[4] 2011 is a reference year for our policy simulations.

[5] In this scenario, we calibrate the baseline to match IMF-based (IMF, 2015) 2011 fossil-fuel subsidy values following approach outlined in Chepeliev et al. (2018b). Fossil-fuel consumption subsidy rates remain unchanged at the 2011 levels over the 2011-2030 simulation horizon.

- oil prices follow "New Policies" scenario of the World Energy Outlook (IEA, 2017a) ("Oil_IEA_np"); fossil-fuel subsidy values are calibrated using 2011 and 2015 data; [6]
- oil prices follow World Bank commodity price forecasts (WB, 2018) ("Oil_WB"); fossil-fuel subsidy values are calibrated using 2011 and 2015 data.[6]

Appendix G represents evolution of the world oil prices and global fossil-fuel subsidy values under different baseline scenarios. As can be seen from Figure G.2, under "Oil_const" scenario global fossil fuel subsidies increase from around 500 bn USD in 2011 to 900 bn USD in 2030. This scenario can be viewed as the world with relatively high oil prices. Both "Oil_IEA_np" and "Oil_WB" scenarios are set up to capture an observed reduction in the global fossil-fuel subsidy values, therefore in both of them 2015 subsidy values roughly exceed 300 bn USD. In case of "Oil_IEA_np" scenario, as oil prices recover over time and reach 2011 levels around 2027, global fossil-fuel subsidy values increase to almost 600 bn USD in 2030 (Figure G.2). Under "Oil_WB" scenario oil prices gradually decrease after 2020 and the value of fossil-fuel consumption subsidies in 2030 is 450 bn USD – 6% lower than 2011 value (Figure G.2).

After running the ENVISAGE baseline scenarios with the outlined assumptions, we observe a GHG emissions profiles in some cases significantly different from those assumed by NDC-based BaU paths. Though in many cases, GHG emissions are relatively close and difference does not exceed 10% (e.g. Ukraine, Kyrgyzstan, Jordan, United Arab Emirates, etc.), cases with much higher deviations are also observed (Figure 3). For some countries, like Pakistan, Ghana and Zimbabwe, as discussed above, NDC-based BaU emissions profiles seem to be inconsistent (too high) with historical trends and available macroeconomic and technological forecasts. In all cases for the purpose of policy simulations, we keep the developed BaU emissions profiles. To ensure consistency between NDC targets and developed baseline emissions, NDC targets are rescaled to keep the same level of GHG emissions reductions w.r.t. BaU path, as reported by NDC.[7] Figure 3 reports

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[6] Baseline is calibrated to match 2011 and 2015 subsidy values provided by IMF (2015). Fossil-fuel subsidy rates are changed between 2011 and 2015 to match the 2015 values. After 2015 fossil-fuel consumption subsidy rates remain unchanged.

[7] For instance, if NDC-based BaU provides reference GHG emissions to be 1.5 in 2030 w.r.t 2011 levels and reports NDC target to be 0.8 w.r.t. BaU in 2030 (i.e. 1.5 x 0.8 = 1.2 w.r.t. 2011 levels), we use the same level of NDC target w.r.t. BaU in 2030 and apply it to the updated (ENVISAGE-based) BaU levels. So if ENVISAGE-based BaU reports 2030 emissions to be 1.45 (w.r.t. 2011), updated NDC target would be 1.16 (1.45 x 0.8). With this approach we may be overestimating

the NDC-based and developed BaU GHG emissions levels in 2030 for selected countries.

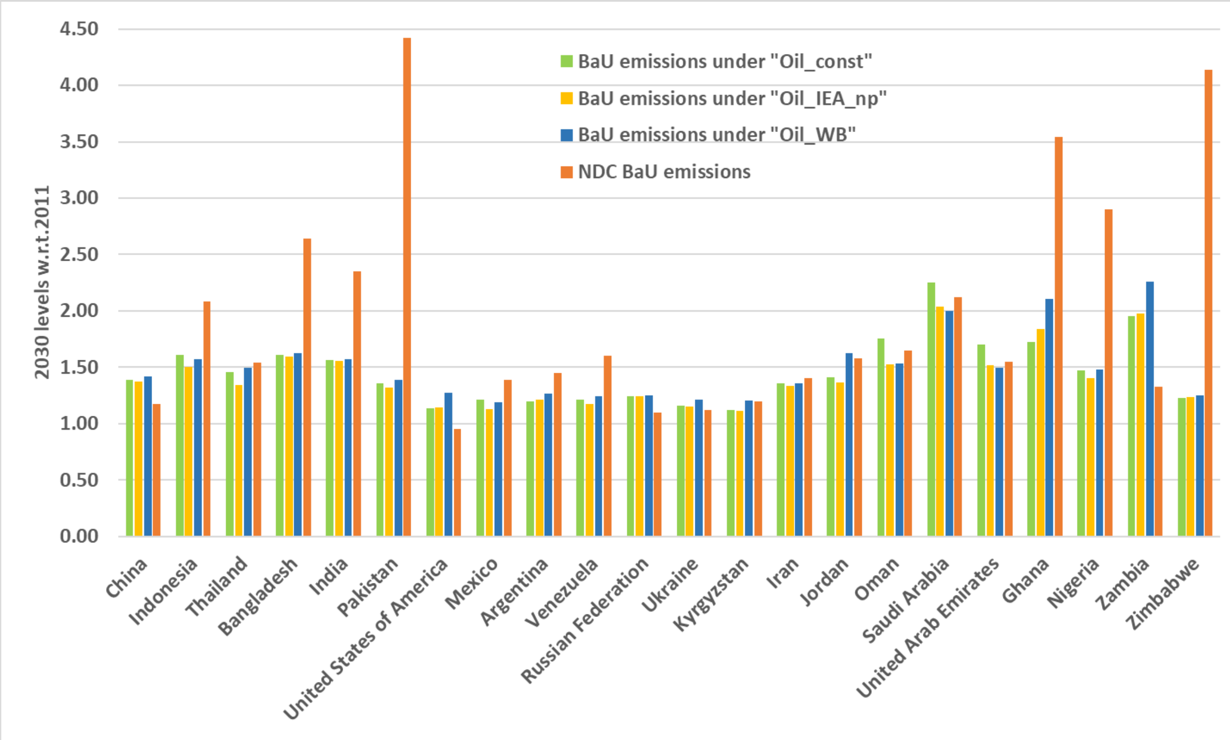

Figure 3. 2030 BaU GHG emissions and NDC targets, 2011=1

Notes: 2030 emissions levels are expressed w.r.t. 2011 levels. 2011 emissions levels are assumed to equal "1". Non-binding NDC targets are not represented.

Source: Estimated by authors based on UNFCCC (2018b), CAT (2018), CW (2018), WB (2017), US EPA (2018), Chepeliev et al. (2018a).

In 13 out of 22 country cases, difference in emissions levels in 2030 between NDC-based BaU and at least one of the developed baselines ("Oil_const", "Oil_WB" or "Oil_IEA_np") is less than 20%. On the global level, according to the comparisons of the developed BaU GHG emissions profiles with other sources, our estimates are close to the baseline scenarios reported in IIASA (2016) and CAT (2018) (Appendix H).

4. Simulation results

With pre-tax fossil-fuel consumption subsidies included in the GTAP database and developed baseline scenarios, we run the policy simulation. Our policy scenario

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necessary reductions for countries with high levels of the NDC-reported emissions (e.g. Ghana, Nigeria, Zimbabwe).

corresponds to the full elimination of fossil-fuel consumption subsidies between 2020 and 2025.

As can be seen, under all three scenarios most significant relative price changes due to pre-tax fossil-fuel consumption subsidies elimination have place in developing and net energy exporting countries (Appendix I). Both in absolute and relative terms, coal is the least subsidized energy commodity, while electricity experiences the highest price increase in most cases. As in case of electricity, subsidization rates are not directly linked to international oil prices, under lower oil price scenarios ("Oil_IEA_np" and "Oil_WB"), electricity subsidization rates are becoming even higher relative to petroleum and natural gas rates (Figure I.2).

On the global level, fossil-fuel consumption subsidies elimination results in GHG emissions reductions by 1.8-3.2% in 2030 depending on the oil price scenario (Figure 4). In general, our simulations show smaller reductions in global emissions compared to most previous studies, as OECD (2009), Magne et al. (2014), Burniax and Chateau (2014) and IEA (2015) report global emissions reductions between 6.5% and 10%, and are more in line with results from Jewell et al. (2018).

Explaining variation in global GHG emissions reductions between different oil price scenarios and comparing the results with other studies (e.g. Jewell et al. (2018) report GHG emissions reductions between 1% and 4%[8]), several factors should be considered. First, in our analysis fossil-fuel subsidies phase out starts in 2020, after oil prices have passed the lowest point in 2016 and recovered to the higher levels. Second, under scenarios with lower oil prices ("Oil_IEA_np" and "Oil_WB") there is a higher energy demand for energy than in the "Oil_const" scenario, which partially compensates for lower prices in terms of subsidy values. Third, electricity subsidies are not significantly impacted by the global oil price changes, as electricity generation costs also depend on other factors.

On the country level, GHG emissions reductions due to subsidies elimination largely vary, with highest reductions of 38% (w.r.t. BaU in 2030) achieved by Kuwait under "Oil_const" scenario (Figure 4). Out of 17 countries with explicitly defined binding NDC emissions reductions targets, five (Iran, Jordan, Oman, Saudi Arabia and United Arab Emirates) are able to meet their unconditional targets following subsidies elimination under "Oil_const" scenario. Four of these countries (excluding Saudi Arabia) meet their unconditional NDC targets under all oil price

[8] It should be noted that 1-4% interval for the global GHG emissions changes reported in Jewell et al (2018) is also influenced by different modelling approaches (study reports results for five different models), while variations within one modelling approach are smaller.

scenarios. Furthermore, Iran meets both conditional and unconditional NDC targets under all oil price scenarios (Figure 4).

