Global Energy Subsidies Reform: Inclusive Approaches to Welfare Assessment

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20th Conference on Global Trade Analysis

Current draft: May 15, 2017

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Abstract

For several decades energy subsidies remain on the top of international policy agenda, serving as one of the most debated and widely used policy tools. Several major international organizations have attempted to quantify global energy subsidies and provide assessment of their potential reform. This includes studies by Organization for Economic Co-operation and Development (OECD), International Energy Agency (IEA) and International Monetary Fund (IMF). While most of these contributions provide estimates of economy-wide effects, they lack consistent assessment of environmental co-benefits of subsidies elimination, which can have a significant influence on aggregate results and their regional distribution.

In this paper, we apply a multistep framework to analyze two global energy subsidies scenarios, which include elimination of pre-tax consumer and post-tax local pollution subsidies. Computable general equilibrium GTAP-E-Power model is used to implement energy subsidy policies, quantify economic impacts, estimate energy use changes and CO_2 emissions. Energy use changes are linked to emission of air pollutants and pollution-mortality impacts are estimated based on the population exposed by pollution and corresponding mortality risks. Finally, welfare benefits related to reduced mortality rates are assessed using country-adjusted willingness-to-pay measure from direct valuation studies.

Results show that inclusion of mortality related benefits has significant impact on net welfare estimates. In case of pre-tax subsidies elimination, such approach turns two regions under consideration from net welfare losers to gainers and triples welfare benefits for China. Much more significant impacts occur in case of pollution subsidies elimination as net world welfare lost (-$400.9 billion) is turned into gain ($606.7 billion) with even more substantial changes on regional level. Considered energy subsidy policies show to substantially reduce air pollution-associated mortality rates – between 20.4 thousand (in case of pre-tax consumption subsidies) and 705.1 thousand (post-tax pollution subsidies) people annually. Global CO_2 emission reduces from 2.8% to 28% depending on scenario.

1. Introduction

For a long time, energy subsidies remain on the top of international policy agenda, serving as one of the most debated and widely applied policy tools. According to International Energy Agency (IEA), value of global fossil-fuel consumption subsidies totaled to $325 billion in 2015 (IEA, 2016), while International Monetary Fund (IMF), based on the broader post-tax subsidies definition, provides estimate of $5.3 trillion (Coady, 2015).

Though in most cases there is a theoretical consensus towards overall damage from subsidization (UNEP, 2003), many countries remain extensively subsidized with only several exceptions of successful reform implementation in recent years, including Morocco, United Arab Emirates, Egypt, China and Ukraine (Sovacool, 2017; OECD, 2016a). Usually, explanation can be found in the absence of political will coupled with the risks of possible regressive impacts on poor households. While in many cases estimated aggregate monetary loss, resulting from subsidization, may exceed profit (IEA, 1999), evaluation of expected utility distribution between economic agents, proper public consultations and development of effective compensatory mechanisms remain one of the most challenging tasks. A misleading assessment and policy implementation may lead to the unexpected social reaction, like protests in Bulgaria after 18% electricity price increase and Brazil due to the bus fare rise by 7 eurocents (The Economist, 2013a, 2013b; Bloomberg, 2013).

At the same time, quantitative assessment of energy subsidy policies often represents a restraining factor per se. In most cases, subsidies reform is associated with an interplay of social, economic and environmental effects, while corresponding policy analysis is performed using standard partial or general equilibrium treatment. Both approaches mainly focus on the impacts that occur within the market economy, usually leaving aside all non-market environmental effects. Naturally, in most cases it results in regressive economic outcomes with declining consumption, output, GDP and welfare, leaving to policy maker to decide whether resulting emission reductions and market liberalization outweigh social and economic damages (Clements, 2003; O'Ryan, 2005; Boccanfuso, 2009). At the same time, according to most studies, elimination of energy subsidies leads to the decrease of fossil fuels consumption and emissions. Both these effects positively contribute to the public welfare through lower mortality, decrease of defensive expenditures on health, higher labor productivity, lower environmental damage and less intensive natural capital depletion.

In this paper, we use the GTAP-E-Power model with added-in pollution module to explore the welfare co-benefits associated with reduced air pollution due to energy subsidies elimination. Developed approach allows us to contribute to the discussion of energy subsidies reform and associated quantitative assessment issues in several ways. Firstly, our study presents and implements a framework towards global energy subsidies integration into GTAP database. Secondly, we provide consistent assessment of global energy subsidies reform, taking into account an interplay of policies between various regions and different definitions of efficient energy prices. Finally, our study extends the conventional approach to welfare estimates and accounts for mortality reduction benefits associated with energy policies under consideration.

2. Definitions and current state of world energy subsidies

While "subsidy" concept is widely used in economic literature, its definition is highly debated (WTO, 2006). Differences in approaches to subsidies definition can be summarized in a form of nested sets (Figure 1).

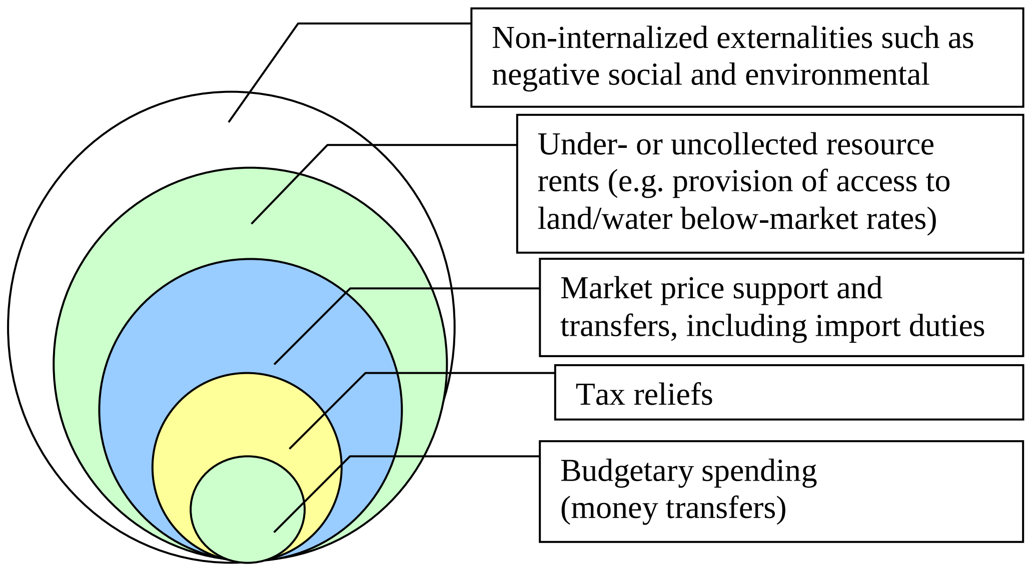

Figure 1. Nested sets of subsidies definition

Source: Adapted from (Gerasimchuk et al., 2012)

Under the narrowest definition, subsidization assumes only direct budget payments to producers or consumers (Morgan, 2007). On the one hand, such approach clearly outlines the set of measures that are included into subsidization, while on the other hand, is too limiting and can be applied only in a few policy cases. Extension of the concept through inclusion of preferential taxation already brings some difficulties caused by necessity to choose the normal (non-preferential) tax rate[2]. More broad definition states that subsidy is "…any measure

[2] For instance, in case of differential (progressive or regressive) taxation, either lowest or highest available tax rate can be treated as normal; alternatively some kind of weighted tax rate can be applied. Each approach would deliver different subsidy estimates.

that keeps prices for consumers below the market level or keeps prices for producers above market level, or that reduces costs for consumers and producers by giving direct or indirect support" (de Moor and Calamai, 1997). IEA defines energy subsidies as "…any government action that concerns primarily the energy sector and that lowers the cost of energy production, raises the price received by energy producers or lowers the price paid by energy consumers". Treatment of non-internalized externalities and corresponding damages together with assessment of fair level of resource rents remains an open issue.

Substantial discussion around the definition of subsidies poses even more difficulty and uncertainty when it comes to measuring their magnitude. Nonetheless, several international agencies consistently monitor world fossil-fuel subsidies. In doing so they apply various approaches, which are summarized in Table 1.

Table 1. Summary of approaches to energy subsidies estimation

Approach	Description	Strengths	Limitations
Producer support estimate (PSE)	Cash value of transfers to energy producers	Includes different types of support	Data intensive. Does not capture market price support measures
Consumer support estimate (CSE)	Cash value of transfers to energy consumers		
General Services Support Estimate (GSSE)	Cash value of transfers that support general services		
Program-specific approach (PSA)/ Program-aggregation	Estimates cash transfers associated with various government programs; aggregates programs into overall support level	Capture transfers regardless their influence on prices	Sensitive to the program selection. Requires highly disaggregated data
Price-gap approach (PGA)	Compares actual end-user prices with reference prices, defined as such prices that would prevail in undistorted markets in the absence of subsidies	Relatively low data requirements; useful for international comparisons	Ignores support that does not influence end-user price; sensitive to reference price estimates

Source: based on UNEP (2003), Honkatukia (2002), Jones and Steenblik (2010)

Estimates usually cover different types of support, vary in regional, commodity and consumer coverage. In addition, they are based on distinct treatment of subsidies interpretation. In particular, OECD measures budgetary spending and tax reliefs (two smallest circles in Fig.1) (OECD, 2015). IEA additionally includes market price support and under collected resource rents (if they lead to price distortions), but excludes any support that does not influence prices[3] (IEA, 2017). Finally, IMF attempts to adopt the broadest definition of energy subsidies by including all categories from budgetary spending to non-internalized externalities (Coady et al., 2015). Such diversity in subsidies' treatment leads to large differences in subsidy estimates and corresponding social, economic and environmental effects from their removal. Table 2 provides comparison of fossil-fuel subsidy estimates by OECD, IEA and IMF.

