Journal of Global Economic Analysis, Volume 3 (2018), No. 1, pp. 84-121.

Including Fossil-fuel Consumption Subsidies in the GTAP Data Base

MAKSYM G. CHEPELIEV[a], ROBERT A. MCDOUGALL[b] AND DOMINIQUE VAN DER MENSBRUGGHE[c]

Historically fossil-fuel consumption subsidies have been one of the most widely used energy and public policy interventions. According to the International Energy Agency (IEA), in 2014 they amounted to $493 billion worldwide, which is equivalent to 0.6% of global GDP. Their contribution is even more significant for most energy exporting countries, in many cases exceeding 5-15% of national GDP. However, despite their large magnitude, fossil-fuel consumption subsidies are not explicitly represented in most global economic databases and models, including the Global Trade Analysis Project (GTAP) Data Base, as they are generally not captured by the input-output framework. In this paper, we present methods to integrate pre-tax fossil-fuel consumption subsidies to the GTAP Data Base and produce a version of the GTAP 9.2 Data Base that includes these subsidies. The proposed approach includes updates of energy commodity market prices and corresponding tax rates, within the GTAP Data Base build process. Including fossil-fuel consumption subsidies in the GTAP Data Base provides several benefits for energy and environmental policy simulations, including availability of an additional policy instrument and more consistent representation of energy prices.

JEL codes: C68, H23, Q41, Q54

Keywords: Applied general equilibrium analysis; Energy policy; Fossil-fuel consumption subsidies; GTAP Data Base; Climate change.

---

[a] Center for Global Trade Analysis, Purdue University, 403 West State Street, West Lafayette, IN 47907 (e-mail: mchepeli@purdue.edu).
[b] Center for Global Trade Analysis, Purdue University, 403 West State Street, West Lafayette, IN 47907 (e-mail: rmcdougall@purdue.edu).
[c] Center for Global Trade Analysis, Purdue University, 403 West State Street, West Lafayette, IN 47907 (e-mail: vandermd@purdue.edu).
[d] This paper published on August 22, 2018 is an updated version of the original paper published on June 26, 2018. See footnote 27 for the main change.

1. Introduction

Fossil-fuel consumption subsidies have been an enduring energy and public policy intervention.[1] In 2014, according to International Energy Agency (IEA) estimates (IEA, 2015), they amounted to $493 billion worldwide, which is equivalent to 0.6% of global GDP (World Bank, 2017). Their contribution is even more significant for most energy exporting countries, in many cases exceeding 5-15% of national GDP (IEA, 2015).

Despite their large magnitude, fossil-fuel consumption subsidies are not generally explicitly represented in most global economic databases and models, including the Global Trade Analysis Project (GTAP) Data Base (Aguiar et al., 2016).[2] The main reason behind such under-representation is that these subsidies are usually associated with domestic underpricing of energy commodities relative to international prices and/or cross-subsidization between different types of users. Therefore, they do not involve direct budgetary transfers and are not captured by input-output (IO) tables or national accounts. In the GTAP 9 Data Base with a 2011 benchmark year (Aguiar et al., 2016) an aggregation of all cases when tax-paid prices faced by energy users are lower than market prices for energy commodities, amounts to only $22 billion, which is less than 5% of the corresponding IEA estimate.

Numerous studies have provided an assessment of energy subsidy reforms both on national and global levels, applying different approaches to the representation of subsidies in the model (for literature reviews see Ellis, 2010; Burniaux and Chateau, 2014; Coady et al., 2015). Although energy subsidies are often explicitly included in databases used for single-country simulations (Alshehabi, 2011; Chepeliev, 2014), most multi-region studies face the need to modify the initial database using additional assumptions and rebalancing techniques (Saunders and Schneider, 2000; OECD, 2009; Magné et al., 2014). While largely under-represented in most global economic databases, fossil-fuel

---

[1] Following the general subsidies definition provided by OECD (2005), fossil-fuel subsidies can be defined as "any measure that keeps fossil-fuel prices for consumers below market levels, or for producers above market levels or that reduces costs of fossil fuel for consumers or producers". In this paper, we use terms "fossil-fuel subsidies" and "energy subsidies" as synonyms, although the latter term is associated with a broader set of energy commodities, as it may include subsidies to non-fossil fuels. A broader discussion around the definition of fossil-fuel subsidies is provided in Section 2.

[2] We use expression "Data Base" with two capital letters to reference the GTAP Data Base or its extensions (e.g. GTAP-E Data Base, GTAP-Power Data Base). In all other cases, we use the term "database" (e.g. IMF energy subsidies database).

consumption subsidies play a crucial role in energy and environmental policies. Motivation for including energy subsidies in a general equilibrium context and the GTAP Data Base is based on a number of reasons.

First, notwithstanding the recent reduction in fossil-fuel prices, a growing number of initiatives in renewable energy development and energy market liberalization, fossil-fuel consumption subsidies remain on the top of international policy agendas. Inertia has been hard to overcome, with only several examples of successful elimination of fossil-fuel consumption subsidies in recent years (Sovacool, 2017).

Second, inclusion of fossil-fuel subsidies in the general equilibrium context provides an additional instrument for energy and environmental policy simulations. This is particularly beneficial as, in several countries, the elimination of energy subsidies is more efficient (less costly) than greenhouse gas taxation in meeting emission reduction targets (OECD, 2012; Burniaux and Chateau, 2014; Magne et al., 2014).

Third, including energy subsidies can influence simulation outcomes even if policies do not directly involve the elimination of subsidies. As long as subsidies impact relative prices in the general equilibrium context, policy simulations (e.g. CO_2 taxation) would lead to different results for databases with and without explicit subsidies representation (OECD, 2012).

Finally, integrating energy subsidies through the GTAP Data Base build procedure is preferable to post-construction inclusions of subsidies, e.g. through adjusting ad valorem taxes (Malcolm, 1998), as it is a more consistent approach.

Therefore, the key purpose of this article is to document incorporation of pre-tax fossil-fuel consumption subsidies in the GTAP Data Base. This results in a special version of the GTAP 9.2 Data Base (GTAP 9.2es) with integrated energy subsidies.[3] An aggregated version of the GTAP-Power 9.2es Data Base is included in the supplementary files published with this article. GTAP 9 Data Base subscribers can obtain the fully disaggregated versions of the GTAP 9.2es and GTAP-Power 9.2es Data Bases upon request by contacting the authors.

The paper is organized as follows. Section 2 discusses the definition of energy subsidies and gives a brief overview of available global estimates. Section 3 describes the methodology developed to integrate pre-tax fossil-fuel consumption subsidies into the GTAP Data Base. Section 4 provides an overview of the GTAP Data Base with energy subsidies included and compares the GTAP 9.2es Data Base with the GTAP 9.2 Data Base. Section 5 discusses several environmental policy applications, either considering energy subsidies as a policy tool or exploring their indirect impact on simulation results. In Section 6, we discuss some limitations of

[3] Compared to the GTAP 9 Data Base, release 9.2 includes updated IO 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.

the current procedure and potential steps to improve the GTAP energy module.[4] Section 7 concludes.