In the case of four large subsidy suppliers that have not provided explicit emissions reductions targets in their NDC contributions (Bahrein, Kuwait, Qatar and Egypt), all these countries meet an average NDC emissions reductions target, which is 15.2%[8] (w.r.t. to BaU in 2030), under "Oil_const" scenario. Two of these countries (Bahrain and Qatar) also meet 15.2% reduction target under "Oil_IEA_np" scenario (Figure 4).

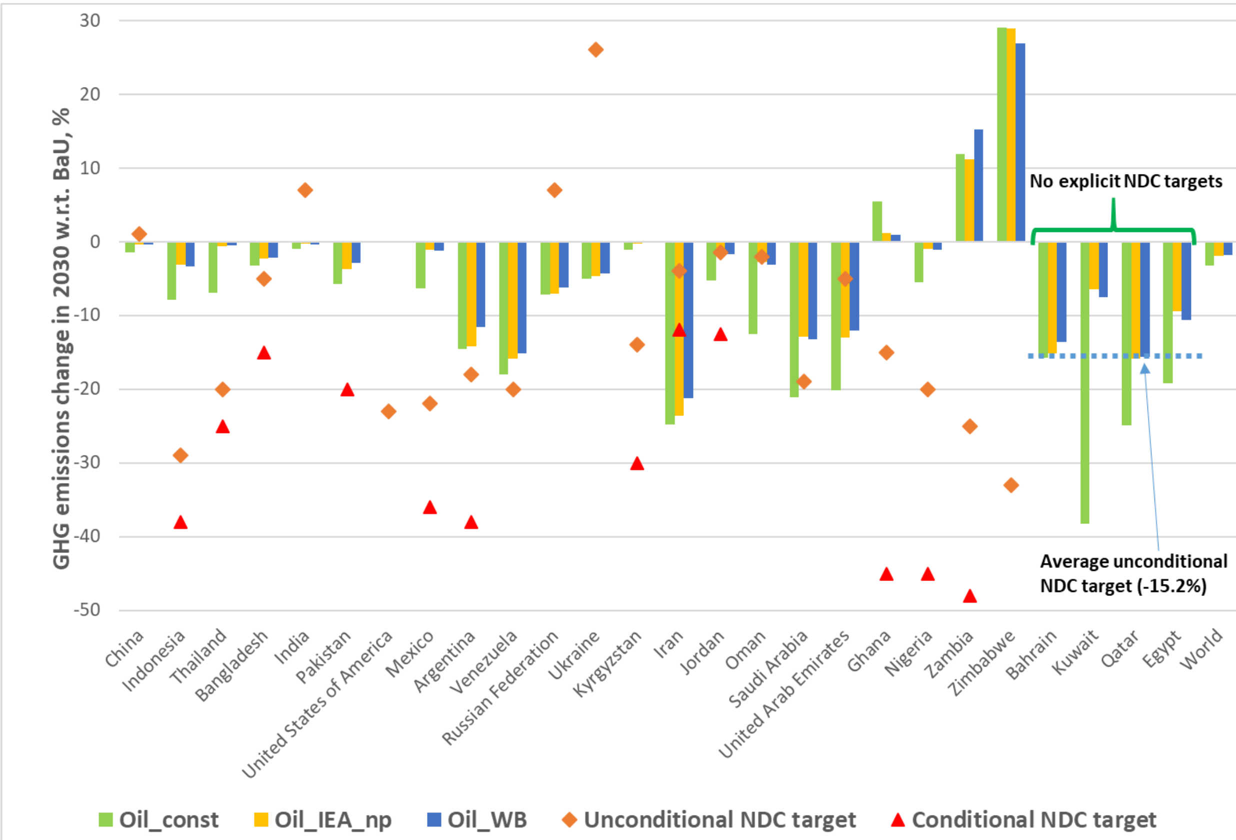

Figure 4. GHG emissions changes following fossil-fuel consumption subsidies elimination under different oil prices scenarios (w.r.t. BaU in 2030)

Notes: In case of Bahrain, Kuwait, Qatar and Egypt NDC do not provide any specific targets. For these countries, an average NDC target (based on the simple average of the NDC reduction targets from the considered country sample[9]) is indicated.
Source: Authors.

[9] Countries used to estimate an average NDC target include Indonesia, Zambia, USA, Mexico, Thailand, Venezuela, Nigeria, Saudi Arabia, Argentina, Ghana, Kyrgyzstan, Bangladesh, United Arab Emirates, Iran, Oman and Jordan.

There is a set of countries that are not fully meeting their unconditional NDC targets following fossil-fuel subsidies elimination, but make a significant progress towards its achievement. In particular, Bangladesh, Argentina and Venezuela reach at least 65% of the reduction targets under "Oil_const" scenario and over 40% under "Oil_WB" scenario with the lowest oil prices (Figure 4). Out of 21 countries with either reported or estimated[10] binding unconditional NDC reduction targets,[11] nine overreach their targets under "Oil_const" scenario, six under "Oil_IEA_np" scenario and five under "Oil_WB" scenario. Ten countries reach at least 50% of their NDC reductions targets following subsidies elimination under the "Oil_WB" scenario (Figure 4). Therefore, though global GHGs emissions reductions under low oil price scenario ("Oil_WB") is 45% lower than in the "Oil_const" case (-1.8% vs -3.2%), low oil price pathway still leaves high incentives for the heavy subsidy providers to proceed with the reform.

While most subsidy providers experience large GHG emissions reductions following subsidies elimination, there is a moderate emissions leakage (Appendix J). In absolute terms, such leakage is mainly associated with developed countries that do not apply fossil-fuel consumption subsidies, but in a few cases, heavy subsidy providers are experiencing GHG emissions increase following subsidies removal (Appendix J). Such countries include Ghana, Zambia and Zimbabwe (Figure 4).

In these countries, most fossil-fuel consumption subsidies are associated with electricity sector (Appendix I), while in the sectoral GHG emissions profile, electricity contributes between 3% and 17% at the national level (Figure K.1). Significant reductions in output and emissions associated with electricity generation is outweighed by growing output in other sectors (mainly, livestock, trade and transport, and other services – Figure K.3), which leads to the sectoral GHG leakages and emissions increase at the national levels (Figure K.2).

In terms of global welfare impacts,[12] fossil-fuel subsidies elimination under all three oil price scenarios results in slightly positive effects (global welfare increases by 0.1%-0.3% in 2030) implying negative costs of GHG emissions reductions (Appendix L). Moderate welfare reductions (on average 1-2%) in the developed countries is compensated by higher welfare gains in the heavy subsidy providers (up to 7% in some cases) (Appendix L).

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[10] Refers to Bahrein, Kuwait, Qatar and Egypt.

[11] Therefore, this set excludes countries with non-binding reduction targets – China, India, Russian Federation and Ukraine.

[12] Welfare changes are estimated in terms of changes in the disposable households' real income.

5. Conclusions

Recent downward trend in the international energy prices, rapid transitions in national energy mixes and wide spreading efforts towards national energy markets liberalization have challenged the mitigation potential of the global fossil-fuel subsidies reform. While some earlier studies suggested that elimination of world fossil-fuel subsidies may result in global GHG emissions reductions by 6.5%-10% (OECD, 2009, Magne et al., 2014, Burniax and Chateau, 2014, IEA, 2015), more recent estimates argue that even under high oil prices such reductions would not exceed 4% and could be as low as 1% under low oil price scenario (Jewell et al., 2018).

NDC submissions of the 13 countries explicitly include fossil-fuel subsidies reform in the set of policies to reach Paris Agreement targets, though in most cases exact contributions of such policies are missing (Terton et al., 2015). In this paper, we focus on 25 countries with large fossil-fuel consumption subsidies and estimate the impacts of fossil-fuel subsidy reform on achieving country-specific emissions reductions targets defined by NDC under different oil price forecasts. For such assessment we use the Global Trade Analysis Project Data Base with included fossil-fuel consumption subsidies (Chepeliev et al., 2018) and dynamic computable general equilibrium ENVISAGE model (van der Mensbrugghe, 2018).

According to our results, while on the global level fossil-fuel consumption subsidies elimination results in GHG emissions reductions by 1.8-3.2% in 2030 depending on the oil price scenario, on the national level, such policies could still be efficient tools for meeting NDC targets. Out of 17 countries with binding unconditional NDC targets,[13] nine overreach their 2030 commitments under high oil price scenario and five under low global oil prices. Furthermore, ten countries reach at least 50% of their NDC reduction targets following subsidies elimination under low global oil price path. Therefore, even low oil price pathway leaves high incentives for the heavy subsidy providers to proceed with the reform, especially taking into account that most of such policies are associated with positive welfare impacts (global welfare increases by 0.1%-0.3% in 2030), implying negative costs of GHG emissions reductions. Iran is the only country, where subsidies elimination leads to the achievement of both conditional and unconditional reduction targets under all oil price scenarios.

[13] This set of countries includes Bahrain, Kuwait, Qatar and Egypt. For these countries conditional GHG emissions reductions targets are not explicitly provided in the NDC submissions, but are estimated as a simple average of the conditional targets provided by other countries. See Section 4 for more details.