Table 2. Comparisons of fossil-fuel subsidy estimates

	OECD+	IEA*	IMF#
Estimates (billion, $2014)[4]	170	493	Pre-tax: 481 Post-tax: 5175
Country coverage	34 OECD members + 6 partner economies	41, mostly developing	188
Product coverage	Petroleum products, coal, natural gas	Gasoline, diesel, kerosene, LPG, heavy fuel oil, coal, natural gas, electricity	Gasoline, diesel, kerosene, coal, natural gas, electricity
Consumer coverage	Consumers and producers	Consumers	Consumers and producers
Definition	Budgetary transfers and tax expenditures that provide benefits to fossil-fuel consumption/production	Government actions that result in end-user prices being lower than full cost of supply	*Pre-tax:* price paid by consumers below supply cost + budgetary transfers that provide benefits to producers *Post-tax:* pre-tax + taxes below efficient level (consumption and corrective "Pigouvian" taxes)
Estimation approach	PSE, CSE, GSSE	PGA	PGA (consumer subsidies), PSE+CSE+GSSE (producer subsidies)

Source: based on IISD (2014), OECD+ (2015), IEA* (2017; 2015b), Coady# (2015)

On the one hand, there is much uncertainty about the scale of inefficient taxation of fossil fuels, mainly due to the necessity to estimate externality costs from different sources, like global warming, local pollution, road damage, congestion etc. For example, global social cost of carbon in 2015 may vary between $6.4 and $89.8 per ton (2005 international USD) depending on different

[3] For instance, in case of Ukraine, which has been implementing energy subsidy reform since 2014, estimated targeted subsidies to low-income households in 2016 were 36.2 billion UAH ($1.4 billion) (OECD, 2016a). As these transfers do not influence consumer price, which was increased for natural gas to the import parity level in 2016, such subsidies would not be picked up by IEA's current approach. In general, they fall under OECD's CSE category, but Ukraine is not in a list of countries considered by OECD.

[4] For comparison reasons estimates are provided for the latest mutually available year.

assumptions (Nordhaus, 2014). Even more uncertainty can be attributed to value of statistical life (VSL) estimates, which are often applied to assess mortality reduction co-benefits of energy policies. Thus, according to meta-analysis provided by Biausque (2010), VSL estimates can vary between $2.7 thousand and $20 million, depending on country and assumptions.

On the other hand, an approach of treating inefficient taxation as a hidden subsidization of fossil fuels looks the most logical from economic point of view (Barany and Grigonyte, 2015). During recent years, more and more countries are introducing carbon pricing as a baseline. Number of implemented initiatives doubled since 2011 and quadrupled since 2007, estimated to reach 42 in 2017, potentially covering between 20% and 25% of global GHG emissions (WB, 2016). After all, high uncertainty around fossil-fuel externalities does not mean that its level is zero and it is not a reason for inaction or negligence.

3. Overview of global energy subsidies reform assessment studies

Considering policy and economic implications key focus of the energy subsidies analysis is put on country level, although in recent years number of studies have attempted to provide assessment of global impacts. While national level subsidies treatment gives details on specific impacts and is much more relevant for policy making comparing to global level assessment, the latter one can give beneficial insights into interregional effects distribution, identify relative policy costs and provide incentives for global cooperation.

First attempts on the global assessment of energy subsidy reform were done in early 1990-s by Larsen and Shah (1992) and Burniax et al. (1992)[5]. An overview of more recent studies is provided in Table 3. While there are significant differences in policy design and methodology, several points can be synthesized.

Firstly, subsidies removal usually results in significant GHG emissions reduction, ranging from 1.1% to 10% in case of pre-tax subsidies and reaching 20.8% in case of post-tax subsidies elimination. Although, Table 3 does not report regional distributions, in most cases developing countries, which have higher rate of subsidization experience bigger emissions reduction, while OECD countries may even have slight emissions increase due to the leakage effects. Examples of such results can be found in Saunders (2000) and OECD (2009), where energy-

[5] An overview of these studies can be found in (Ellis, 2010).

importing OECD countries, especially Japan and European Union, enjoy significant terms-of-trade and income gains from subsidies removal in energy-exporting regions. Such consequences do not hold in case of post-tax subsidies removal (IMF, 2015), which are initially high for all regions, including developed countries, and thus lead to more uniform emission reductions.

Secondly, most studies report small positive global economic effects (GDP, welfare, households income) from subsidies removal, ranging from 0 to 0.7%, reaching 2% only in case of post-tax subsidies reform. At the same time, like in case of emissions, their regional distribution is not uniform and most energy-intensive regions (e.g. oil exporters, Non-EU Eastern European countries) can experience regressive economic effects (OECD, 2009). From the social perspective, such effects can be outweighed by significant emission reductions, but as long as these indicators are reported separately, it is hard to verify this point.

Finally, most studies do not take into account economic feedback from environmental gains, including lower mortality and disease rates, reduced global warming pressure, ecosystem benefits etc. Inclusion of such effects can qualitatively change results for particular regions and provide more consistent grounding for decision-making. Some insights into this issue are provided in IMF (2015) study, although, it uses quit simplified partial equilibrium framework, does not report results for pre-tax subsidies removal, as well as does not account for interregional and economy wide impacts of subsidies elimination.

Table 3. Comparison of existing studies on global energy subsidies reform assessment

Study	Experiment description	Regional coverage	Removal timeframe	Reported year	Assessment approach	Effects estimates, % from BaU		
						GDP	CO_2 emissions	Households income
IMF, 2015	Post-tax energy subsidies removal	188 countries	2013	2013	Static partial equilibrium	2.0[6]	-20.8	-
IEA, 2015a	Gradual phase-out of fossil-fuel consumption subsidies[7]	40 OECD and non-OECD countries	2014-2030	2030	IEA's World Energy Model (partial equilibrium)	-	-10 (energy related GHGs)	-
Magne et al., 2014	Multilateral fossil fuel subsidies removal	35 non-OECD countries, Mexico and South Korea	2013-2020	2035	ENV-Linkages model (dynamic CGE)	0.5	-6.5	0.3
OECD, 2009	Multilateral removal of fossil fuel demand affecting energy subsidies	Non-OECD countries	2013-2020	2050		0.1	-10	0.0
Saunders and Schneider, 2000	Removal of consumer energy subsidies	10 non-OECD regions	2001-2005	2010	ABARE GTEM model (dynamic CGE)	0.1 (developed) 0.45 (10 non-OECD)	-1.1 (all GHGs)	-
IEA, 1999		8 non-OECD countries	1997-1998	1997-1998	Static Partial-Equilibrium	0.73 (8 non-OECD)	-4.6	-

[6] Net welfare gain, % of GDP.
[7] Exception applies to few countries in the Middle East, where reforms progress at a slightly lower pace. No assumptions are made about reforms of fossil-fuel production subsidies.

4. Overview of environmental co-benefits assessment studies

Review of the global energy subsidies assessment studies shows that one of the key points missed in the subsidy reform analysis is treatment of environmental co-benefits, which can potentially have a significant influence on aggregate effects of energy policies and their regional redistribution (OECD, 2016a; OECD, 2012; Saari et al., 2015; Matus et al., 2012). Several streams of such environmental interactions can be derived from existing literature.

Perhaps, the most studied link connects energy policy and *climate change*. Numerous studies have provided assessment of regional and global level actions towards GHGs emission reduction to keep global temperature increase under certain level (IPCC, 2017). In addition, some studies provide estimates of climate change impact functions and assess aggregate damage costs by linking relative variations in temperature to economic effects in various dimensions, including sea level change, agriculture and labor productivity, water availability, forestry, human health, tourism flows, energy consumption etc. (Tol, 2002; Roson and van der Mensbrugghe, 2012; WHO, 2014; Roson and Sartori, 2016).

Another set of studies attempts to assess the human-related influence on *biodiversity and ecosystems* (Lovett et al., 2009; Stevens et al., 2004; Phelps, 2012), which services provide significant benefits to human welfare with some estimates exceeding global GDP (OECD, 2012; Costanza et al., 1997). A separate sub stream of this field of studies can be associated with planetary boundaries concept (Rockstrom et al, 2009; Steffen et al, 2015). This approach attempts to identify levels of the human perturbations of the Earth system (ES) beyond which ES functioning may be substantially altered. According to Steffens et al (2015), nine such boundaries can be identified. In addition to already mentioned climate change, they include change in biodiversity integrity, stratospheric ozone depletion, ocean acidification, biogeochemical flows, land-system change, freshwater use, atmospheric aerosol loading and introduction of novel species.

In contrast to the climate change assessment studies, while ecosystem impacts can in overall be even more important to human's welfare changes, it is much harder to measure such effects in a conventional manner and design monetary metrics for further comparisons. One of the approaches to take into account such effects is to treat them (where possible) as a boundaries/target rates in addition to conventional environmental impacts assessment[8].

[8] For example, in addition to emission and air pollution assessment within energy subsidies elimination policies such variables as amount of forest cover remaining, freshwater use, phosphorus and nitrogen flows changes due to policy implementation can be monitored.