2. Energy subsidies: definitions and global estimates

In this section, we start with an overview of approaches to define energy subsidies. We further provide a summary of fossil-fuel subsidy estimates at the global level and justify the choice of data sources that we use in this study.

2.1 Energy subsidy definitions

The broad literature on energy subsidies provides various definitions and interpretations of energy subsidy as a policy instrument, ranging from direct budgetary transfers to non-internalized externalities with most definitions in between (Morgan, 2007; IEA, 1999; Kojima and Koplow, 2015).

In this paper, we consider only energy subsidies that satisfy the following criteria:

- *Are associated with fossil fuels.* The article does not consider any renewable energy subsidies, such as subsidies to wind or solar electricity. Although their magnitude has significantly increased during recent years (IEA, 2016), they are mostly associated with producers, which is not the focus of this paper.
- *Levied on consumers.* Only subsidies received by final or intermediate consumers are considered in this study. Any type of producer support (e.g. tax relief for coal production) are not incorporated to the GTAP Data Base under the discussed methodology.
- *Influence (reduce) consumer prices relative to international prices (supply costs).* The current approach includes only subsidies that lower the consumer price of an energy commodity relative to a reference price. The reference price is equivalent to the international market price in case of traded energy commodities, such as petroleum products, or supply-cost, if the commodity is not traded, such as electricity. The next section discusses reference prices in more detail. Our methodology excludes the case of a subsidy that does not influence consumer prices (e.g. direct money transfers to households) or the case of a consumption price that is higher than the reference price. Externality costs associated with air pollution,

[4] The energy module is a procedure in the GTAP Data Base build process; it prepares energy data that are included in the GTAP Data Base (see McDougall and Lee (2006) for more details).

climate change or road damage are not included in the reference price estimates.

- *Are not associated with tax measures.* We do not consider subsidies that result from under taxation (tax-related subsidies), e.g. application of a reduced value-added tax (VAT) rate in the electricity industry.

There are several motivations behind the choice of these criteria. First, our focus on pre-tax consumer energy subsidies is motivated by the fact that some (or even most) producer and tax-related consumer subsidies are already included in the GTAP Data Base and their further treatment may result in double counting. For instance, if a lower production tax or VAT is applied to the coal sector relative to other sectors, it is captured by the relevant IO table. The same reasoning applies to cost-covering and capital expenditure producer support, which are included in production taxes in IO tables.[5] Although not included in this study, such subsidy types (forms of support) can be beneficial in improving the GTAP Data Base and overwriting the initial data, as currently implemented in the GTAP 9 Data Base (Aguiar et al., 2016). Data on fossil-fuel budgetary support and tax expenditures is consistently reported by the Organisation for Economic Co-operation and Development (OECD) (OECD, 2017). Including such data in the GTAP Data Base is beyond the scope of this paper, but may be a valuable addition for future extensions.

Second, the motivation to exclude renewable energy subsidies in the current contribution is twofold: *a)* we do not have enough data for their consistent representation by regions and sectors; and *b)* we lack subsidy-related sectors (e.g. biofuels, wind and solar power generation) in the standard GTAP Data Base.

Third, while there is some economic reasoning behind the treatment of inefficient taxation as hidden subsidization (Barany and Grigonyte, 2015; Coady, 2015), there is much uncertainty associated with the scale of inefficient taxation of fossil fuels, mostly due to externality cost estimates (Nordhaus, 2014; Biasque, 2010). Therefore, in the current contribution we do not go beyond international market prices or supply-costs in defining the reference price.

Finally, as any measure that do not impact prices (such as direct money transfers) may already be included in the GTAP Data Base, we focus only on those cases that influence consumer prices by reducing their level below the reference price.

2.2 Global subsidy estimates and database choice

While there are many discussions around the definition and quantitative assessment of fossil-fuel subsidies, several international agencies consistently

[5] See, for example, Chepeliev (2015) for the case of Ukrainian coal production subsidies represented in the GTAP Data Base.

monitor their magnitudes on a global level. Estimates usually cover various types of support and vary in regional, commodity and consumer coverage. In addition, they are based on different subsidy definitions. In particular, subsidy estimates of the OECD include income transfers and tax expenditures whether or not they affect commodity prices (OECD, 2015). They also include both consumers and producers. However, the OECD approach does not include subsidy measures that involve price regulation (e.g. a price cap on electricity for rural households) or cross subsidization (price differentiation for different types of consumers).

A broader concept is used by the IEA, as it includes market price support, under collected resource rents and taxes, but at the same time excludes any support that does not influence prices (IEA, 2017). The IEA uses a price-gap approach to estimate fossil-fuel subsidies and includes value-added taxes in the reference prices where the tax is levied on final energy sales, as a proxy for taxes on economic activities throughout the economy.

A similar approach for estimating energy subsidies is applied by the International Monetary Fund (IMF), although it does not include any taxes for supply cost estimates and thus accounts only for pre-tax fossil-fuel subsidies. It should be noted that the price-gap approach, applied by both the IEA and IMF, usually treats the international market price (if the commodity is traded) as a supply-cost. In some cases, this approach may underestimate subsidies if the actual domestic cost of energy commodity production is higher than the international market price and the government subsidizes this commodity to make it competitive with imports.[6] Table 1 provides a comparison of fossil-fuel subsidy estimates by the OECD, IEA and IMF.

While both the IMF and IEA apply similar approaches to fossil-fuel consumption subsidy estimates, the IMF data better suits our purposes. First, as IMF reports consumer prices, supply costs and energy volumes, the data enables a full replication of fossil-fuel subsidy estimates.[7] Furthermore, such data provide an opportunity for explicit use of energy commodity prices in the subsidies database construction process. Second, the IMF data covers more countries than the IEA data. In particular, for 2011 databases IMF reports 98 countries with non-zero fossil-fuel subsidies, while IEA reports 41. Additionally, although IEA-reported countries cover over 95% of global fossil-fuel subsidies, IMF's higher coverage is important in terms of regional consistency in the representation of subsidies. Finally, in contrast to the IEA estimates, the IMF-reported supply costs do not include taxes and thus make it easier to avoid double counting.

[6] That is, for an energy commodity, the subsidy reduces the cost of domestic production to match the import price (see, for example, Chepeliev (2015) for the case of coal production subsidies in Ukraine).

[7] In comparison, IEA reports only subsidy values, which does not allow us to replicate the estimates and compare international market prices with the ones used in GTAP Data Base.

Table 1. Comparison of fossil-fuel subsidy estimates.