While most subsidy providers experience large GHG emissions reductions following subsidies elimination, there is a moderate emissions leakage. In absolute terms, such leakage is mainly associated with developed countries that do not apply fossil-fuel consumption subsidies, but in a few cases, heavy subsidy providers experience GHG emissions increase following subsidies removal. Such countries include Ghana, Zambia and Zimbabwe. In these countries, most fossil-fuel consumption subsidies are associated with electricity sector, which accounts for only 3%-17% of national emissions. As a result, fossil-fuel subsidies elimination leads to the electricity-related emissions reductions, but growing output in other sectors (mainly, livestock, trade and transport, and other services) leads to the sectoral GHG leakages and emissions increase at the national levels. In case of these countries subsidies elimination on its own is not an efficient policy to cut the GHG emissions and additional policy instruments should be implemented.

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Appendix A. Regional Aggregation

No.	Aggregate region	GTAP region
1.	Iran (IRN)	Iran
2.	Saudi Arabia (SAU)	Saudi Arabia
3.	Indonesia (IDN)	Indonesia
4.	Russian Federation (RUS)	Russian Federation
5.	India (IND)	India
6.	Egypt (EGY)	Egypt
7.	Mexico (MEX)	Mexico
8.	Venezuela (VEN)	Venezuela
9.	United Arab Emirates (ARE)	United Arab Emirates
10.	China (CHN)	China
11.	Kuwait (KWT)	Kuwait
12.	Pakistan (PAK)	Pakistan
13.	Argentina (ARG)	Argentina
14.	Ukraine (UKR)	Ukraine
15.	United States of America (USA)	United States of America
16.	Qatar (QAT)	Qatar
17.	Thailand (THA)	Thailand
18.	Bangladesh (BGD)	Bangladesh
19.	Nigeria (NGA)	Nigeria
20.	Oman (OMN)	Oman
21.	South Central Africa (XAC)	South Central Africa
22.	Ecuador (ECU)	Ecuador
23.	Zimbabwe (ZWE)	Zimbabwe
24.	Bahrain (BHR)	Bahrain
25.	Ghana (GHA)	Ghana
26.	Zambia (ZMB)	Zambia
27.	Jordan (JOR)	Jordan
28.	Bolivia (BOL)	Bolivia
29.	Mozambique (MOZ)	Mozambique
30.	Trinidad and Tobago (TTO)	Trinidad and Tobago
31.	Kyrgyzstan (KGZ)	Kyrgyzstan
32.	Rest of North Africa (XNF)	Rest of North Africa
33.	Rest of East Asia (XEA)	Rest of Oceania, Mongolia, Rest of East Asia, Brunei Darussalam, Cambodia, Laos, Malaysia, Philippines, Vietnam, Rest of Southeast Asia
34.	Rest of Sub-Saharan Africa (XSS)	Benin, Burkina Faso, Cameroon, Cote d'Ivoire, Guinea, Senegal, Togo, Rest of Western Africa, Central Africa, Ethiopia, Kenya, Madagascar, Malawi, Mauritius, Rwanda, Tanzania, Uganda, Rest of Eastern Africa, Botswana, Namibia, South Africa, Rest of South African Customs Union, Rest of the World
35.	Rest of Western Asia (XWS)	Rest of Western Asia

No.	Aggregate region	GTAP region
36.	Rest of energy producers in ECA (XEE)	Kazakhstan, Azerbaijan
37.	Rest of Latin America and Caribbean (XLC)	Brazil, Chile, Paraguay, Peru, Uruguay, Rest of South America, Costa Rica, Guatemala, Honduras, Nicaragua, Panama, El Salvador, Rest of Central America, Dominican Republic, Jamaica, Puerto Rico, Caribbean, Colombia
38.	Rest of MENA (XMN)	Turkey, Morocco, Tunisia
39.	Rest of high-income (XHY)	New Zealand, Hong Kong, Special Administrative Region of China, Japan, South Korea, Taiwan, Republic of China, Singapore, Canada, Rest of North America, Switzerland, Norway, Rest of EFTA, Israel
40.	Rest of South Asia (XSA)	Nepal, Sri Lanka, Rest of South Asia
41.	Rest of Europe and Central Asia (XEC)	Albania, Belarus, Croatia, Rest of Eastern Europe, Rest of Europe, Armenia, Georgia, Tajikistan, Rest of Former Soviet Union
42.	European Union (E28)	Austria, Belgium, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Poland, Portugal, Slovakia, Slovenia, Spain, Sweden, United Kingdom, Bulgaria, Romania

Appendix B. Distribution of the fossil-fuel consumption subsidies by aggregate regions

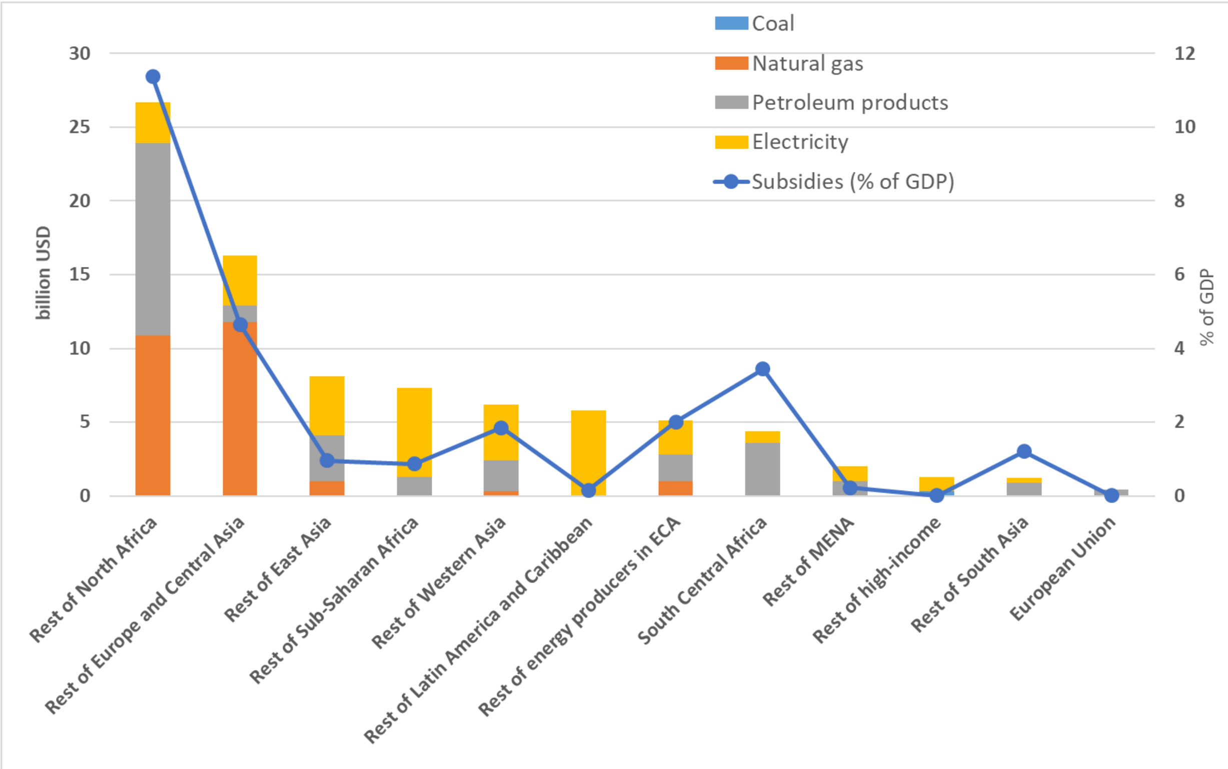

Figure B. Distribution of the fossil-fuel consumption subsidies by aggregate regions

Notes: Regional mapping is provided in Appendix A.

Source: Estimated by authors based on IMF (2015), Coady et al (2015), Aguiar et al (2016).

Appendix C. Verification of the BaU GHG emissions for selected countries

Country	NDC-based BaU GHG emissions annual growth rates, % (2012-2030)	Predicted annual GDP growth rates, %	
		IMF (2018); 2012-2023 average growth rate	OECD (IIASA, 2016); 2012-2030 average growth rate
Pakistan	8.1	4.6	4.4
Ghana	6.9	5.8	6.9
Zimbabwe	7.8	4.4	3.9

Notes: In case of GDP forecasts by OECD, we use the SSP2 scenario from the Share Socioeconomic Pathways (SSP) database (IIASA, 2016). SSP2 scenario represents "middle of the road" pathway with intermediate socio-economic challenges for mitigation and adaptation.

Source: Estimated by authors based on IMF (2018), IIASA (2016), UNFCCC (2018b).