Finally, the third stream of studies explores influence on *human health*, which, in case of energy policies, is usually associated with air pollution[9]. An extensive literature provides estimates of human-related benefits/costs of air pollution (OECD, 2012; Kunzli et al., 2000; EPA, 1999; see Bell et al. (2011) for additional studies review). Number of studies have provided contribution to the assessment of economic consequences of air pollution (OECD, 2016a; IMF, 2015; Saari et al., 2015; Matus et al., 2012).

In particular, OECD (2016a) study looks at the long-term costs of air pollution. It applies OECD's ENV-Linkages model to provide projections of economic activities from 2015 to 2060, estimates PM2.5 and ozone concentration changes and links them to impacts on number of lost working days, hospital admissions and agricultural productivity. Each health end point is further attributed a monetary value. Authors conclude that total annual market costs of outdoor air pollution are projected to rise from 0.3% of global GDP in 2015 to 1.0% in 2060.

Paper by Saari et al (2015) applies an integrated assessment framework to model air quality co-benefits from U.S. climate policies. The framework first implements policies in the USREP economic model, which provides impacts on welfare, production, and emissions. Using associated changes in fine particulate matter concentrations authors estimate human health impacts. Morbidities are taken into account through lost wages, lost leisure, and medical expenses. Adopted framework accounts for mortality by reducing the supply of labor accordingly. Finally, health impacts are input to USREP to estimate the welfare effects of air pollution.

Study by Matus et al (2012) evaluates historical air pollution-related health impacts on the Chinese economy by using an expanded version of the MIT EPPA model. In each time period between 1970 and 2005 the number of cases for every health outcome are calculated, which is further mapped to corresponding costs and quantity changes determined by health service inputs, lost labor, and leisure. Introduction of these changes as a shocks to the model provides assessment of the scenarios under consideration.

Another approach to link health damages from air pollution to welfare costs is to use the VSL derived from willingness-to-pay (WTP) estimates (OECD, 2016a; IMF, 2015). VSL is usually quantified by aggregating individuals WTP to secure a marginal reduction in the risk of premature death over defined timespan. Estimated in such a way country/region specific VSL are applied to the premature

[9] Other key impacts associated with human health include unsafe water supply and poor sanitation, chemical hazards, exposure and climate change-related diseases (OECD, 2012). While the last set of impacts is associated with climate change effects, which we mentioned earlier, other impacts usually are not directly linked to energy policies, which we are focusing on in this paper, therefore, we do not discuss them in detail.

death changes associated with air pollution and welfare costs from premature deaths are derived.

5. Theoretical framework and methods

We use a multistep framework to model the economic consequences of global energy subsidies reform (Figure 2). At the first step, global subsidy reform scenarios are developed. The GTAP-E-Power model (Peters, 2016b), a static computable general equilibrium (CGE) model, is next used to implement energy subsidy policies, quantify economic impacts, estimate energy use changes and CO_2 emissions. Energy use changes are linked to emissions of air pollutants (SO_2, NO_x and PM2.5) based on IMF data on post-tax energy subsidy estimates (IMF, 2015; Coady et al., 2015; Parry et al., 2014). Pollution-mortality impacts are estimated based on the population exposed by pollution and corresponding mortality risks for chronic obstructive pulmonary disease, lung cancer, ischemic heart disease and stroke. Finally, welfare benefits related to reduced mortality rates are estimated based on the country-adjusted WTP measure from direct valuation studies (IMF, 2015; OECD, 2016b).

Figure 2. World energy subsidies reform assessment framework

5.1. GTAP database and pre-tax energy consumption subsidies

We use GTAP-E-Power model (Peters, 2016b) with added-in environmental module to analyze two global energy subsidies scenarios, estimate their economic impacts and pollution co-benefits. GTAP-E-Power is a static computable general equilibrium model with detailed representation of the electricity sector based on the extension of global trade analysis project (GTAP) version 9 database (Aguiar et al., 2016). GTAP original electricity sector is disaggregated into 12 new sectors, which results in a database with 68 sectors. For the purpose of this paper, we adopted a 9.2[10] version of the GTAP database with 2011 benchmark year.

In order to perform energy subsidies reform analysis within GTAP framework we expand subsidies representation in the database. According to current GTAP build, only $22.2 billion of energy consumption subsidies are

[10] 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 1 new IO table for Tajikistan.

explicitly represented in the database. Such representation includes cases, when market value of consumed domestic or imported energy commodity is higher than corresponding agents' prices value. It should be noted that such treatment can be missing subsidies associated with positive, but lower than "normal" levels of consumption tax rates. As long as we do not have information on the level of "normal" tax rate within GTAP framework, we cannot estimate such subsidies.

In order to expand the representation of pre-tax consumption energy subsidies in the GTAP database we adopt an IMF energy subsidies data (IMF, 2015). Comparing to the IEA database (IEA, 2015b) IMF provides higher country coverage (Table 2) and reports both supply costs (adjusted international price or domestic "cost-recovery price") and consumer prices (actual retail price) for each energy product under consideration, which is particularly useful in terms of subsidies integration to the GTAP database. We have done several steps to integrate consumption energy subsidies to the GTAP data build.

Firstly, we map IMF-sourced data to GTAP regional classification. This includes mapping of domestic basic energy prices, supply costs and energy consumption for six energy products (gasoline, diesel, kerosene, gas, coal and electricity) and two consumer types (final and intermediate). For aggregated regions, we estimate average weighted prices.

In case of some energy products and consumers, IMF data reports negative weighted consumption. In particular, in case of coal consumption by intermediate users in Argentina, Brazil, Costa Rica, Dominican Republic, El Salvador, Guatemala, Jamaica, Mexico, Peru, Uruguay and Venezuela. Although it should be noted that aggregated intermediate and final consumption is positive in all cases. In order to eliminate negative numbers, intermediate consumption is assumed to equal zero and corresponding number is deducted from final consumption. For aggregated regions (with two or more countries), energy consumption is estimated only in case of data availability for all countries from corresponding region. Weighted prices for aggregated regions are estimated if consumer price and weighted consumption are available at least for one country from the region. In cases when supply cost is not available, it is assumed to equal consumer price.

Secondly, retrieved data is converted to uniform units and mapped to GTAP energy sectors. We estimate "fair" price, which corresponds to the price of energy product, which would prevail in the economy in case no consumption energy subsidies are in place.

Conversion is done based on the GTAP database conversion factors, except for Kerosene, which conversion factors are sourced from IEA (2005, p. 181). Intermediate and final consumer prices are averaged using IMF energy consumption volumes. For electricity, coal and gas energy prices can be derived directly from IMF data. In case of petroleum products, we estimate average weighted prices using IMF energy consumption data. If consumer price is higher than supply cost, then the first one is treated as "fair". If opposite inequality holds and supply cost is positive the latter one is used as a "fair" price.

Finally, we update market prices and commodity tax rates in GTAP database. IMF-sourced "fair" prices are used to update domestic energy prices. If IMF data is not available GTAP-sourced prices are applied. Commodity tax rates are updated using IMF subsidies data through deduction of USD/toe subsidization rate from current commodity tax rate. Subsidization rate is estimated by dividing IMF-based energy subsidy value by GTAP-based energy consumption volume. During this process, we apply two adjustments.

In cases, when IMF-based energy consumption is much higher than GTAP-based, IMF-sourced domestic tax estimates may result in negative average prices (weighted import and domestic prices). To eliminate such cases (in particular, issue with negative prices arises in case of electricity use in Malawi), we updated IMF subsidy estimates by applying GTAP energy consumption data.

Another issue, which should be treated, is large difference between IMF-based fair prices and GTAP-based import prices for imported subsidized energy commodities. In particular, this is the case of Benin, where such deviation for electricity exceeds 300%. In addition, Benin has low share of domestic electricity production (around 14%). Thus, increase of domestic prices (using IMF-based fair prices) does not significantly influence average price, which is defined mostly by import price, at the same time IMF reports subsidies level (USD/toe) higher than GTAP-based import price, which leads to the negative average price estimate. To solve the Benin electricity sector issue, IMF energy subsidies are rescaled by treating GTAP-based export price as a supply cost.

Corresponding steps are implemented into GTAP database build procedure (Aguiar et al., 2016) and GTAP 9.2 database with integrated energy subsidies is produced. Taking into account subsidies adjustments through GTAP-based energy volumes application and Benin energy price changes, implemented approach accounts for 99% of IMF-sourced energy subsidies. Considering that GTAP database represents net tax rates (taxes excluding subsidies), resulting database explicitly accounts for $417 billion or 82% of the IMF-sourced energy consumption subsidies. Based on the GTAP 9.2 database with integrated energy subsidies we produce GTAP-Power database (Peters, 2016a). For further policy analysis, we map 121 countries and 20 composite regions to 14 aggregate regions (Appendix A) and 68 activities to 21 aggregate sectors (Appendix B). Figure 2 provides distribution of IMF-sourced pre-tax energy consumption subsidies.