	OECD	**IEA**	**IMF**
Value (bn USD, 2014)	170	493	481
Country coverage	34 OECD members and 6 partner economies	41, mostly developing	188
Reported products	Petroleum products (eight types), coal (seven types), natural gas	Coal, natural gas, electricity, oil	Gasoline, diesel, kerosene, coal, natural gas, electricity
Consumer coverage	Consumers and producers	Consumers	Consumers
Subsidies definition	Budgetary transfers and tax expenditures that provide benefits to fossil-fuel consumers and producers	Government actions that result in end-user prices being lower than supply cost	Price paid by consumers below supply cost (pre-tax consumer subsidies)
Estimation approach*	CSE, PSE, GSSE	PGA	PGA
Inclusion of tax subsidies	Yes	Yes	No
Data source	Mainly country's annual budgets	IEA, government sources and other reports	IEA subsidy estimates, IMF, World Bank and other reports
Additional data reported	Subsidies are reported by mechanisms, levels, measures, incidences, indicators and stages	None	Energy commodity consumer prices, supply costs and consumption volumes by intermediate and final users
Time coverage	2006-2014	2007-2016	2003-2015

Source: OECD data is based on OECD (2015, 2017). For OECD data, estimates are also available on a more disaggregated commodity level (up to eight petroleum products and seven coal types). IEA data is sourced from IEA (2015; 2017). For IEA estimates, subsidies for oil include gasoline, diesel, kerosene, liquefied petroleum gas and heavy fuel oil (IEA (2015) reports energy subsides only for oil in aggregate). IMF data is described by Coady et al (2015) and IMF (2015). For IMF data, not all 188 countries have full product level subsidy estimates available; Coady et al (2015) also report post-tax and producer subsidies, but they are not discussed here. Comparison template is sourced from IISD (2014). Most common time spans are reported; data quality and availability by years may vary.

Note: * CSE – consumer support estimate; PSE – producer support estimate; GSSE – general services support estimate; PGA – price-gap approach.

Therefore, in this paper we use the IMF 2011 fossil-fuel consumer subsidy estimates. We may consider alternative data sources in the future depending on their availability.

It should be noted that in case of both IMF and GTAP, energy volumes data is sourced from IEA (Coady et al., 2015; McDougall and Lee, 2006). At the same time, the IMF energy subsidies database reports energy volumes for selected energy commodities, which are considered to be subsidized, while in case of GTAP, IEA-sourced energy volumes undergo additional processing and balancing (McDougall and Lee, 2006). As a result, both IMF and GTAP-reported energy volumes differ from IEA data.

Figure 1 depicts the regional distribution of the total value of pre-tax fossil-fuel consumption subsidies estimated by IMF (Coady et al., 2015) that are included in the GTAP Data Base. The total value of fossil-fuel subsidies is highest in developing and energy exporting countries, in particular the Middle East and North Africa (MENA), with Iran being the largest subsidy provider with almost USD 74 billion.

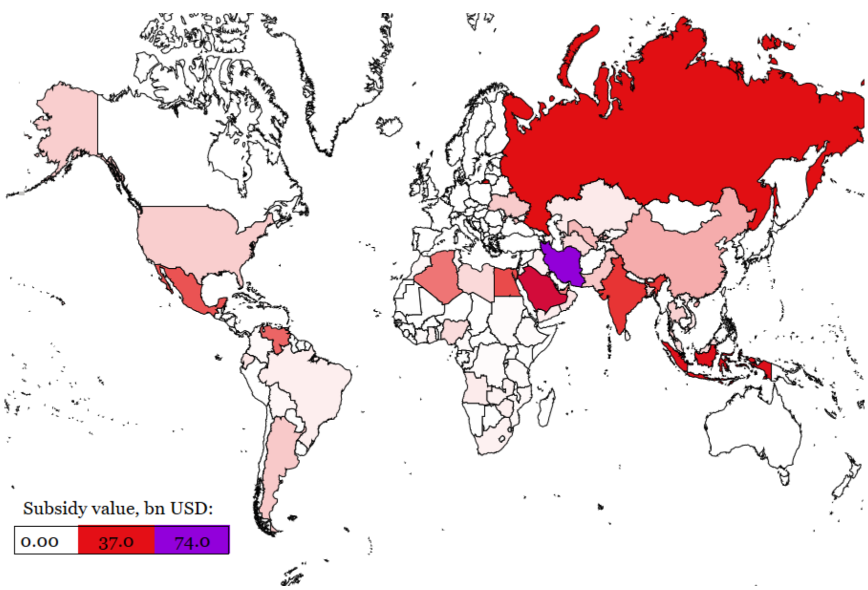


Figure 1. Regional distribution of 2011 pre-tax fossil-fuel consumption subsidies.

Source: Authors calculations based on IMF (2015) and using openheatmap.com.

3. Including energy subsidies in the GTAP Data Base

This section describes the general methodology and data processing steps used to integrate pre-tax fossil-fuel consumption subsidies into the GTAP Data Base. We start with an overview of the approach and then discuss the data and program related details.

3.1 General methodology

We include fossil-fuel consumption subsidies in the GTAP Data Base by subtracting subsidy rates, which are estimated as a ratio of IMF-sourced subsidy values (in USD) and GTAP-based energy consumption (in tons of oil equivalent, toe) from GTAP energy commodity taxes (USD per toe). In this approach, supply cost (the tax-inclusive price paid by energy users) is unchanged, as the impacts of fossil-fuel consumption subsidies are already included in the observed equilibrium, even though they are not explicitly represented.[8] This concept can be illustrated using a supply-demand diagram (Figure 2). All prices, tax and subsidy rates are measured in USD per toe, unless otherwise noted. To refer to the taxes and subsidies in the percentage terms we use the term "ad valorem".

For ease of explanation, assume that we are dealing with a natural gas exporter, with prices for domestic natural gas consumers (P_D) significantly lower than the export price (P_M^1). We cannot correctly identify this fact from the GTAP Data Base or underlying input-output table, as we do not directly observe the corresponding prices. Therefore, in the current example (Figure 2) and standard version of the GTAP Data Base, we assume that domestic consumers pay price P_D, which is not lower than market price P_M^0.[9] Thus, implying that the export price also equals P_M^0 if no export taxes are applied.

As we can see from Figure 2a, the actual subsidy rate per unit of natural gas equals ($P_M^0 - P_M^1$), but as long as there is some positive tax rate in the GTAP Data Base without included energy subsidies ($P_D - P_M^0$) the net subsidy rate in the updated GTAP Data Base would equal ($P_D - P_M^1$).[10]

Our estimates of fossil-fuel subsidies measure energy commodity prices and taxes in USD per toe. To include fossil-fuel subsidies in the GTAP 9.2 Data Base, we subtract our estimates of fossil-fuel subsidy rates from the tax rates reported in the energy module component of the GTAP 9.2 Data Base build stream. After these changes, we run the new build stream and develop the GTAP 9.2es Data Base with included pre-tax fossil-fuel consumption subsidies. In the GTAP Data Base, all taxes and subsidies are reported as ad valorem equivalents (in percentage terms),