Appendix D. BaU (reference) scenario emissions and NDC targets for selected countries

Region	CO_2 emissions, 2011 (Mtoe)	BaU emissions in 2030 (2011=1)	Unconditional NDC target (2030 BaU=1)	Conditional NDC target (2030 BaU=1)	Comment
China	9.6	1.17/ 1.21**	1.01-1.09/ 0.98-1.05**	NA	For the BaU path, an average of CAT current policy projections is taken. Unconditional targets are derived from CAT estimates.
Indonesia	0.6	2.08*	0.71	0.62	To estimate 2011 emissions from 2010 data, a 2000-2012 average GHG emissions growth rate of 3.2% is applied.
Thailand	0.3	1.54*	0.8	0.75	2012 GHG emissions are estimated based on per capita emissions provided in NDC and WB population data. 2011 emissions are derived from 2012 estimates based on Thailand’s' GHG emissions growth rates from CW (2018).
Bangladesh	0.2	2.64*	0.95	0.85	Bangladesh's NDC refers only to power, transport and industrial sectors. The same reduction target is applied to all other sectors.
India	2.8	2.35/ 1.74**	1.07 (0.84)/ 1.45(1.14)**	NA	BaU emissions are based on average of the current policy projection scenarios from CAT (2018). Unconditional target is derived from CAT (2018). Target in brackets corresponds to the Draft Indian electricity plan target (is not contributed to NDC).
Pakistan	0.3	4.42*	NA	0.8	Under the BaU scenario, Pakistan's NDC assumes GHG emissions growth rate higher than GDP growth rate.
United States of America	6.0	0.95/ 0.89**	0.77-0.79/ 0.82-0.84**	NA	In the NDC contribution emissions changes are provided w.r.t. to 2005 levels in 2025. BaU path is estimated as an average of “Current policy projections” scenarios from CAT (2018). 2030 emissions reductions targets are estimated as continuation of 2020-2025 reduction rates and corresponds to the “Obama Administration Mid-Century Strategy” (CAT, 2018).
Mexico	0.6	1.39*/1.07**	0.78/1.01**	0.64/0.83**	Historical emissions are sourced from CAT (2018).
Argentina	0.3	1.45*	0.82	0.62	Historical emissions are sourced from CAT (2018).
Bolivia	0.1	NA	NA	NA	Bolivia does not provide any details on emissions in the NDC.
Ecuador	0.05	NA	0.806-0.75	0.6	Unconditional NDC target is provided for energy sector only. No details on the BAU emissions are provided.

Region	CO_2 emissions, 2011 (Mtoe)	BaU emissions in 2030 (2011=1)	Unconditional NDC target (2030 BaU=1)	Conditional NDC target (2030 BaU=1)	Comment
Venezuela	0.2	1.6*	0.8	NA	BAU emissions in 2030 (w.r.t. 2011) are estimated based on the figure provided in NDC.
Trinidad and Tobago	0.04	NA	NA	0.85	Unconditional target is provided for the public transportation sector only. No data on the BaU emissions are provided.
Russian Federation	2.2	1.1/ 0.96**	1.07-1.13/ 1.23-1.29**	NA	No BaU path is provided in the NDC. Emissions reductions targets are provided w.r.t. 1990 levels. BaU path and NDC targets w.r.t. to BaU emissions are sourced from CAT (2018).
Ukraine	0.4	1.12	1.26	NA	BAU emissions are based on Chepeliev et al. (2018a). NDC reports emissions targets w.r.t. 1990 levels.
Kyrgyzstan	0.01	1.2*	0.86-0.89	0.69-0.71	BaU emissions are estimated based on the figure provided in NDC.
Bahrain	0.03	NA	NA	NA	Bahrain does not specify any targets in the NDC.
Iran	0.6	1.4	0.96	0.88	No BAU emissions are provided in the Iranian NDC. BaU emissions are estimated based on the BaU CO_2 growth rates provided in Cline (2011).
Jordan	0.02	1.58*	0.985	0.875	2030 BaU emissions (w.r.t. 2011) are estimated based on the 2006-2030 emissions growth rates from the NDC.
Kuwait	0.1	NA	NA	NA	No data for BaU path or commitments are provided in the NDC.
Oman	0.1	1.65*	0.98	NA	BaU emissions correspond to the "Total GHG Emission (without INDC)" scenario provided in Oman's NDC.
Qatar	0.1	NA	NA	NA	No data for BaU path or commitments are provided in the NDC.
Saudi Arabia	0.4	2.12	0.81-0.97		2030 BaU emissions are estimated as an average of CAT-reported NDC reference paths.
United Arab Emirates	0.2	1.55	0.95-0.97	NA	UAE contribution does not explicitly define BAU path or emissions reductions targets. Both are derived from CAT (2018) estimates. An average of CAT reported “Current policy projections” is taken as a BaU path. Estimates of the unconditional targets are based on the extrapolation of the CAT 2021 estimates.
Egypt	0.3	NA	NA	NA	No data for BaU path or commitments are provided in the NDC.

Region	CO_2 emissions, 2011 (Mtoe)	BaU emissions in 2030 (2011=1)	Unconditional NDC target (2030 BaU=1)	Conditional NDC target (2030 BaU=1)	Comment
Ghana	0.03	3.54*	0.85	0.55	BAU emissions (w.r.t. 2011) are derived from the NDC-reported BaU path with 2010 benchmark.
Nigeria	0.2	2.9*	0.8	0.55	BaU emission estimates are based on the figure provided in the NDC.
Mozambique	0.03	NA	NA	NA	No BAU emissions are provided.
Zambia	0.01	1.33*	0.75	0.52	Estimates are based on the figure provided in the NDC.
Zimbabwe	0.02	4.14*	0.67	NA	Unconditional target is estimated for the energy sector only (49% of total GHG emissions in 2000).

Notes: "NA" – data not available. * indicates BaU path reported in the NDC contribution. ** indicates estimates for the BaU/reference emissions paths sourced from US EIA (2016a).

Source: Estimated by authors based on UNFCCC (2018b), CAT (2017), CW (2018), WB (2018), US EPA (2018), Chepeliev et al (2018a).

Appendix E. Energy-environmental assumptions of the BaU path, %

Assumption	Implementation	Specific assumptions
Costs of renewables are declining over time	The cost reduction is implemented using a hyperbola specification with a cost asymptote. The curve is calibrated to three parameters – the asymptote (relative to current costs), a targeted reduction and the year the target is reached.	Wind – the asymptote is 80% of today's price and the costs are dropping by 10% between 2011 and 2030. Solar and other renewables – the asymptote is 60% and the costs are dropping by 20% between 2011 and 2030.
Non-price related changes in preferences towards renewables	Preference 'twist' parameters change the preference for one set of commodities in a demand system relative to other commodities, but without changing the aggregate cost (Dixon and Rimmer, 2002; van der Mensbrugghe, 2018).	We assume a target for renewable electricity as a share of total electricity demand and implement the twist assuming no change in prices (from the base year). The assumed shares are provided in Appendix E. The actual shares are likely to be higher given the decline in costs and the developments in the cost of other power activities. We do not introduce renewables, as a new technologies, in case of countries with "0" renewables share in the benchmark 2011 year (corresponding cases are marked "na" in the Appendix E).
Target increase in electricity share for agents (trend towards electrification following IEA (2017a))		We assume 1.3 times increase in electricity share in transportation sector (in corresponding regional energy consumption) for all regions by 2030. We also assume 1.1 times increase in electricity share for all non-energy industries.
Energy efficiency improvements	Improvements in energy efficiency are captured by the autonomous energy efficiency improvement parameter (AEEI). We assume AEEI to be differentiated by countries and changing over time.	In the benchmark year, AEEI is set at one per cent per annum across all activities, energy sources, and vintages (old vintage represents installed capital, while new vintage represents most recent supply of capital). AEEI values are further linked to the GDP growth rates and assume to increase with higher per capita GDP growth. For instance, if GDP growths at two per cent per annum, AEEI equals one per cent per annum, while if GDP increase at the rate of eight per cent per annum, AEEI equals five per cent per annum. We use a power function with defined

		elasticities to establish such link between GDP growth and AEEI values and use lower (0.5%) and upper (5.5%) bounds to cap AEEI levels. Fixed AEEI values are used for coal consumption (one per cent in developing countries and 0.5% in developed). In selected countries we further adjust (increase) the AEEI parameters to have a BaU GHG emissions more in line with NDC provided baselines. Such countries include China, USA, Russia, Kyrgyzstan, Oman, Saudi Arabia, United Arab Emirates, EU-28 and Zimbabwe.
Improvements in international transport costs		Costs decline by one per cent per annum.

Appendix F. Assumed renewables share in electricity generation in 2030 for BaU path, %

Aggregate region/country	Target renewable share	Aggregate region/country	Target renewable share
China	25	Rest of Western Asia	na
Indonesia	15	Egypt	15
Thailand	15	Rest of North Africa	na
Bangladesh	na	Ghana	na
India	12	Nigeria	na
Pakistan	na	South Central Africa	na
United States of America	20	Mozambique	na
Mexico	15	Zambia	na
Argentina	10	Zimbabwe	10
Bolivia	15	Rest of East Asia	15
Ecuador	10	Rest of South Asia	15
Venezuela (Bolivarian Republic of)	na	Rest of energy producers in ECA	na
Trinidad and Tobago	na	Rest of Europe and Central Asia	10
Russian Federation	10	Rest of MENA	15
Ukraine	12	Rest of Sub-Saharan Africa	10
Kyrgyzstan	na	Rest of energy producers in LAC	15
Rest of Former Soviet Union	na	Rest of Latin America and Caribbean	20
Bahrain	na	European Union	30
Iran	10	Rest of high-income	25
Jordan	10		
Kuwait	na		
Oman	na		
Qatar	na		
Saudi Arabia	na		
United Arab Emirates	na		

Source: Authors' estimates.

Notes: "na" stands for country/regions cases with "0" renewables share in the benchmark year (2011).