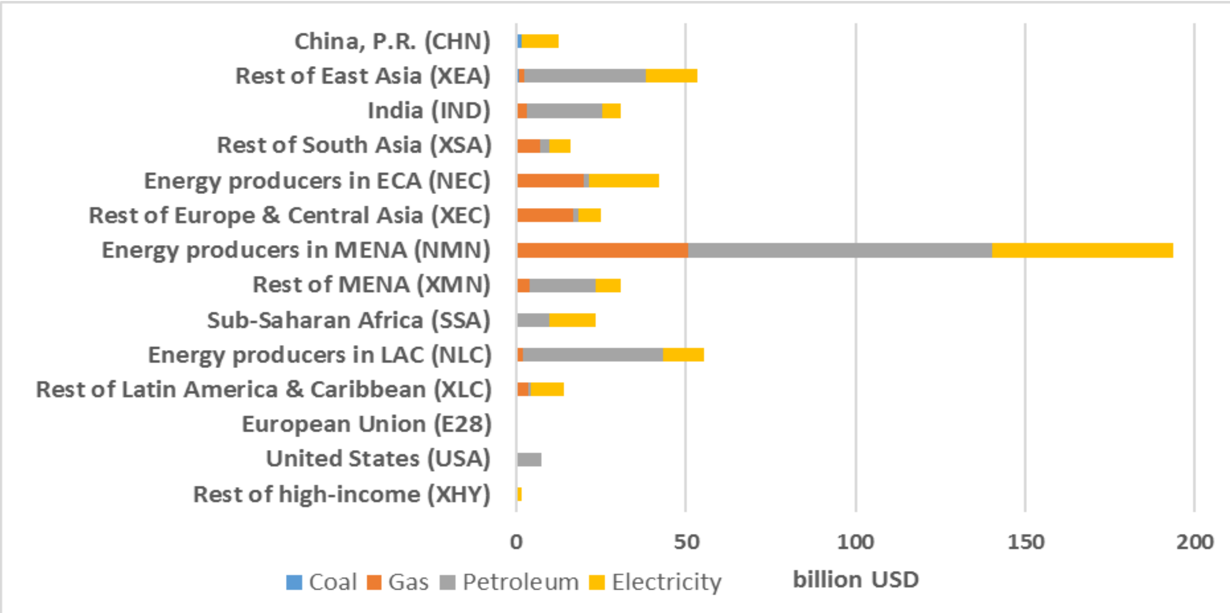

Figure 2. Pre-tax energy consumption subsidies distribution

5.2. Pollution database and environmental co-benefits assessment

To proceed with analysis of the pollution post-tax subsidies and assessment of pollution co-benefits of the energy subsidies reform we construct a GTAP-consistent pollution database. In contrast to the pre-tax energy subsidies data integration process, described in section 5.1, pollution database is designed as a stand-alone complement to the GTAP database. We use IMF post-tax subsidies data and methodology (IMF, 2015; Parry, 2014), which integrates data from several other sources, to construct the pollution database.

From the IMF database (IMF, 2015) we access data on country-specific emission factors for five energy commodities (coal, natural gas in power generation, natural gas in domestic heating, gasoline and diesel) and three emitters (SO_2, NO_x and PM2.5). Data is based on the IIASA GAINS model estimates (IIASA, 2013) and represents average emission factors with and no control technologies adopted.

Deaths per ton for each emitter, three types of energy products (coal, natural gas and ground level sources) and four diseases (chronic obstructive pulmonary disease, lung cancer, ischemic heart disease and stroke) are sourced from IMF database (IMF, 2015). These estimates are based on the World Health Organization's Global Burden of Disease project[11]. It should be noted that premature deaths of population under 25 are excluded in IMF data, thus making the pollution damage in general understated (Parry et al., 2014).

[11] http://www.who.int/healthinfo/global_burden_disease/about/en/

To provide the possibility of monetary valuation of welfare co-benefits from pollution changes we estimate emission costs following the IMF approach. OECD VSL estimates based on the WTP approach is adopted as a starting value. It equals $3 million per life saved ($2005) for the group of OECD countries (OECD, 2016b). This value is updated to $2011 based on the inflation rates and further country-specific adjustments (IMF, 2015). In particular, corrections for purchasing power parity GDP per-capita, assuming an elasticity of 0.8 (OECD, 2012).

Using IMF energy volumes and emission factors data we estimate country-specific SO_2, NO_x and PM2.5 emissions for four energy products (coal, petroleum products[12], natural gas used for domestic heating and natural gas used for power generation). We further map estimated emissions to GTAP regions and region-specific emission costs data (based on adjusted VSL estimates) to derive the pollution costs associated with mortality risks for GTAP regions, which globally total to almost $2.3 trillion (Figure 3).

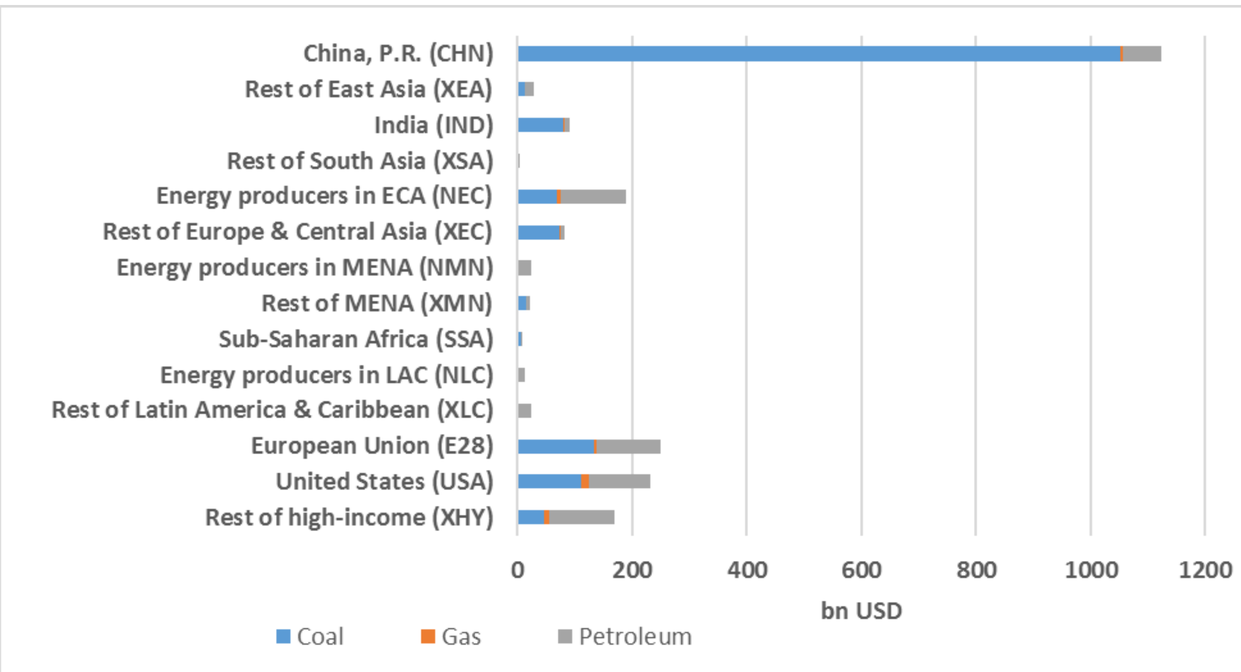

Figure 3. Regional distribution of local air pollution subsidies (costs) associated with mortality risks

Opposite to the pre-tax subsidies (Figure 2), almost 71% of local air pollution costs are associated with coal. Furthermore, significant pollution damage occurs in developed countries, including USA and EU28. It should be noted that

[12] IMF database provides energy consumption and emission factors for three petroleum products: gasoline, diesel and kerosene. We estimate aggregate emissions for all three petroleum products to match the GTAP sectoral classification.

much uncertainty surrounds mortality-associated pollution damage valuations, including assumptions on country-specific VSL values and choice of concentration-response functions, which link pollution concentrations to changes in mortality levels. Both these factors can significantly influence pollution damage estimates. VSL estimates exhibit high degree of variability between different studies – up to 7500 times (Biausque, 2010), while uncertainty involved in exposure-response functions can bring additional large error bars to corresponding central estimates (Matus et al., 2012). Therefore, pollution-related mortality damages used in this study should be viewed with a great cautious.

Although both GTAP and IMF energy consumption data are sourced from IEA (Aguiar et al., 2016; IMF, 2015), in some country cases significant differences can occur, mostly with GTAP energy consumption exceeding corresponding IMF estimates. Key reasons include aggregation of nuclear fuel with petroleum products sector and heat supply with electricity sector in GTAP database. Another factor is that IMF data accounts only for three types of petroleum products (gasoline, kerosene and diesel), while in some countries there may be significant consumption of other commodities, in particular, fuel oil, liquefied petroleum gases, naphtha and natural gas liquids, which are all represented in GTAP database. Considering such differences, for further policy simulations we re-estimate emission factors using IMF-derived pollution volumes and GTAP-based energy consumption data.

For both considered scenarios, we provide assessment of subsidies elimination co-benefits associated with SO_2, NO_x and PM2.5 pollution reductions. We use GTAP-calibrated emission factors to estimate reductions in corresponding pollutants due to energy use changes. Afterwards, we apply statistics on death per ton of each emitter to estimate related mortality reductions and multiply them by region-specific VSL values to derive the associated welfare benefits, which we repot in addition to conventional environmental and economic indicators.

Attempting to incorporate the economic and welfare feedback of pollution-related health outcomes to adopted modelling framework, we have also estimated the impact of mortality reductions on labor supply by regions. However, as long as this feedback did not prove to have significant impacts on welfare (associated benefits were less than 1% of total welfare changes) we do not consider it current set up. Perhaps, extension of such approach towards inclusion of morbidity effects through changes in medical expenses, lost wages, and lost leisure (Saari et al., 2015), as well as more broad ecosystem benefits assessment could provide a more consistent way of including non-market impacts into CGE framework.