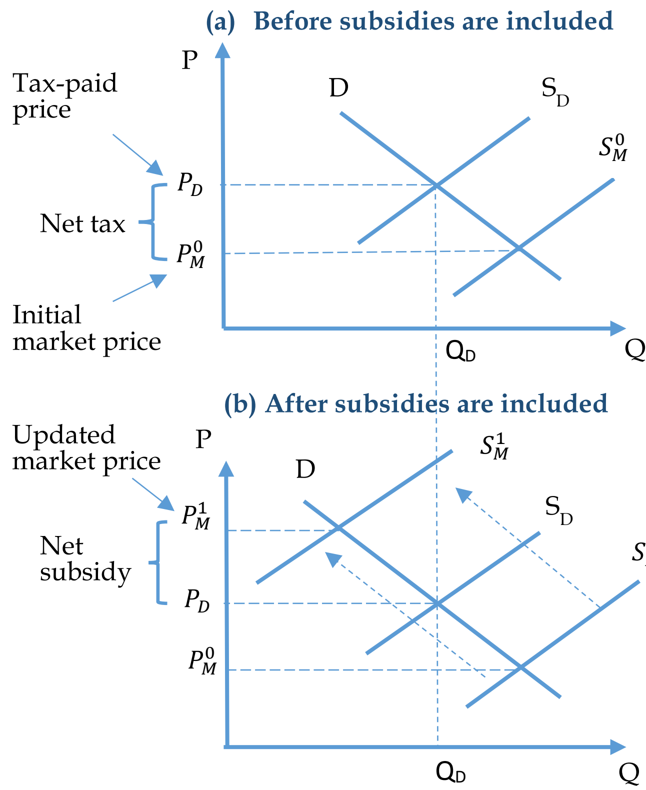
---

[8] In terms of GTAPv6.2 model notation, tax-paid prices faced by energy users correspond to agent's prices faced by energy consumers (in our particular case – households). But as the new version of GTAP model (version 7) (Corong et al., 2017) moves away from agent's price notation and uses producer or supply (post-income tax) notation instead, we use a more general tax-paid prices terminology.

[9] Assuming there are some positive taxes (e.g. VAT) and ignoring transportation and supply costs for simplification. If there are no natural gas consumption taxes, then $P_D = P_M^0$. It can also be the case that the GTAP Data Base reports subsidies for natural gas ($P_D < P_M^0$) and as a result of including subsidies, P_M would be further increased.

[10] We use expression "updated GTAP Data Base" to identify the GTAP Data Base after fossil-fuel subsidies are included.

therefore during the build process, specific tax rates (in USD per toe) are converted to the ad valorem equivalents. Although it should be noted that the GTAP Data



Base reports energy volumes (in million toe) and values (in million USD). Therefore users can estimate specific tax rates (in USD per toe) from available data.

Figure 2. Supply-demand representation of the inclusion of energy subsidies in the GTAP Data Base.

Source: Authors.

Inclusion of pre-tax fossil-fuel consumption subsidies involves updating ad valorem taxes on firms' domestic and import purchases ("tfd" and "tfm"), government domestic and import purchases taxes ("tgd" and "tgm"), as well as private domestic and import consumption taxes ("tpd" and "tpm").[11] For the ad valorem taxes noted above, the GTAP 9.2es Data Base includes only updated values (i.e., values after fossil-fuel subsidies are included) and no new identifiers or variables are introduced to the GTAP 9.2es Data Base. To simulate changes in

[11] To maintain balanced social accounting matrices, inclusion of pre-tax fossil-fuel consumption subsidies also impacts the values of other variables (apart from "tfd", "tgd", "tpd", "tfm", "tgm" and "tpm").

fossil-fuel subsidies in a model built on the GTAP 9.2es Data Base, users should shock the updated ad valorem taxes for "tfd", "tgd", "tpd", "tfm", "tgm" and "tpm". A simulation evaluating the elimination of pre-tax fossil-fuel subsidies would involve setting the relevant tax variables equal to their original values, reported in the GTAP 9.2 Data Base (generally not to "0").[12]

It should be noted that in the current contribution we do not provide information on the levels of the normal (unsubsidized) ad valorem taxes. In the example above, if the lower (relative to other commodities) VAT rate is applied to natural gas we do not indicate it in the GTAP Data Base with or without included fossil-fuel consumption subsidies.

3.2 Input data processing

In this subsection, we discuss data processing procedures in detail. All steps are applied for 2011 data, unless stated otherwise.

In the *first step*, we source supply costs, consumer prices and weighted energy consumption volumes from the IMF energy subsidies database (IMF, 2015) (Figure 3). Data is available for 188 countries, 6 energy commodities (coal, electricity, natural gas, gasoline, diesel and kerosene) and 2 types of consumers (final and intermediate).

In the case of some energy commodities and consumers, the IMF database reports negative weighted consumption volumes. Particularly this is the case for intermediate coal consumption in Argentina, Brazil, Costa Rica, Dominican Republic, El Salvador, Guatemala, Jamaica, Mexico, Peru, Uruguay and Venezuela. Although, it should be noted, that aggregate intermediate and final consumption volumes are positive in all cases. Negative energy consumption volumes are set to "0" in our estimation procedure.

Energy commodities from the IMF database are mapped to four GTAP energy sectors – Petroleum, coal products ("p_c"), Coal ("coa"), Gas ("gas") and Electricity ("ely") (Appendix A). A one-to-one mapping between IMF and GTAP energy products is achieved only in the case of electricity, while for other commodities the corresponding GTAP commodities serve as supersets. For example, petroleum products in the IMF database (gasoline, kerosene and diesel) are mapped to the "p_c" sector in GTAP Data Base, which also includes other petroleum products (e.g. naphtha, heavy fuel oil, liquefied petroleum gas etc), coal products and nuclear fuel. Therefore, in most cases, per unit energy subsidy rates, measured in USD per toe, in the updated GTAP Data Base are lower than the corresponding values in the IMF database. An additional consequence of the many-to-one mapping is that, in the updated GTAP Data Base, fossil-fuel subsidies are applied to some (aggregated) unsubsidized products (or products with no information regarding their subsidization).

[12] Relevant tax variables are set to "0" if their original values are negative.

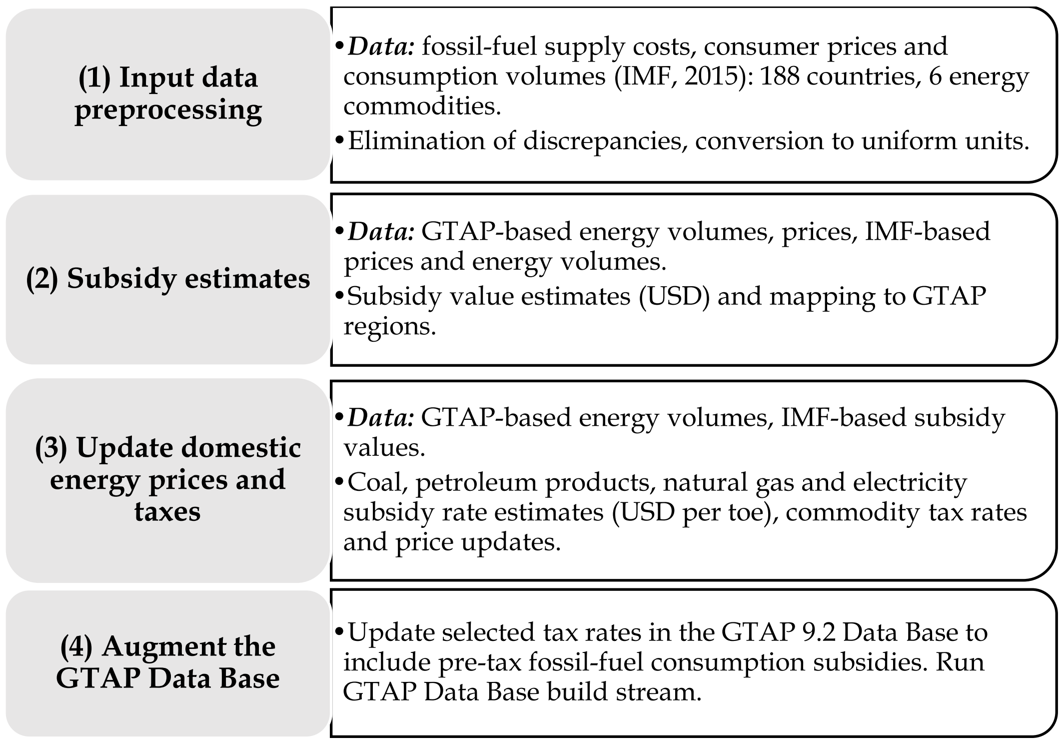


Figure 3. Steps to introduce fossil-fuel consumption subsidies to GTAP Data Base.