Appendix G. Crude oil prices and fossil-fuel subsidy values under different baseline scenarios

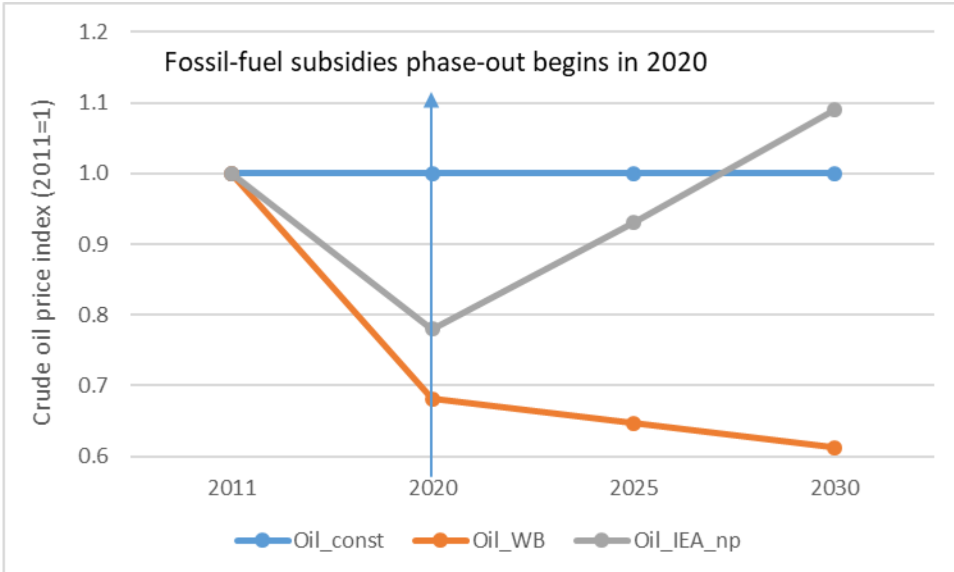

Figure G.1. Crude oil price assumptions under different baseline scenarios (2011=1)

*Source***:** WB (2018), IEA (2017a).

Notes: "Oil_const" corresponds to the scenario with fixed international crude oil prices w.r.t. to the manufactures unit value (MUV) index at the 2011 level; under "Oil_WB" scenario oil prices follow the World Bank commodity price forecasts; "Oil_IEA_np" corresponds to the International Energy Agency "New Policies" scenario.

Figure G.2. Fossil-fuel subsidy values under different baseline scenarios

Notes: "Oil_const" corresponds to the scenario with fossil-fuel subsidies calibrated to the 2011 levels; under "Oil_IEA_np" and "Oil_WB" scenarios fossil-fuel subsidy values are calibrated to the 2015 levels.

Source: Authors.

Appendix H. Baseline GHG emissions scenarios

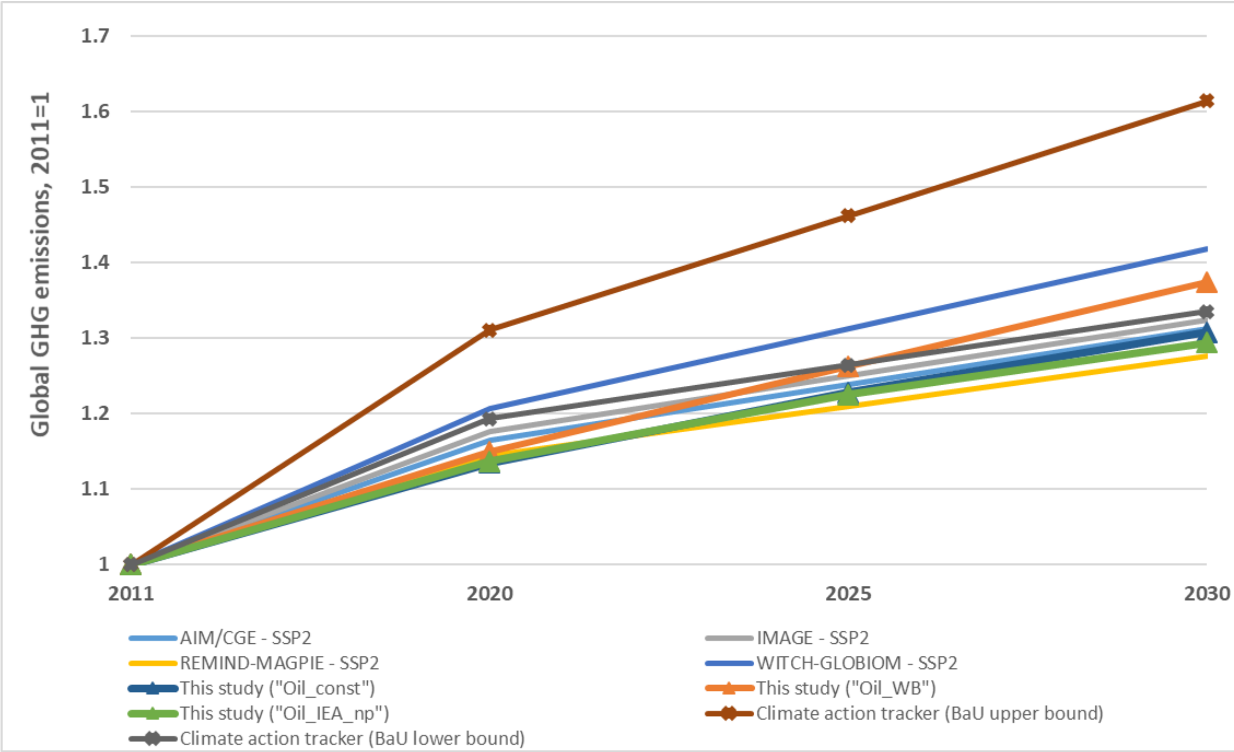

Figure H. Comparison of baseline GHG emission scenarios (2011=1)

Source: IIASA (2016), CAT (2018), authors' estimates.

Appendix I. Fossil-fuel consumption subsidy rates under different baseline scenarios

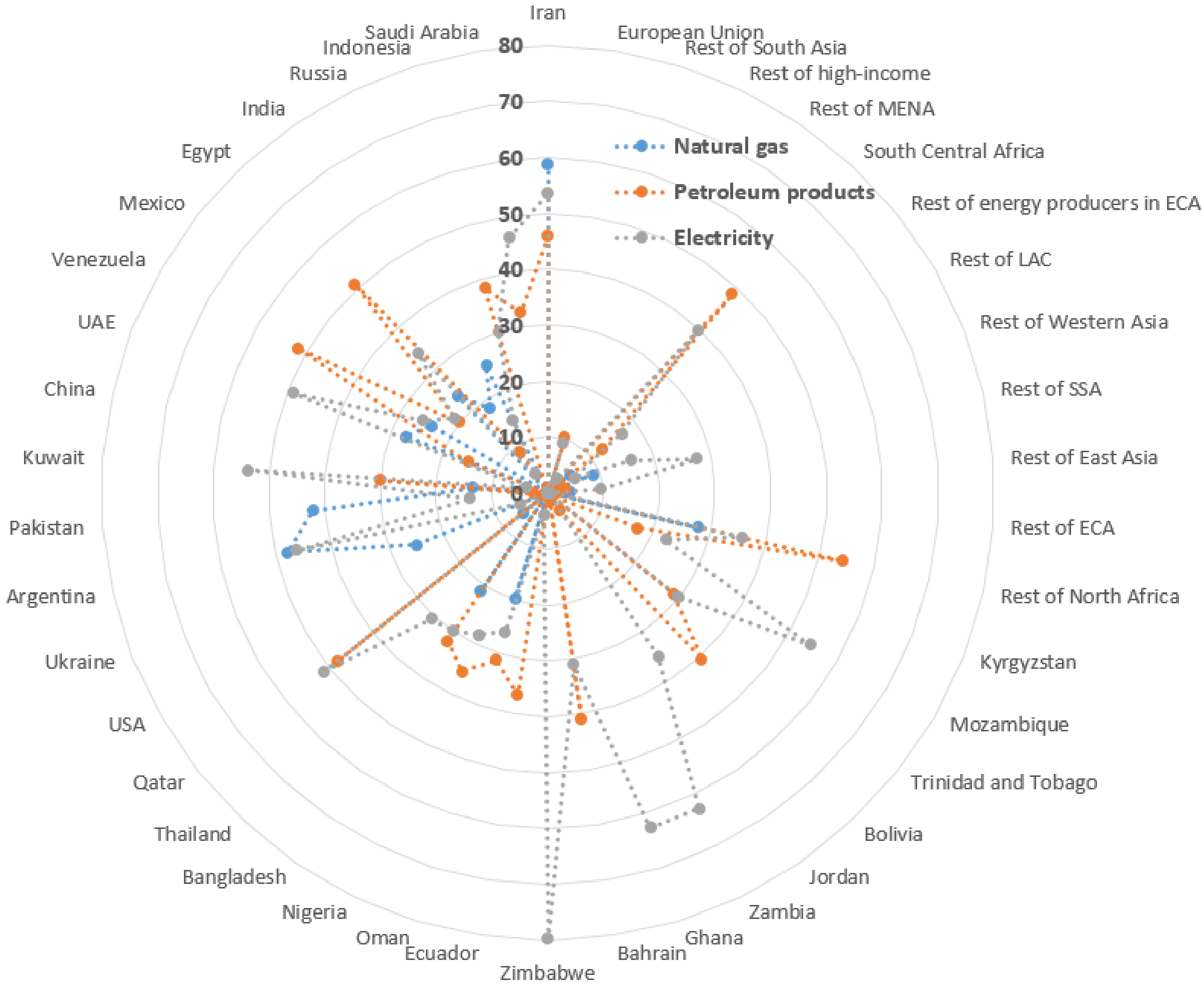

Figure I.1. Weighted average target energy consumption tax rate changes due to fossil-fuel consumption subsidies elimination under "Oil_const" scenario

Notes: Tax rates are estimated as a ratio of energy subsidies to domestic and imported energy commodities consumption at market prices.

Source: Authors.