6. Simulation and results

6.1. Energy Subsidy Policies

With pre-tax energy consumption subsidies integrated to the GTAP-Power database and developed pollution database, we study two energy subsidy policies. First scenario includes elimination of pre-tax energy consumption subsidies. As long as GTAP database explicitly accounts for $417 billion or 82% of the IMF-sourced energy consumption subsidies, we target final and intermediate energy consumption tax rates (Figure 4) to match the IMF data (Figure 2).

As can be seen, most significant relative price changes due to pre-tax energy consumption subsidies elimination should have place in developing and net energy exporting countries. Both in absolute and relative terms, coal is the least subsidized energy product, while electricity experiences the highest price increase in most cases.

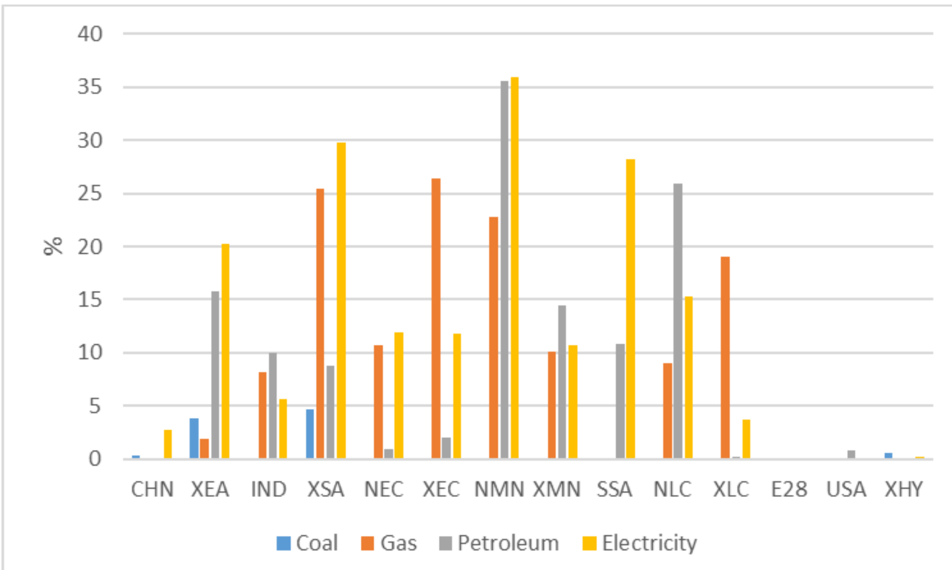

Figure 4. Weighted average target energy consumption tax rate changes due to pre-tax consumption subsidies elimination

Second scenario, in addition to pre-tax subsidies elimination, includes imposition of corrective pollution taxes (Figure 5), which account for the cost of pollution damage due to increasing mortality risks. Associated tax rates increases are more uniform on the regional level, comparing to pre-tax subsidies scenario, influencing both high income and developing countries, with the highest prices increase for coal, which is the most pollution-intensive fossil fuel.

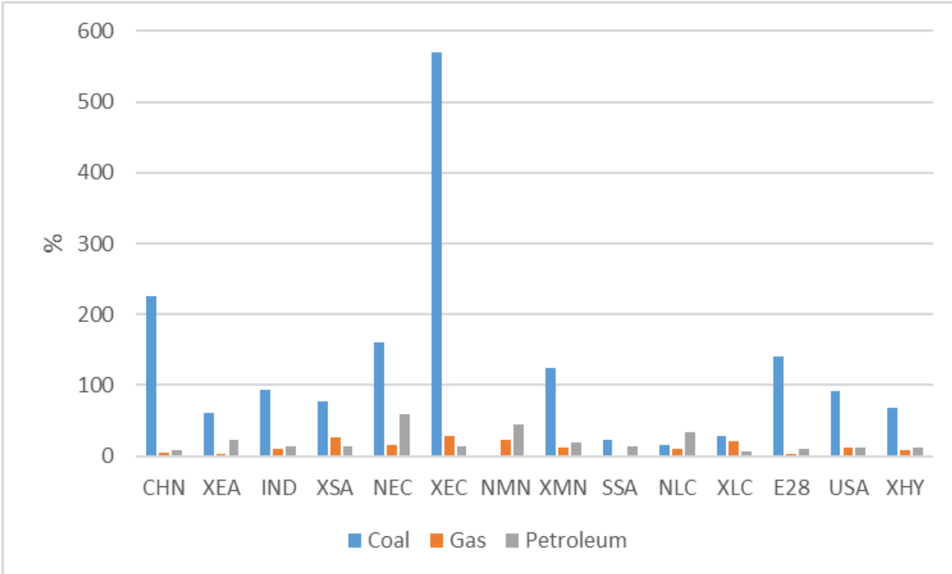

Figure 5. Weighted average energy consumption tax rate changes associated with pollution-related energy subsidies elimination

To make our simulation results more consistent with mid-term timeframe of the effects and to allow for better substitution possibilities within and outer energy nest, we have assumed higher elasticity values in several cases comparing to the benchmark GTAP-E-Power values (Peters, 2016b). Summary of reconsidered elasticity values is provided in Appendix C.

6.2. Pre-tax consumption energy subsidies elimination

Elimination of pre-tax consumption energy subsidies results in global welfare and GDP benefits, mainly due to allocative efficiency effects (Table 4). The most significant positive changes in relative terms are experienced by Rest of Europe and Central Asia regions. High-income countries, as they do not have large consumption energy subsidies, are mainly influenced by positive terms of trade effects due to falling energy prices in energy exporting countries. As a result, moderate CO_2 leakage effects have place as corresponding emission increases in all three developed regions – European Union, United States and Rest of high-income (Table 4). Although, global CO_2 emissions reduce by almost 3%.

In terms of output structural changes (Appendix D), both on regional and global levels, the most significant downturn is experienced by natural gas production, which suffers not only from gas consumption subsidies removal, but also from electricity subsides elimination, as electricity generation significantly relies on natural gas in several regions. This also results in shift towards coal consumption use in Rest of East Asia, Energy producers in LAC and especially Rest of MENA regions.

Table 4. GDP, welfare and CO_2 effects of pre-tax consumption energy subsidies elimination

Region	GDP		Welfare	CO_2 emissions, %	Air pollution welfare co-benefits, bn \$2011	Net welfare changes, bn \$2011
	bn, \$2011	%	bn, \$2011			
China	2.5	0.0	6.3	-0.9	12.6	18.9
Rest of East Asia	2.3	0.1	0.4	-8.3	2.0	2.4
India	-2.9	-0.2	**-0.3**	-2.7	1.9	**1.6**
Rest of South Asia	1.7	0.4	1.1	-13.0	0.2	1.4
Energy producers in ECA	10.1	0.5	**-5.1**	-7.9	1.9	**-3.2**
Rest of Europe & Central Asia	6.1	1.2	3.5	-13.3	1.6	5.1
Energy producers in MENA	23.1	0.9	**-5.1**	-19.5	3.4	**-1.7**
Rest of MENA	0.8	0.1	2.8	-4.4	0.2	3.0
Sub-Saharan Africa	1.8	0.1	**-5.3**	-2.2	0.1	**-5.2**
Energy producers in LAC	1.4	0.1	**-1.4**	-14.1	1.8	**0.5**
Rest of Latin America & Caribbean	-1.5	0.0	1.8	-3.9	-0.1	1.8
European Union	17.7	0.1	37.3	1.8	-2.6	34.7
United States	2.3	0.0	16.6	0.3	-0.9	15.7
Rest of high-income	8.5	0.1	19.1	1.2	-2.4	16.7
World	**73.9**	**0.1**	**71.7**	**-2.8**	**19.8**	**91.6**

Significant output reduction is also observed in fossil fuel based electricity production, particularly in energy exporting, mid- and low-income regions (Appendix E). In several cases substitution for renewable energy has place (Rest of South Asia, Rest of MENA, Energy producers in LAC, Rest of Latin America and Caribbean), but globally Renewable energy generation output slightly reduces, as this sector also undergoes consumer subsidies elimination[13].

Reduced energy consumption with slight shift towards renewable energy generation results in lower air pollutants emission (Figure 6). As in case of CO_2 emissions, moderate leakage effects have place for high-income countries. Substantial SO_2 emissions increase is observed in Rest of Latin America & Caribbean region due to the shift towards coal consumption, which has high SO_2 intensity.

[13] In the GTAP-Power database, IMF-sourced electricity consumption subsidies are distributed between all types of generation proportionally to output. As long as on a country basis electricity consumption subsidies are estimated and reported on a sectoral level and consumer demands electricity as a single product, we do not have enough statistical evidence to apply generation-specific approach to electricity consumption subsidies distribution.