Source: Authors.

In the *second step***,** we provide harmonization between the IMF and GTAP data. In some cases, IMF energy consumption volumes are higher than GTAP energy consumption.[13] Potentially, this can lead to negative energy prices after application of updated subsidy rates.[14] As we want to achieve consistency between IMF pre-tax fossil-fuel subsidy estimates and GTAP energy consumption data, in such cases, we replace IMF-sourced energy consumption volumes with GTAP-based consumption volumes. To convert IMF-sourced energy quantities in liters, terajoules and terawatt-hours to toe, we use conversion factors provided in McDougall and Lee (2006) for all energy products except kerosene. For kerosene, IEA-based conversion factors are used (IEA, 2005).

[13] As noted above, in most cases the opposite inequality holds.

[14] For example, assume that the IMF reports a reference/international market price of $600/toe and a price gap equal to $400/toe. Further assume that the IMF-reported energy consumption volume of the subsidized commodity is 10 toe and the GTAP-reported consumption volume is 5 toe. In such a case, the IMF-based subsidy value would be 400*10=$4000. At the same time, the GTAP energy consumption volume-based subsidy rate estimate is $800/toe (4000/5), which is higher than reference/international market price ($600/toe).

In some cases, the IMF-based fossil-fuel subsidy rates can be higher than GTAP-based international market prices. If the import share is small, this does not become an issue, as an increase in the domestic price will result in a similar increase in the average market price. However, if imports are a large share of domestic consumption, an increase in the domestic price would not significantly influence the average market price, which can potentially lead to negative tax-paid price estimates after the deduction of subsidy rates from the updated market price. To eliminate such potential issues, we identify country/commodity cases with an energy import share over 50% of total consumption and subsidy rates higher than GTAP-based free on board (FOB) prices. For these cases, we rescale subsidy values treating the GTAP-based import price as a supply cost.

Finally, taking into account these two adjustments, we estimate fossil-fuel consumption subsidies values and map them to the 141 GTAP regions.

In the *third step*, fossil-fuel consumption subsidy values (VS, in USD) and GTAP-based energy consumption volumes (ED, in toe) are used to estimate subsidy rates (USD per toe). Subsidy rates are further used to update energy market prices and commodity tax rates. Updated market prices are derived by adding the subsidy rate to initial market prices: $P_M^1 = P_M^0 + VS/ED$ (Figure 2).

In the case of commodity tax rates, the subsidy rate is subtracted from the initial tax rate level. Thus, tax-paid prices faced by energy users for subsidized commodities are not changed by the inclusion of subsidies.

In the build stream used for the GTAP 9.2 Data Base, energy commodity tax rates are introduced either in the energy module (McDougall and Lee, 2006), if they are available from external sources (e.g. the IEA), or adopted from IO tables, if this is the only available source, in a later stage of the FIT process (Aguiar et al., 2016).[15] If introduced in the energy module, commodity tax rates are not overwritten by the FIT procedure. In our approach, we introduce subsidy rates within the energy module, combining them with energy commodity tax rates.

Finally, in the *fourth step*, updated energy market prices and commodity tax rates are introduced into the energy module component of the GTAP Data Base build stream. After running the new build stream, we derive a GTAP 9.2 Data Base that includes pre-tax fossil-fuel consumption subsidies, which we call GTAP 9.2es. The GTAP 9.2es Data Base has the same list of variables as the GTAP 9.2 Data Base, but variable values are changed. This is because after changes in energy commodity tax rates and prices (both in USD per toe) are made in the energy module, the GTAP Data Base is rebalanced. While inclusion of the fossil-fuel consumption subsidies to the GTAP Data Base corresponds to the changes in the ad valorem taxes ("tfd", "tgd", "tpd", "tfm", "tgm" and "tpm"), values of other

[15] The FIT process is an adjustment procedure used in the construction of GTAP Data Base to fit IO tables to the international data sets using entropy methods (see Aguiar et al. (2016) and James and McDougall (1993) for more details).

variables, such as intermediate consumption, factor purchases, sectoral output, etc., are also updated. These changes are discussed in more detail in Section 4.2.

Table 2 provides some country and commodity specific examples of fossil-fuel subsidies included in the energy module component of the GTAP Data Base build stream, focusing on the procedure that updates consumption tax rates for households. The first two examples in Table 2 (Ukraine and Bahrain) represent cases without the need to rescale IMF subsidy rates. In the case of natural gas in Ukraine, the energy module of the GTAP Data Base reports a commodity tax rate of 139.3 USD per toe. After subtraction of the IMF-based subsidy rate (107.9 USD per toe), the natural gas net tax rate is significantly lower, but still positive (31.4 USD per toe). Bahrain experiences a high subsidy rate for domestic consumers of petroleum products (almost 90% of the FOB price) and an initially low commodity tax rate is reported in the energy module of the GTAP Data Base (10.5 USD per toe), therefore the updated commodity tax rate is negative (-574 USD per toe), i.e. the updated rate is a subsidy.

In the case of 2011 fossil-fuel consumption subsidies, the electricity sector in Benin represents the only case where subsidy values are recalculated due to the differences between international and domestic market prices (Table 2). As a result, the IMF-sourced electricity subsidy rate (USD per toe) is reduced by almost 50%. Venezuela’s electricity sector is a case where the IMF subsidy is rescaled due to differences in IMF and GTAP energy consumption volumes. As the IMF-reported consumption volume is higher than that in the GTAP 9.2 Data Base, the initial subsidy rate is reduced by 3% (Table 2).