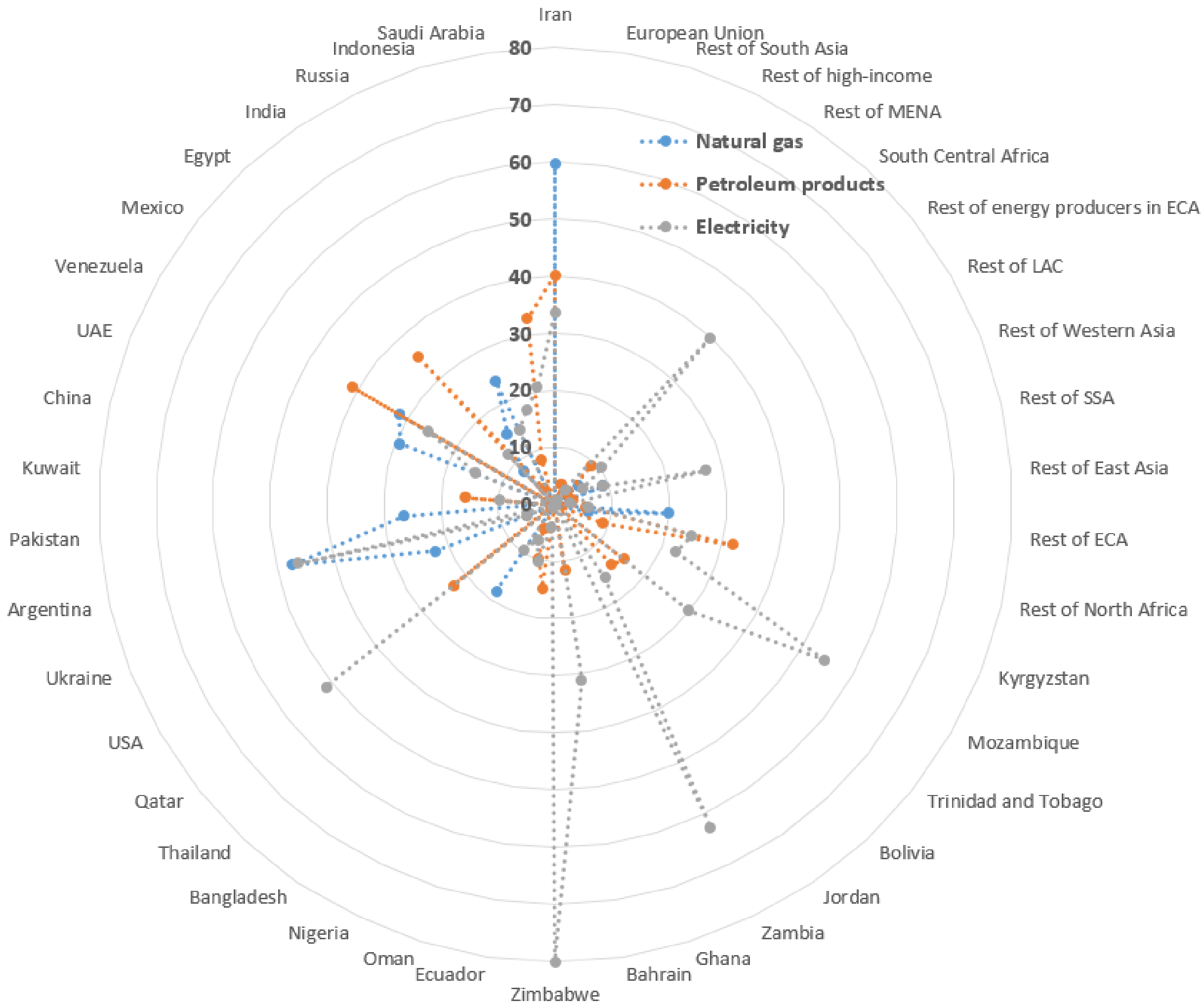

Figure I.2. Weighted average target energy consumption tax rate changes due to fossil-fuel consumption subsidies elimination under “Oil_IEA_np” and “Oil_WB” scenarios

Notes: Tax rates are estimated as a ratio of energy subsidies to domestic and imported energy commodities consumption at market prices. Depicted rates correspond to the 2015 fossil-fuel subsidy rates in the “Oil_IEA_np” and “Oil_WB” baselines.

Source: Authors.

Appendix J. Change in GHG emissions by regions w.r.t. BaU scenario in 2030 following fossil-fuel consumption subsidies elimination, %

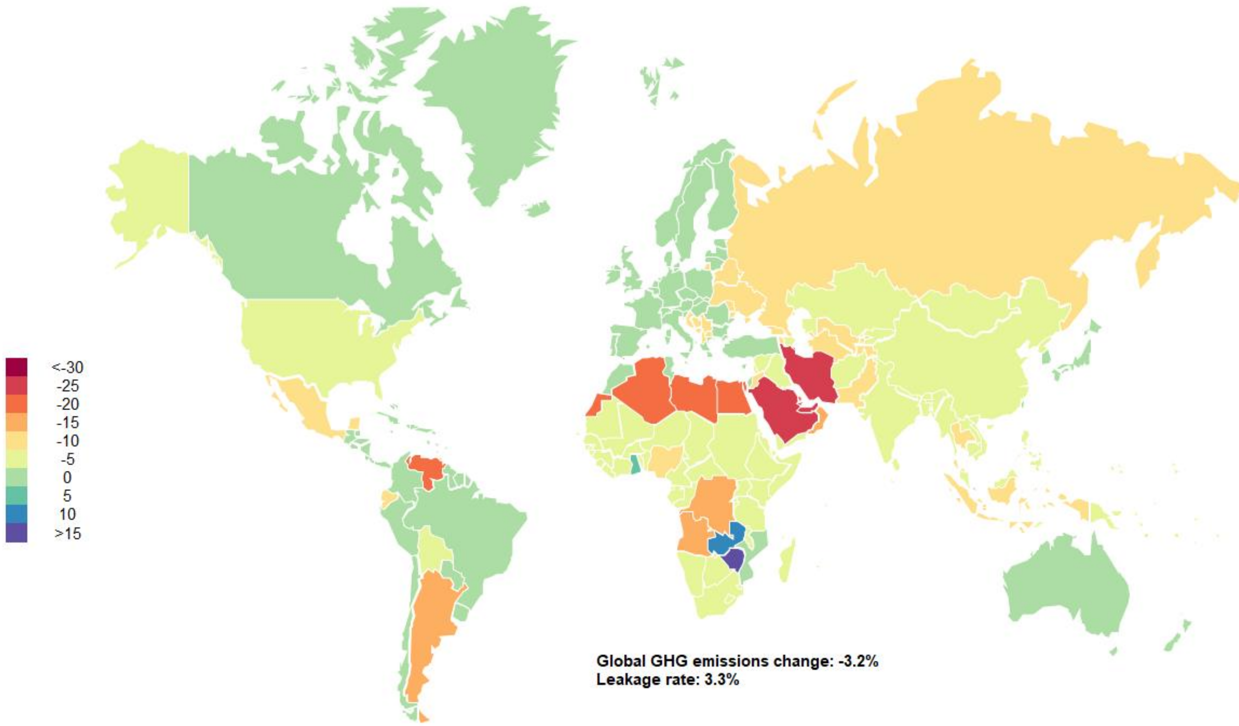

Figure J.1. GHG emissions change under "Oil_const" price scenario, %

Source: Authors.

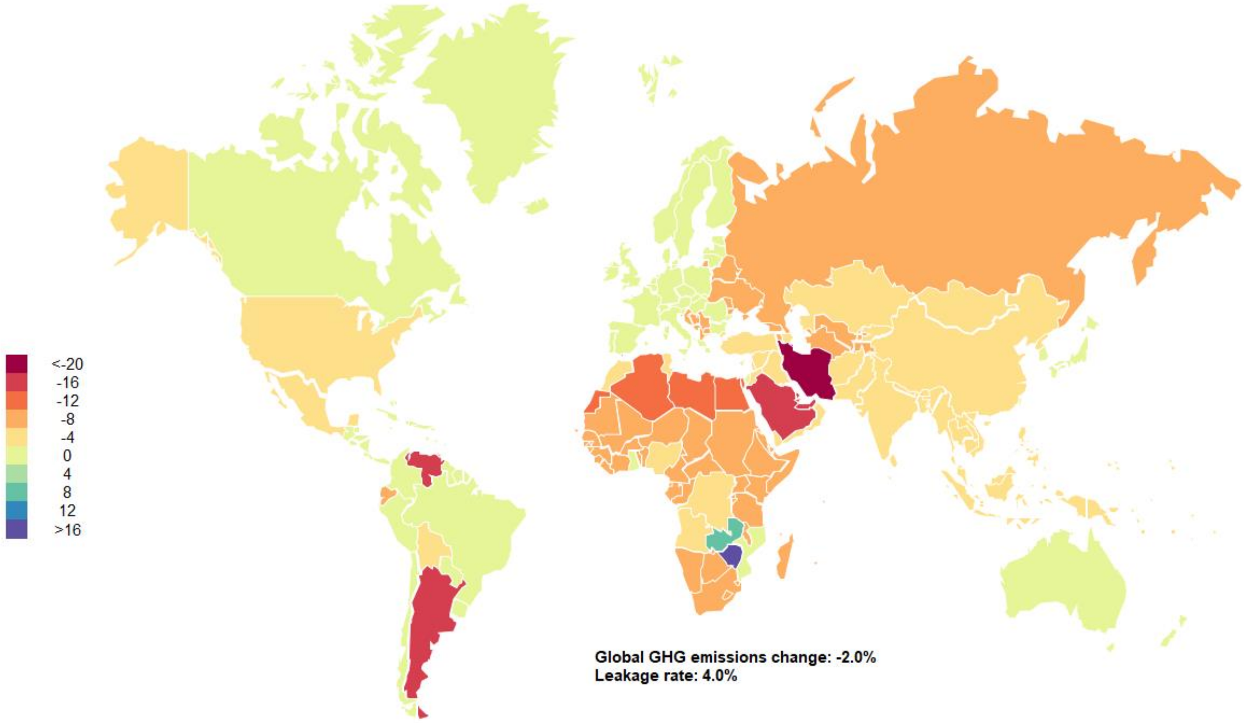

Figure J.2. GHG emissions change under "Oil_IEA_np" price scenario, %

Source: Authors.