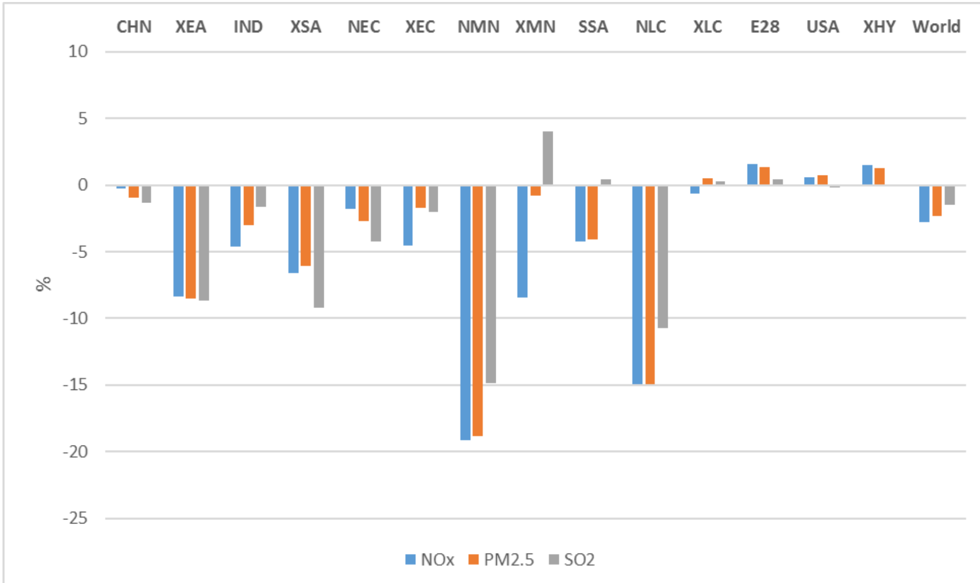

Figure 6. Air pollutants emission changes associated with pre-tax consumption energy subsidies elimination, % of 2011 benchmark

On average pre-tax energy subsidies elimination leads to global air pollutants emission reduction by 2%, which results in avoidance of 20.4 thousand deaths. Most significant benefits from mortality air pollution co-benefits in absolute terms is experienced by China, which accounts for nearly half of total lives saved (Figure 7). Key mortality reductions come from stroke and ischemic heart diseases, which are together associated with 80% of total co-benefits.

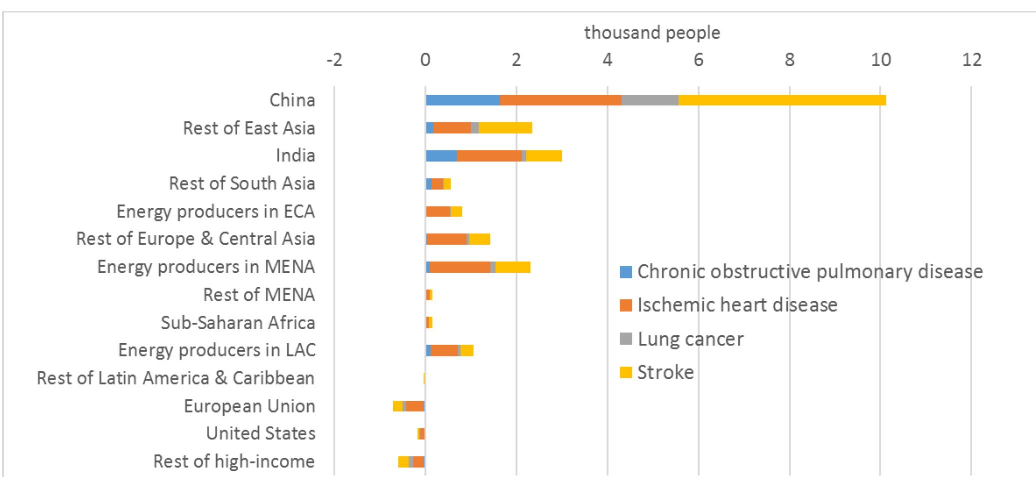

Figure 7. Mortality co-benefits of pre-tax consumption energy subsidies elimination, % of 2011 benchmark

In monetary values, global mortality co-benefits of pre-tax energy subsidies elimination contribute to almost $20 billion, turning several regions from net welfare losers to gainers (Table 4). In particular, this is the case for India and

Energy producers in Latin America. Number of other regions experience significant increase in net welfare levels with the most prominent example of China, which welfare triples after introduction of air pollution reduction co-benefits, and Rest of East Asia, which experiences welfare increase from $0.4 billion to $2.4 billion. In case of high-income countries, welfare benefits resulting from terms of trade effects are large enough to overstate moderate welfare reduction due to air pollution-associated mortality increase.

6.3. Post-tax pollution energy subsidies elimination

Pollution subsidies elimination scenario, in addition to pre-tax consumer energy subsidies reform, assumes imposition of pollution taxes (in a form of consumption tax) to account for premature mortality cases. Such policy leads to much more significant changes in GDP, welfare and CO_2 levels (Table 5). As global GDP reduces insignificantly (-0.3%), most coal-intensive regions, including China, India and Rest of Europe and Central Asia, experience more substantial reduction (between -0.7% and -2.9%).

Table 5. GDP, welfare and CO_2 effects of pre-tax consumption and post-tax pollution energy subsidies elimination

Region	GDP		Welfare	CO_2 emissions, %	Air pollution welfare co-benefits, bn $2011	Net welfare changes, bn $2011
	bn, $2011	%	bn, $2011			
China	-211.0	-2.9	**-366.1**	-52.9	630.2	**264.1**
Rest of East Asia	0.3	0.0	**-7.4**	-16.3	4.6	**-2.8**
India	-13.1	-0.7	**-16.7**	-30.8	34.1	**17.5**
Rest of South Asia	2.4	0.6	4.3	-15.5	0.4	4.8
Energy producers in ECA	11.4	0.5	**-39.3**	-32.3	83.2	**43.9**
Rest of Europe & Central Asia	-8.5	-1.7	**-16.0**	-39.0	55.4	**39.4**
Energy producers in MENA	19.3	0.8	**-65.0**	-18.9	3.5	**-61.5**
Rest of MENA	-1.2	-0.1	**-0.3**	-16.2	5.4	**5.0**
Sub-Saharan Africa	1.0	0.1	**-18.7**	-7.6	0.3	**-18.4**
Energy producers in LAC	-1.3	-0.1	**-12.9**	-16.6	2.1	**-10.8**
Rest of Latin America & Caribbean	3.7	0.1	21.2	-8.0	1.0	22.3
European Union	-14.0	-0.1	78.2	-16.2	104.1	182.3
United States	-18.8	-0.1	8.8	-20.0	58.6	67.4
Rest of high-income	-16.9	-0.1	28.9	-14.3	24.7	53.6
World	**-246.8**	**-0.3**	**-400.9**	**-28.0**	**1007.6**	**606.7**

In terms of welfare changes, most gains come from terms of trade effects, benefiting mainly high-income countries and Rest of Latin America, while allocation efficiency provides mostly negative contribution. Associated with much higher energy consumption taxes, air pollution subsidies elimination contributes to significant global CO_2 emissions reduction (-28%) with almost 53% fall in China.

Air pollution subsidies elimination is accompanied with significant output structural changes, substantial fossil fuel production decrease and shift towards renewable generation (Appendix E). The only case with renewable generation share decrease is observed for Sub-Saharan Africa. Such effects are driven solely by pre-tax subsidies elimination, while pollution tax introduction is lowering the rate of renewables reduction.

Due to fossil fuel consumer price increase, significant pressure is put on energy intensive industries (Appendix E). On the other hand, such structural changes significantly contribute to air pollution emissions reduction (Figure 8). Air pollution taxation policy leaves no space for leakage effects and emissions reduction in high-income countries is even more substantial than in some developing regions. The only exception is Energy producers in MENA region, which SO_2 and CO_2 emissions slightly increase after pollution taxes introduction, but still substantially reduce relative to the benchmark level. It happens mainly because this region has the lowest level of air pollution-related coal consumption externalities and corresponding tax increase are very small (Figure 5), while oil and petroleum consumption has significantly lower air pollution intensity than coal.

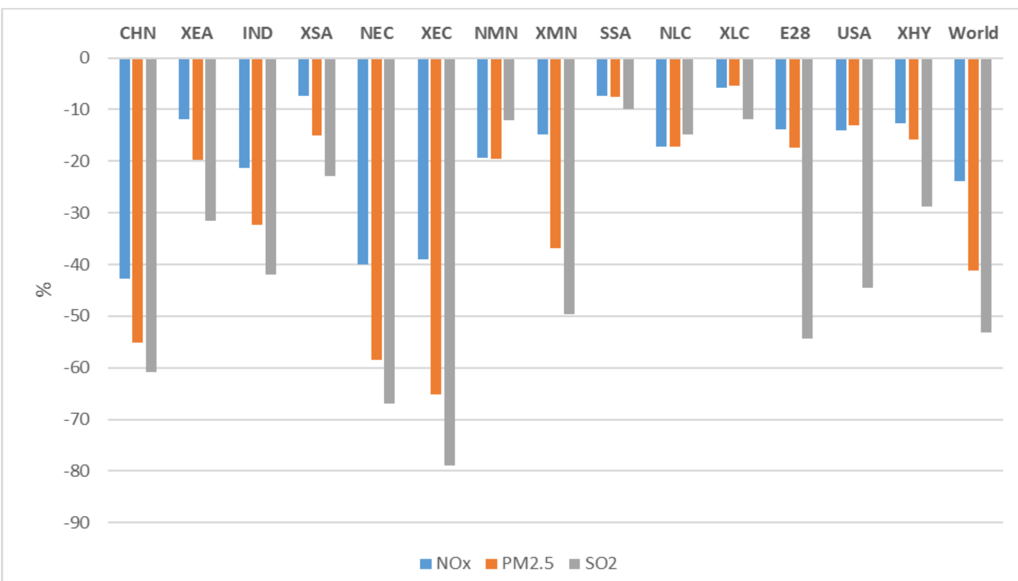

Figure 8. Air pollutants emission changes associated with pre-tax consumption and post-tax pollution energy subsidies elimination, % of 2011 benchmark

Significant NO_x, SO_2 and PM2.5 emissions drop results in substantial mortality-related benefits with global air pollution-related premature deaths reduction of over 705 thousand people (Figure 9). Most of these benefits are experienced by China with over 500 thousand lives saved and almost half of it corresponding to the stroke fatal cases. In other regions ischemic and heart disease fatal cases reduction proves to be the main contributor of air pollution-related mortality co-benefits. Contrary to the pre-tax consumption energy subsidies elimination, post-tax pollution subsidies reform brings significant mortality-related gains to developed regions with total mortality reduction in EU, USA and Rest of high-income countries equal to 46 thousand people.