Table 2. Selected country and commodity specific examples of final energy consumption subsidies included in the GTAP Data Base

No.	Indicator\country		Ukraine	Bahrain	Benin	Venezuela
	Input data					
1	Energy commodity		Natural gas	Petroleum products	Electricity	Electricity
2	GTAP-based energy consumption, Mtoe		47.8	2.1	0.1	10.3
3	IMF-based energy consumption, Mtoe		46.8	1.7	0.1	10.6
4	GTAP-based FOB price, USD per toe		369.3	664.8	754.8	981.3
5	IMF-based subsidy rate, USD per toe		107.9	584.5	1557.0	304.7
6	Domestic consumption less import, Mtoe		15.1	1.3	0.0	10.2
7	Import, Mtoe		32.8	0.8	0.1	0.0
8	GTAP-based commodity tax rate, USD per toe		139.3	10.5	6.8	-9.0
	Update of the energy commodity tax rate					
9	**Step 1.** Compare energy consumption data and adjust if necessary	If (2)/(3)<1, multiply IMF-based subsidy rate by this ratio; otherwise do nothing	1.02>1 => do nothing	1.2>1 => do nothing	1=1 => do nothing	0.97<1 => reconcile
10	**Step 2.** Compare FOB price and subsidy rates	If [(4)/(5)]<1 and [(6)-(7)]<0, multiply IMF-based subsidy rate by (4)/(5); otherwise do nothing	(4)/(5) = 3.4 >1, (6)-(7) = -17.7<0 => do nothing	(4)/(5) = 1.1 >1, (6)-(7) = 0.5>0 => do nothing	(4)/(5) = 0.5 <1, (6)-(7) = -0.1<0 => reconcile	(4)/(5) = 3.2 >1, (6)-(7) = 10.2>0 => do nothing
11	**Step 3.** Reconcile the subsidy rate (if required)	Depending on the results of steps 1 and 2, rescale the IMF-based subsidy rate (USD per toe) or leave it unchanged	107.9 (no rescaling)	584.5 (no rescaling)	754.8 [(5)*(4)/(5)]	295.6 [(5)*(9)]
12	**Step 4.** Update the energy commodity tax rate	Subtract subsidy rate from the GTAP-sourced commodity tax [(8)-(11)], USD per toe	31.4	-574.0	-748.2	-304.6

Notes: Numbers in the round brackets refer to the lines in the table.

Source: Authors.

4. Overview of the GTAP 9.2es Data Base

This section provides an overview of the GTAP 9.2es Data Base, an extension of the GTAP 9.2 Data Base that has been augmented to include pre-tax fossil-fuel consumption subsidies. We explore the regional and sectoral distribution of energy subsidies, as well as changes in the commodity tax rates. After adjusting the relevant tax rates and prices to account for fossil-fuel consumption subsidies, as noted in the previous section, running the new GTAP Data Base build stream causes changes in other variables, so this section also compares the GTAP 9.2 and 9.2es Data Bases.

According to IMF estimates, pre-tax fossil-fuel consumption subsidies amounted to over $506 billion in 2011 (IMF, 2015). After the data preprocessing described in Section 3, our reconciled value of global energy subsidies amounts to nearly $505 billion, or 99.7% of the initial IMF estimate. For convenience of presentation and publicly sharing the supplementary files, data is presented for aggregate regions. GTAP users with a license to the GTAP 9 Data Base can obtain the fully disaggregated versions of the GTAP 9.2es and GTAP-Power 9.2es Data Bases from the Centre for Global Trade Analysis upon request.

4.1 Fossil-fuel consumption subsidy rates

While almost 80% of global pre-tax fossil-fuel consumption subsidies (in value terms) are associated with net energy exporters, many energy importing middle and low income economies apply high subsidy rates (Figure 4, Appendix C).[19] However, this is not the case for natural gas, where the highest subsidy rates are almost exclusively observed in energy exporters in the MENA, with only several exceptions for net energy importers (Appendix C, Figure C.2).[20] Different patterns can be observed for petroleum products and electricity. Subsidy rates for these products are relatively high in net energy importing countries. This is especially the case for electricity subsidies in Sub-Saharan Africa, as almost all cases with subsidy rates over 1000 USD per toe occur in this region (Appendix C, Figure C.1).

[19] We identify energy exporters by estimating the difference between a country's exports and imports aggregated over five GTAP energy commodities: coal (coa), oil (oil), gas (gas), petroleum products (p_c) and electricity (ely).

[20] In particular, there are only three net energy importers with natural gas subsidy rates of 100 USD per toe or higher – Bangladesh, Ukraine and Pakistan.

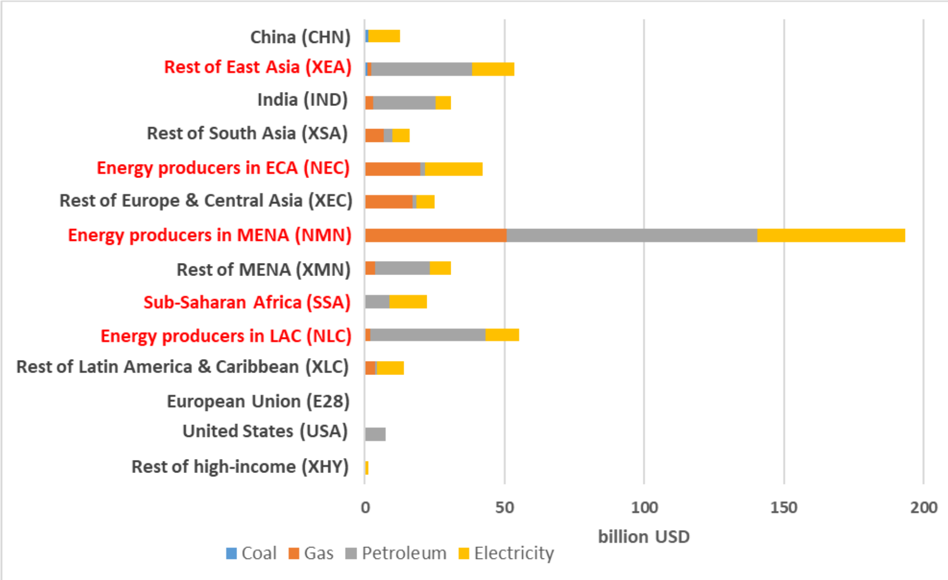


Figure 4. 2011 fossil-fuel consumption subsidy values by commodities and regions.

Notes: Regional mapping is provided in Appendix B. Regions in red text are net energy exporters. Coady et al (2015) report similar figure for the post-tax energy subsidies distribution.

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

Thus, while in value terms most pre-tax fossil-fuel consumption subsidies are associated with energy producing countries, large changes in energy commodity ad valorem taxes in the updated GTAP Data Base are often introduced for developing energy-importing regions. In many cases, they represent government initiatives to support low-income households and ensure energy accessibility for all consumers. Region and commodity specific ad valorem subsidies are provided in Figure 5.