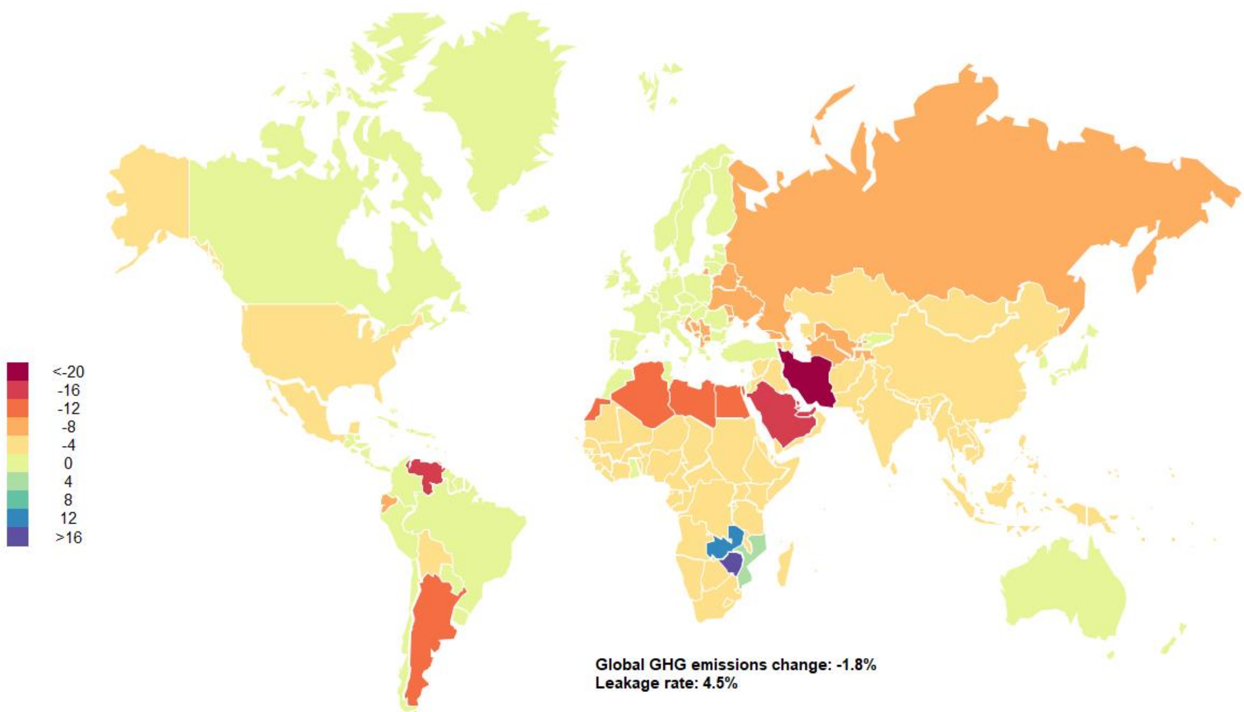

Figure J.3. GHG emissions change under "Oil_WB" price scenario, %

Source: Authors.

Appendix K. Sectoral GHG emissions leakages in selected countries

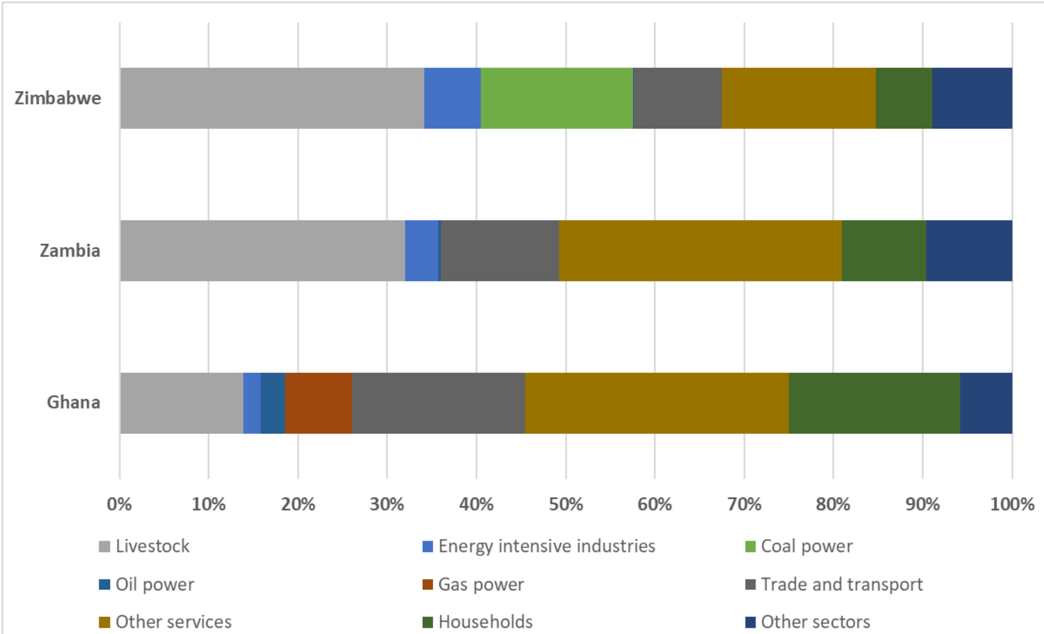

Figure K.1. Sectoral distribution of the GHG emissions in selected countries, 2011 (%)

Source: Authors.

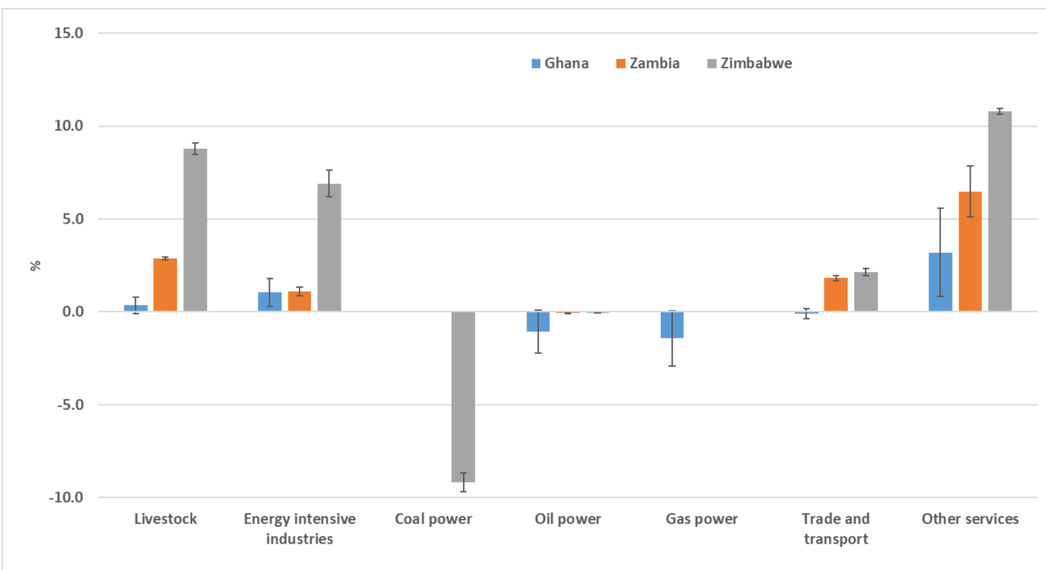

Figure K.2. GHG emissions changes for selected countries and sectors w.r.t. to BaU in 2030, % of the total emissions change

Notes: Column bars report simple average changes over three oil price scenarios; error bars report standard deviations from the simple average.

Source: Authors.

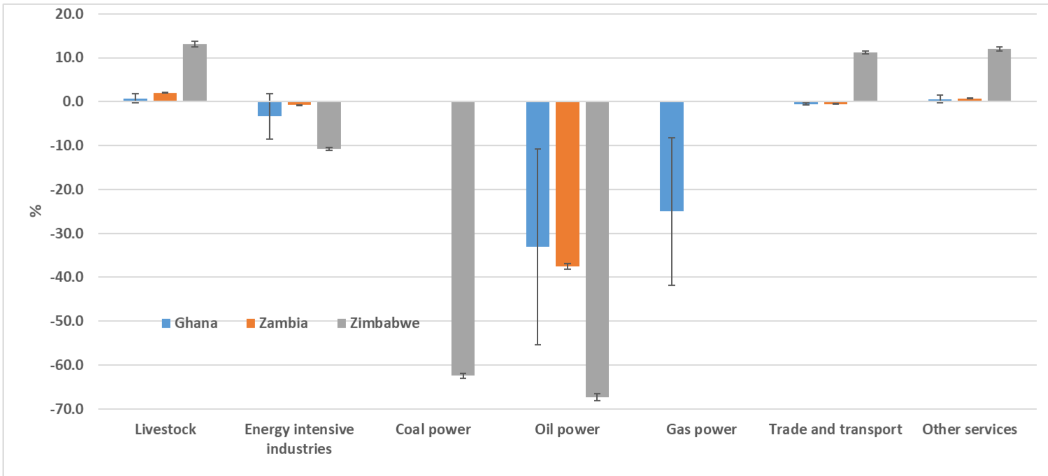

Figure K.3. Output changes for selected countries and sectors w.r.t. BaU in 2030, %

Notes: Column bars report simple average changes over three oil price scenarios; error bars report standard deviations from the simple average.