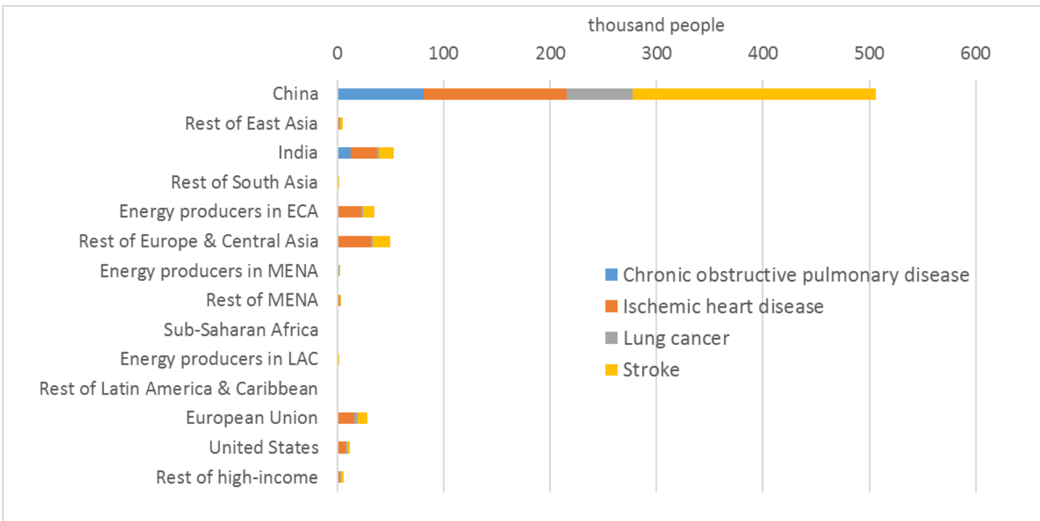

Figure 9. Mortality co-benefits of pre-tax consumption and post-tax pollution energy subsidies elimination, % of 2011 benchmark

Introduction of air pollution-related mortality co-benefits to the conventional welfare estimates brings significant changes to the results both on aggregate and regional level (Table 5). Net world welfare loss (-$400.9 billion) is turned into gain ($606.7 billion), with China turning from main loser to key gainer. Out of 9 regions that experience welfare reduction after pollution subsidies elimination 5 turn to be in a win-win position after pollution-related co-benefits are taken into account.

7. Conclusion and Discussion

For many years energy subsidies remain on the top of international policy agenda, being extensively criticized for inefficiency and at the same time widely used as a policy instrument. In many cases reluctance towards subsidy reform is associated with possible negative economic impacts, especially for poor households and domestic energy producers. At the same time, most energy subsidies assessment studies lack consistent representation of environmental co-benefits associated with policies implementation.

In this paper, we apply a multistep framework to examine two global energy subsidies reform scenarios, which include elimination of pre-tax consumer and post-tax local air pollution subsidies. Our approach includes application of static CGE model (GTAP-E-Power), estimation of energy use changes due to policies implementation, their linkage to air pollution and related mortality impacts and further monetization of benefits using country-specific values of statistical life estimates.

Results show that in case of both scenarios, inclusion of air pollution-related mortality co-benefits to net welfare estimates significantly influences results. We estimate that in case of pre-tax consumption energy subsidies elimination global CO_2 emission falls by 2.8% and air pollutants emission reduces by 2%, which results in avoidance of 20.4 thousand deaths. Global monetary welfare co-benefits of such policy contribute to almost $20 billion, turning some regions from net welfare losers to gainers. Most high-income countries experience insignificant pollution and mortality increase due to leakage effects.

Elimination of post-tax pollution subsidies, in addition to pre-tax subsidies reform, provides much more significant reduction of CO_2 and air pollutants emission – by 28% and 36% respectively, with premature deaths reduction of over 705 thousand people. Introduction of air pollution-related mortality co-benefits to the conventional welfare estimates turns world welfare loss (-$400.9 billion) into gain ($606.7 billion), with China turning from main loser to key gainer. Out of 9 regions that experience welfare reduction after pollution subsidies elimination 5 turned to be in a win-win position after introduction of welfare co-benefits.

While our results are associated with significant uncertainty and mainly serve to provide grounding towards further research on inclusive approaches to energy subsidies reform assessment, most evidences show that within the current framework we are more likely to be underestimating than overestimating welfare co-benefits.

Firstly, due to the static nature of employed CGE model and corresponding mid-term timeframe of policy results, CO_2 emission and air pollution changes in this paper seem to be significantly underestimated comparing to the dynamic modelling approach and long-term policy assessment (OECD, 2009; Magne et al., 2014).

Secondly, while emissions reduction contributes to the welfare benefits in several ways, we have considered only one such feedback in this paper, in particular pre-mature mortality changes due to air-pollution reduction. Although, this channel often proves to represent a major share of the benefits of environmental policies (Hammit and Robinson, 2011), inclusion of welfare effects associated with avoided global warming, morbidity reduction and ecosystem benefits may significantly influence our results.

Thirdly, we have excluded from our analysis premature deaths of population under 25 and did not include pollution-related assessment for number of country-commodity cases due to the lack of corresponding data (IMF, 2015).

Finally, one of the most significant causes for uncertainty can be associated with the value of statistical life estimate, which we have assumed to equal 3 million $2005 per life saved for the group of OECD countries (OECD, 2012), with further country-specific adjustment based on the per capita GDP PPP levels. Recent studies show that this value can be rather under than overestimated in case of some low-income countries and suggest to bound it below by estimates of future income or consumption (Hammit and Robinson, 2011).

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Appendix A. Regional Aggregation

Aggregate region	GTAP region
China, P.R. (CHN)	China (CHN)
Rest of East Asia (XEA)	Rest of Oceania (XOC), Mongolia (MNG), Rest of East Asia (XEA), Brunei Darussalam (BRN), Cambodia (KHM), Indonesia (IDN), Laos (LAO), Malaysia (MYS), Philippines (PHL), Thailand (THA), Viet Nam (VNM), Rest of Southeast Asia (XSE)
India (IND)	India (IND)
Rest of South Asia (XSA)	Bangladesh (BGD), Nepal (NPL), Pakistan (PAK), Sri Lanka (LKA), Rest of South Asia (XSA)
Energy producers in ECA (NEC)	Russian Federation (RUS), Kazakhstan (KAZ), Tajikistan (TJK), Azerbaijan (AZE)
Rest of Europe & Central Asia (XEC)	Albania (ALB), Belarus (BLR), Croatia (HRV), Ukraine (UKR), Rest of Eastern Europe (XEE), Rest of Europe (XER), Kyrgyzstan (KGZ), Rest of Former Soviet Union (XSU), Armenia (ARM), Georgia (GEO)
Energy producers in MENA (NMN)	Bahrain (BHR), Iran (IRN), Kuwait (KWT), Oman (OMN), Qatar (QAT), Saudi Arabia (SAU), United Arab Emirates (ARE), Rest of Western Asia (XWS), Rest of North Africa (XNF)
Rest of MENA (XMN)	Jordan (JOR), Turkey (TUR), Egypt (EGY), Morocco (MAR), Tunisia (TUN)
Sub-Saharan Africa (SSA)	Benin (BEN), Burkina Faso (BFA), Cameroon (CMR), Côte d'Ivoire (CIV), Ghana (GHA), Guinea (GIN), Nigeria (NGA), Senegal (SEN), Togo (TGO), Rest of Western Africa (XWF), Central Africa (XCF), South-Central Africa (XAC), Ethiopia (ETH), Kenya (KEN), Madagascar (MDG), Malawi (MWI), Mauritius (MUS), Mozambique (MOZ), Rwanda (RWA), Tanzania (TZA), Uganda (UGA), Zambia (ZMB), Zimbabwe (ZWE), Rest of Eastern Africa (XEC), Botswana (BWA), Namibia (NAM), South Africa (ZAF), Rest of South African Customs Union (XSC), Rest of the World (XTW)
Energy producers in LAC (NLC)	Mexico (MEX), Bolivia (BOL), Colombia (COL), Ecuador (ECU), Venezuela (VEN)
Rest of Latin America & Caribbean (XLC)	Argentina (ARG), Brazil (BRA), Chile (CHL), Paraguay (PRY), Peru (PER), Uruguay (URY), Rest of South America (XSM), Costa Rica (CRI), Guatemala (GTM), Honduras (HND), Nicaragua (NIC), Panama (PAN), El Salvador (SLV), Rest of Central America (XCA), Dominican Republic (DOM), Jamaica (JAM), Puerto Rico (PRI), Trinidad and Tobago (TTO), Rest of Caribbean (XCB)
European Union (E28)	Austria (AUT), Belgium (BEL), Cyprus (CYP), Czech Republic (CZE), Denmark (DNK), Estonia (EST), Finland (FIN), France (FRA), Germany (DEU), Greece (GRC), Hungary (HUN), Ireland (IRL), Italy (ITA), Latvia (LVA), Lithuania (LTU), Luxembourg (LUX), Malta (MLT), Netherlands (NLD), Poland (POL), Portugal (PRT), Slovakia (SVK), Slovenia (SVN), Spain (ESP), Sweden (SWE), United Kingdom (GBR), Bulgaria (BGR), Romania (ROU)
United States (USA)	United States of America (USA)
Rest of high-income (XHY)	Australia (AUS), New Zealand (NZL), Hong Kong (HKG), Japan (JPN), Korea (KOR), Taiwan (TWN), Singapore (SGP), Canada (CAN), Rest of North America (XNA), Switzerland (CHE), Norway (NOR), Rest of EFTA (XEF), Israel (ISR)