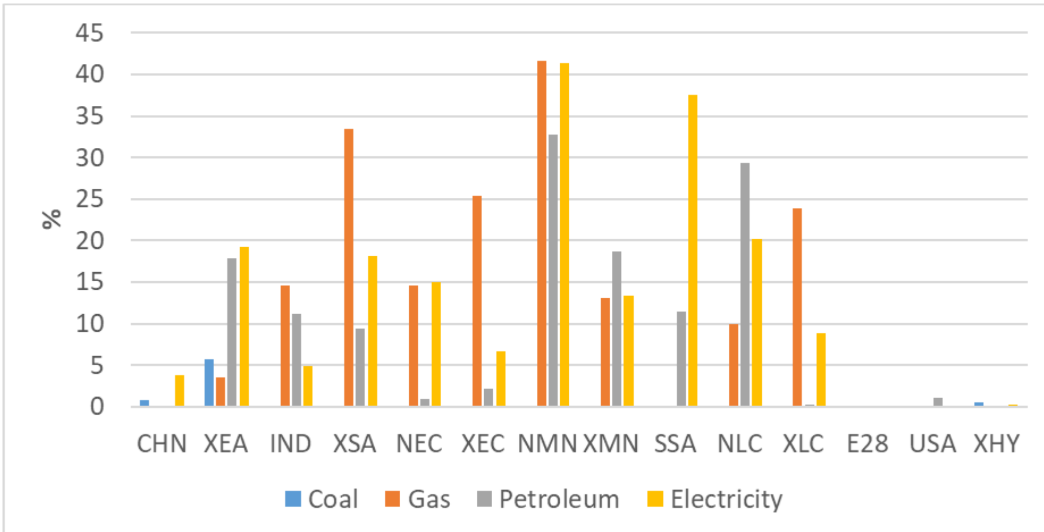


Figure 5. Region and commodity specific fossil-fuel consumption ad valorem energy subsidies, %.

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

Source: Authors' calculations.

4.2 Comparison of GTAP 9.2 and 9.2es Data Bases

We further explore results of energy subsidies included in the GTAP Data Base by comparing energy commodity ad valorem taxes in versions 9.2 (which does not include fossil-fuel subsidies) and 9.2es (which does include subsidies). Sections 4.1 and 4.2 use country-specific data sourced from the energy module of the GTAP Data Base. This section compares ad valorem taxes in the GTAP 9.2es Data Base for 141 regions and three energy commodities (natural gas, petroleum products and electricity).[21] In Figure 6, for each commodity, we report percentage-point changes in weighted-average energy commodity ad valorem taxes between version 9.2 and 9.2es of the GTAP Data Base (our estimate of energy subsidies) on the vertical axis, and net energy export intensity on the horizontal axis.[22]

[21] For expositional reasons, coal is dropped from the comparison as subsidy rates for this commodity tend to be low.

[22] Net energy export intensity is defined as, aggregated across energy commodities, net energy exports divided by the sum of domestic energy consumption and energy exports.

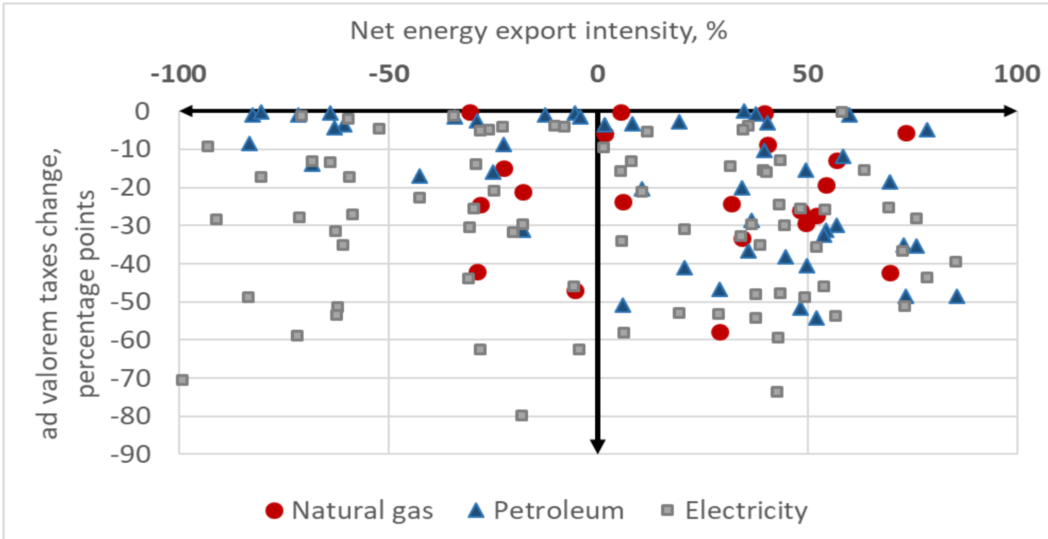


Figure 6. Change in energy tax rates after incorporating fossil-fuel consumption subsidies to GTAP 9.2 Data Base.

Notes: Net energy export intensity calculated by aggregating across all energy commodities.

Source: Authors calculations.

In some cases, especially for electricity, the change in ad valorem taxes exceeds 50 percentage points, even for net energy importing countries. Nonetheless, changes in ad valorem subsidies are on average higher for net energy exporters (regions with positive net energy export intensities). The simple average change of fossil-fuel consumption ad valorem taxes for all regions equals 22.2 percentage points for natural gas, 18.4 percentage points for petroleum products and 29.7 percentage points for electricity. Appendix D (Tables D.1-D.4) provides aggregated Social Accounting Matrices (SAM) for GTAP 9.2 and 9.2es Data Bases for selected regional aggregations.

In terms of changes in the aggregate SAM values, including fossil-fuel consumption subsidies in the GTAP 9.2 Data Base significantly reduce sales tax values on energy commodities. At the same time, increases in the energy market prices after fossil-fuel consumption subsidies are included (in GTAP 9.2es Data Base) lead to the increase in the total energy output value (compared to the GTAP 9.2 Data Base) for both energy producing and other subsidizing regions (Appendix D). As might be expected, most changes in cost structures are associated with an increasing value of endowment and energy purchases by non-energy and energy activities.

5. GTAP 9.2es Data Base policy simulations

Including pre-tax fossil-fuel consumption subsidies in the GTAP Data Base can affect policy simulations in two ways. First, it introduces a new policy instrument that can be used to achieve energy, environmental or social targets. One of the benefits of this option is that in some cases the elimination of fossil-fuel subsidies is more efficient (less costly) than emissions taxation in meeting environmental targets (OECD, 2012; Burniaux and Chateau, 2014; Magne et al., 2014). Second, inclusion of fossil-fuel consumption subsidies in the GTAP Data Base changes relative prices and optimal resource allocation patterns. Therefore, even if a policy simulation does not directly include changes in ad valorem energy subsidies, simulation results can still be influenced by the inclusion of such subsidies. In this section, we explore both cases using a policy experiment that includes achieving the Paris Agreement targets (UNFCCC, 2017).

The main purpose of this Section is to provide a numerical illustration and policy-based exploration of the GTAP 9.2es Data Base. In terms of policy simulations, our analysis complements existing literature on the global fossil-fuel subsidies reform (IEA, 1999; OECD, 2012; IMF, 2015; Burniaux and Chateau, 2014; Magne et al., 2014). We extend existing studies by looking at subsidies reform in the context of Paris Agreement targets, as well as comparing numerical assessment of the environmental policies with and without the explicit representation of fossil-fuel based consumption subsidies.

5.1 Policy experiment design

As of August 2017, 160 countries have ratified the Paris Agreement within the context of the United Nations Framework Convention on Climate Change (UNFCCC, 2017). Each country has defined its own emission reduction target, by providing nationally determined contributions (NDCs). Countries use different approaches, timeframes and benchmarks to define the reduction target, e.g. relative to a historical data, Business as Usual (BaU) scenario, in terms of GDP carbon intensity, etc. For the policy simulation, we harmonize all targets by converting them into CO_2 emissions reduction relative to a BaU scenario.