Source: Authors.

Appendix L. Households welfare changes w.r.t. BaU scenario in 2030 following fossil-fuel consumption subsidies elimination, %[14]

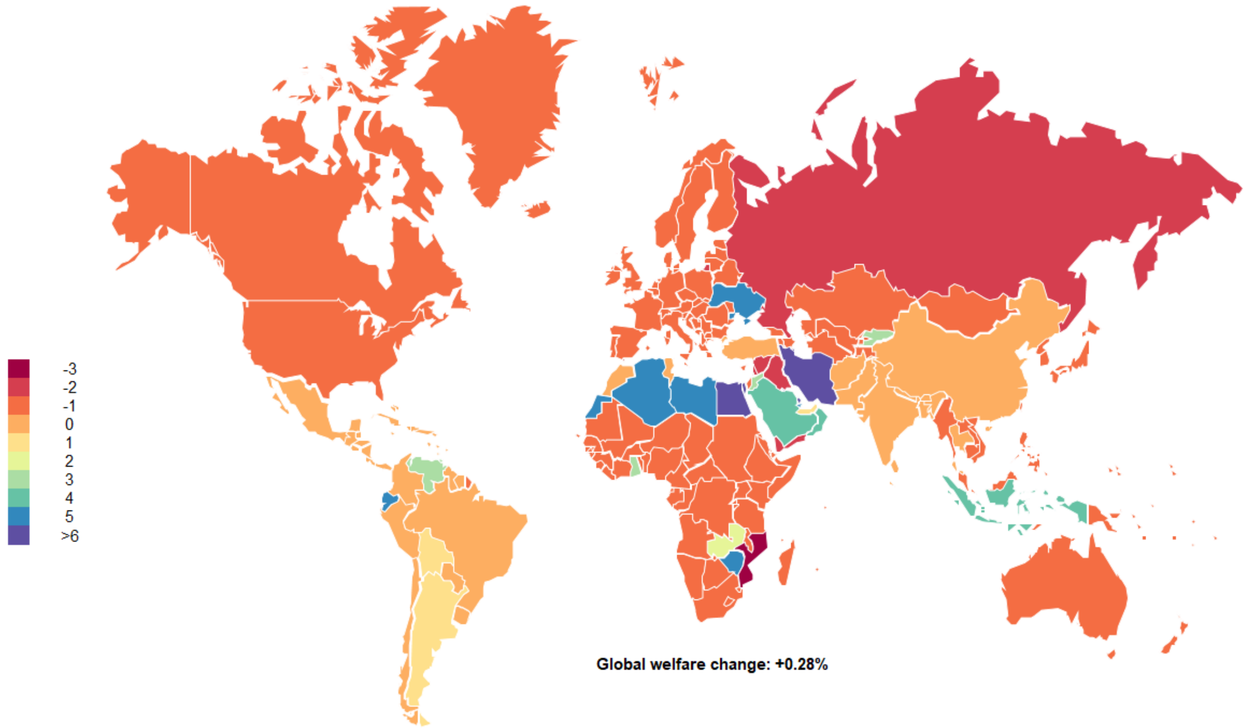

Figure L.1. Welfare changes under "Oil_const" price scenario in 2030, %

Source: Authors.

[14] Welfare changes are estimated in terms of changes in the disposable households' real income.

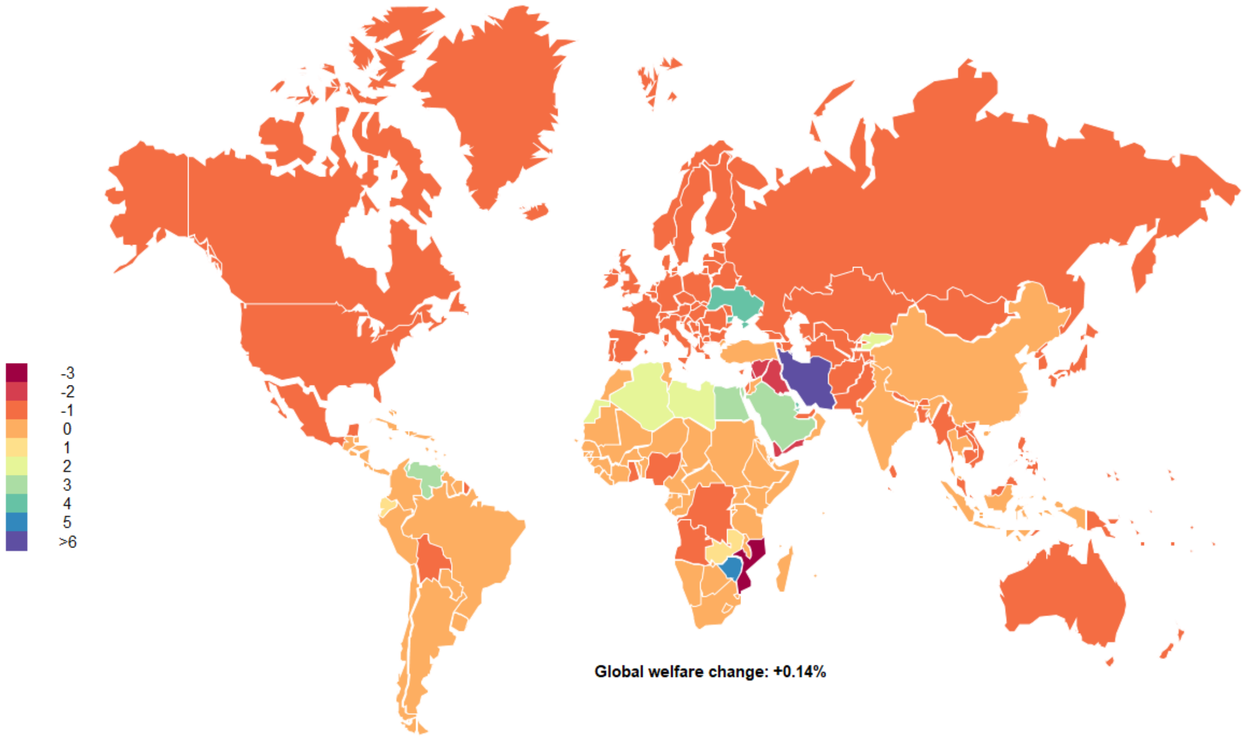

Figure L.2. Welfare changes under “Oil_IEA_np” price scenario in 2030, %

Source: Authors.

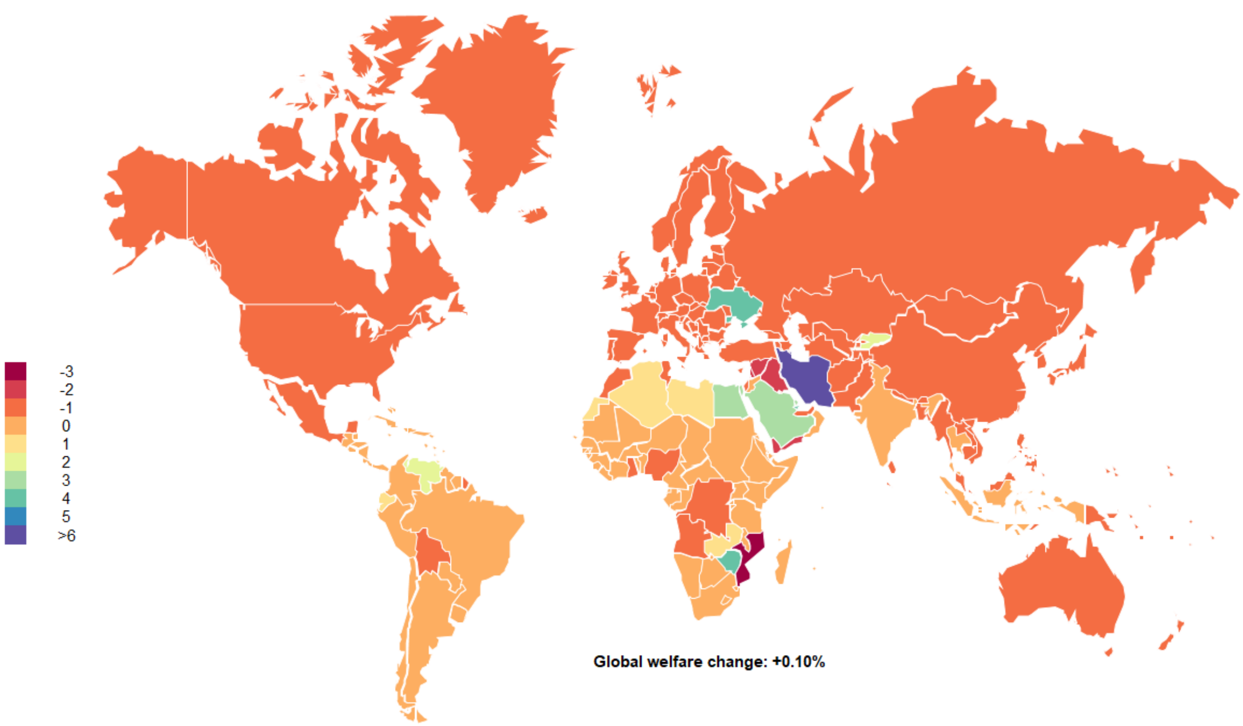

Figure L.3. Welfare changes under “Oil_WB” price scenario in 2030, %

Source: Authors.