Appendix B. Sectoral Aggregation

Sector code	Sector description	GTAP-E-Power sector
Agriculture	Grains and Crops	pdr wht gro v_f osd c_b pfb ocr ctl oap rmk wol frs fsh
Coal	Coal	coa
Oil	Oil	oil
Gas	Gas	gas gdt
Oil_Pcts	Petroleum and coal	p_c
TnD	Electricity transmission	TnD
NuclearBL	Nuclear power	NuclearBL
CoalBL	Coal-fired power	CoalBL
GasBL	Gas-fired power in base load	GasBL
WindBL	Wind power	WindBL
HydroBL	Hydro power in base load	HydroBL
OilBL	Oil-fired power in base load	OilBL
OtherBL	Other power	OtherBL
GasP	Gas-fired power in peak load	GasP
HydroP	Hydro power in peak load	HydroP
OilP	Oil-fired power in peak load	OilP
SolarP	Solar power	SolarP
En_Int_Ind	Energy intensive industries	omn crp nmm i_s nfm
Oth_Ind	Other industries	cmt omt vol mil pcr sgr ofd b_t tex wap lea lum ppp fmp mvh otn ele ome omf
TransComm	Transport and Communication	trd otp wtp atp cmn
Services	Other Services	wtr cns ofi isr obs ros osg dwe

Appendix C. Changes in elasticity values relative to the benchmark GTAP-E-Power model assumptions

Elasticity type	GTAP-E-Power value	Updated value	Comment
Armington CES for domestic/imported allocation (ESBD)	0 (for electricity generation technologies)	0.3	Updated value is agreed with MIT EPPA model (Paltsev et al., 2005)
Armington CES for regional allocation of imports (ESBM)	0 (for electricity generation technologies)	0.5	Updated value is agreed with MIT EPPA model (Paltsev et al., 2005)
Elasticity of intermediate input substitution (ESBT)	0	0.5	0.5 elasticity value is used as a default for substituting 0 value, where necessary. In general it agrees with assumptions on energy substitution elasticities (in different nests) in MIT EPPA model (Paltsev et al., 2005), which are between 0.3 and 1.0. Non-zero substitution elasticities both for energy and other nests are used in several other CGE models, including GEMINI-E3, with elasticities ranging from 0.1 to 1.5 (Bernard et al., 2008), and EMPAX-CGE, with elasticities range in energy nest from 0.5 to 1.0 (RTI International, 2008).
Elasticity of substitution in energy subproduction (EFEN)	0 (for all energy subsectors and capital goods)	0.5	
Elasticity of substitution in capital-energy subproduction (EFKE)	0 (for all energy subsectors and capital goods)	0.5	
Elasticity of substitution in non-coal energy subproduction (EFNC)	0 (for all energy subsectors and capital goods)	0.5	
Elasticity of substitution in non-electricity energy subproduction (EFNL)	0 (for all energy subsectors and capital goods)	0.5	
Elasticity of substitution in value-added energy subproduction (EFVE)	0 (for all energy commodities)	0.5 (including agriculture, oil and gas sectors)	
Elasticity of intermediate input substitution at regional level (SBTR)	0 (all commodities)	0.5 (except capital goods)	
Armington CES for domestic/imported allocation at region level (SBDR)	0 (for electricity generation technologies)	0.3	Assumed the same as ESBD
Armington CES for regional allocation at region level (SBMR)	0 (for electricity generation technologies)	0.5	Assumed the same as ESBM
Substitution between electricity distribution and generation (SBTG)	0 (all commodities)	0.7	Updated value is agreed with JGCRI – Phoenix model (Sue Wing et al., 2011)
Substitution between base and peak load (SBBP)	0 (all commodities)	1.0	Updated value is agreed with JGCRI – Phoenix model (Sue Wing et al., 2011)

Appendix D. Output effects of pre-tax consumption energy subsidies elimination[14]

Region/Sector	Agriculture	Coal	Oil	Gas	Oil products	Renewable electricity	Other electricity	Energy intensive industries	Other industries	Services
China	0.1	-1.6	-3.2	**-7.9**	0.7	-1.1	-2.1	0.3	0.0	0.2
Rest of East Asia	0.2	0.8	-2.0	**-9.1**	-3.5	-4.1	**-15.7**	-1.6	0.7	-0.7
India	-0.1	-0.9	-4.0	**-9.8**	**-7.0**	**-7.0**	-4.4	-3.0	-0.4	-0.2
Rest of South Asia	0.2	-3.4	**-10.5**	**-22.9**	-4.5	4.4	**-27.5**	**-8.6**	1.1	-0.6
Energy producers in ECA	0.9	-1.5	0.0	**-9.4**	1.7	-4.6	**-14.3**	-1.1	1.0	-0.4
Rest of Europe & Central Asia	0.4	-1.6	-0.5	**-18.7**	-0.7	-2.7	**-17.5**	**-6.4**	1.5	-0.2
Energy producers in MENA	-0.1	-4.6	1.4	-4.4	**-13.0**	-0.7	**-24.8**	**-10.7**	0.7	-1.5
Rest of MENA	-0.9	**6.9**	-2.7	**-19.1**	**-11.5**	**12.3**	**-11.9**	-2.5	0.2	-0.3
Sub-Saharan Africa	0.4	0.3	-1.5	**-7.6**	-0.8	**-39.8**	**-9.1**	0.5	0.9	-0.3
Energy producers in LAC	0.1	2.6	-1.7	**-12.5**	**-14.4**	**13.9**	**-23.5**	**-5.8**	1.5	-0.6
Rest of Latin America & Caribbean	0.0	-2.9	-3.2	**-17.0**	0.1	0.4	-4.1	-0.2	-0.1	0.1
European Union	-0.2	-1.2	-3.4	**-13.5**	1.2	-1.0	0.2	0.9	-0.2	0.2
United States	-0.2	-0.7	-3.0	**-7.2**	0.5	-0.4	0.1	0.2	-0.1	0.1
Rest of high-income	-0.1	-4.1	-3.9	**-12.8**	1.4	-1.3	1.1	1.2	-0.1	0.2
World	**0.0**	**-1.3**	**-0.7**	**-9.4**	**-1.2**	**-0.6**	**-4.3**	**-0.1**	**0.0**	**0.1**

[14] Cells with absolute values over 5% are highlighted.

Appendix E. Output effects of pre-tax consumption and post-tax pollution energy subsidies elimination[15]

Region/Sector	Agriculture	Coal	Oil	Gas	Oil products	Renewable electricity	Other electricity	Energy intensive industries	Other industries	Services
China	2.6	-59.2	-6.9	-3.9	-21.4	17.9	-63.0	-9.2	4.8	-8.2
Rest of East Asia	0.0	-45.3	-7.4	-11.7	0.0	12.2	-17.1	2.7	0.0	0.3
India	-0.6	-38.1	-6.4	-1.6	-7.2	9.2	-34.1	-11.7	-1.8	0.0
Rest of South Asia	-0.6	-27.8	-24.1	-24.5	-3.7	6.7	-27.5	-10.0	-0.5	0.4
Energy producers in ECA	-0.3	-59.1	-2.4	-3.5	-33.3	13.3	-33.1	-21.0	0.4	-2.7
Rest of Europe & Central Asia	0.0	-71.6	-9.1	-12.2	-33.5	16.5	-39.6	-16.7	3.2	-2.7
Energy producers in MENA	1.0	-18.6	-3.8	-5.8	-11.3	3.7	-23.5	-0.6	2.8	-0.3
Rest of MENA	-1.7	-35.7	-9.8	-24.2	-11.6	21.3	-23.2	-1.7	-1.2	0.0
Sub-Saharan Africa	0.4	-22.5	-8.7	-17.8	1.3	-29.3	-14.5	7.7	1.9	0.2
Energy producers in LAC	-0.3	-44.7	-9.4	-18.0	-16.6	17.5	-23.8	-2.5	0.1	0.3
Rest of Latin America & Caribbean	-2.9	-28.7	-13.1	-28.8	-4.3	1.5	-6.3	-2.3	-2.8	1.1
European Union	-3.6	-41.4	-13.6	-25.9	-5.4	7.5	-9.9	-1.8	-4.5	0.6
United States	-2.1	-46.4	-9.9	-18.8	-5.5	17.3	-21.5	-0.7	-1.8	0.3
Rest of high-income	-2.6	-48.0	-12.5	-23.7	-6.6	9.1	-5.6	-2.1	-3.7	0.7
World	**-0.6**	**-51.6**	**-6.4**	**-11.5**	**-10.3**	**7.4**	**-23.3**	**-4.2**	**-1.0**	**-0.4**

[15] Cells with absolute values over 5% are highlighted.