In the first step, we source CO_2 emissions reduction commitments by countries (UNFCCC, 2017). Almost half of the revised contributions are provided relative to the BaU path, either explicitly (e.g. reduction of CO_2 emissions by 10% relative to BaU) or implicitly (e.g. reduction in GDP carbon intensity).[23] In the second step, we represent all commitments as a CO_2 emissions reduction relative to the BaU scenario. Baseline CO_2 emissions and GDP growth rates are sourced from the International Energy Outlook (EIA, 2016) and complemented with data from Cline (2011). In most cases, the BaU scenario starts in 2015 and runs through the NDC

[23] For instance, GDP carbon intensity reduction targets are pledged by China, India, Singapore, Malaysia and Chile.

target year, normally 2030.[24] We estimate CO_2 emissions reduction targets for countries that account for 88% of global CO_2 emissions. Finally, we map estimated reduction targets to aggregate regions (Appendix B), by using 2011 CO_2 emission weights from the GTAP 9.2 Data Base. In the case of India, CO_2 emissions reduction target equals "0", as according to the sources we use to calculate emission reduction targets. India's NDC does not require reduction in emissions relative to the BaU scenario (Figure 7).

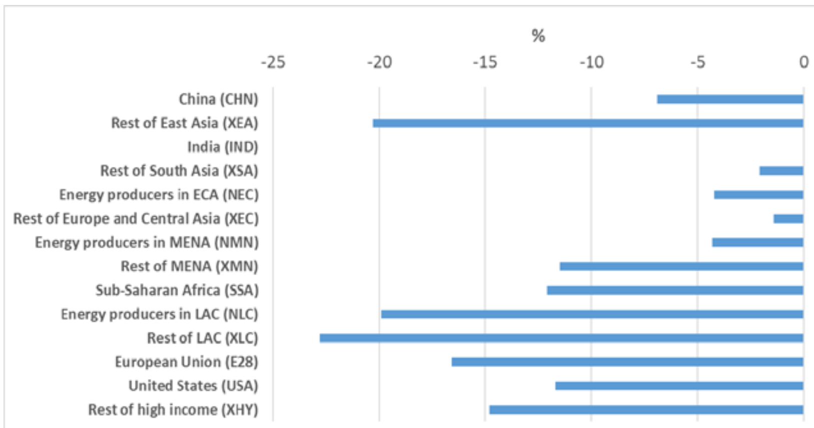


Figure 7. CO_2 emissions reduction targets relative to BaU scenario according to Paris Agreement, %.

Source: Authors calculations based on UNFCCC (2017), EIA (2016) and Cline (2011).

To estimate the impacts of NDC emissions reduction targets we use the GTAP-E-Power model (Peters, 2016b) that is an extension of the static computable general equilibrium GTAP-E model (Burniaux and Truong, 2002; McDougall and Golub, 2007). Both these models are based on the standard GTAP model that is documented in Hertel (1997).[25]

The GTAP-E-Power model disaggregates the electricity sector of the GTAP-E model into 12 sub sectors—providing details on 11 generation activities, including renewables, and a separate transport and distribution activity. Correspondingly, the GTAP-Power Data Base (Peters, 2016a) has 68 activities. For our policy simulations, we have mapped the 121 countries and 20 composite regions to 14 aggregate regions (Appendix B) and the 68 activities to 20 (Appendix E).[26]

---

[24] Some countries provide contributions with a different timeframe. For example, the U.S. uses 2025, while Iraq considers a BaU scenario till 2035.

[25] For the latest version of the Standard GTAP model (version 7), see Corong et al. (2017).

[26] The GTAP-Power Data Base is developed as a post-processing disaggregation of the standard GTAP Data Base, therefore we first include fossil-fuel subsidies to the GTAP 9.2

Two policy options are considered. They include a) achieving the NDC targets using only emission taxes; and b) combining the elimination of energy subsidies with emission taxes. We compare results for GTAP Data Bases with and without included pre-tax fossil-fuel consumption subsidies with no international trade in emission permits.

To make our simulation results more consistent with mid-term timeframe and to allow for better substitution possibilities within and outer energy nest, we use higher substitution elasticity values compared to the benchmark GTAP-E-Power parameters. Updated elasticity values are adopted from Chepeliev and van der Mensbrugghe (2017).

5.2 Policy simulation results

We consider three policy scenarios assuming no international trading of emission permits. The first two scenarios apply CO_2 taxes to achieve NDC targets using GTAP 9.2 Data Base with (in the first scenario) and without (in the second scenario) energy subsidies included. The third scenario includes the elimination of fossil-fuel subsidies – which we simulate by setting "tfd", "tgd", "tpd", "tfm", "tgm" and "tpm" (ad valorem purchase taxes) in the GTAP 9.2es Data Base equal to values in the GTAP 9.2 Data Base – and additional CO_2 taxation (if necessary) to achieve NDC targets.[27] The first two scenarios have identical regional and global emission reductions, while the third scenario results in a higher reduction in global emissions, as in some regions the elimination of energy subsidies results in CO_2 reductions that surpass NDC targets.[28]

Without emissions trading, each region has to meet the NDC target using its own policy instruments. In this case, simulations using the GTAP 9.2es Data Base result in slightly higher CO_2 taxes to reach the NDC targets than when the GTAP 9.2 Data Base is used. As the inclusion of energy subsidies reduces import purchases at tax-paid prices, it also indirectly affects (increases) the CO_2 intensities of the imported energy products. When the CO_2 intensity of imports is higher, energy users have fewer possibilities to substitute away domestic commodities when there is a CO_2 tax. The CO_2 intensity of imports is lower when energy subsidies are not explicitly represented as underlying energy volumes (and corresponding emissions) are associated with higher import values at tax-paid prices reported in the GTAP Data Base without included fossil-fuel consumption

Data Base and then develop the corresponding GTAP-Power Data Base with energy subsidies included (GTAP-Power 9.2es Data Base).

[27] The results for this scenario originally published in this paper contained an error. Original shocks corresponded to the partial (not full) elimination of the global fossil-fuel consumption subsidies. Revised results and supplementary files in the current paper.

[28] Specifically, the reduction in global CO_2 emissions is 10.5% in the first two scenarios and 12.8% in the third scenario (with the elimination of energy subsidies) (Appendix F).

subsidies (GTAP 9.2) than in the updated GTAP Data Base (GTAP 9.2es). Therefore, a higher CO_2 tax is needed to persuade energy users to substitute away from fossil fuels in the model using the GTAP 9.2es Data Base than the model built on the GTAP 9.2 Data Base. However, in most cases tax increases do not exceed 5% (Figure 8).

Elimination of pre-tax fossil-fuel consumption subsidies significantly reduce the required CO_2 taxes. Furthermore, in the case of heavily subsidized regions (e.g., Rest of South Asia (XSA), Energy producers in Europe and Central Asia (NEC), and Energy producers in Middle East and North Africa (NMN)), no additional emission taxes are needed, as the elimination of energy subsidies is sufficient to meet and surpass the NDC emissions reduction target (Appendix F).

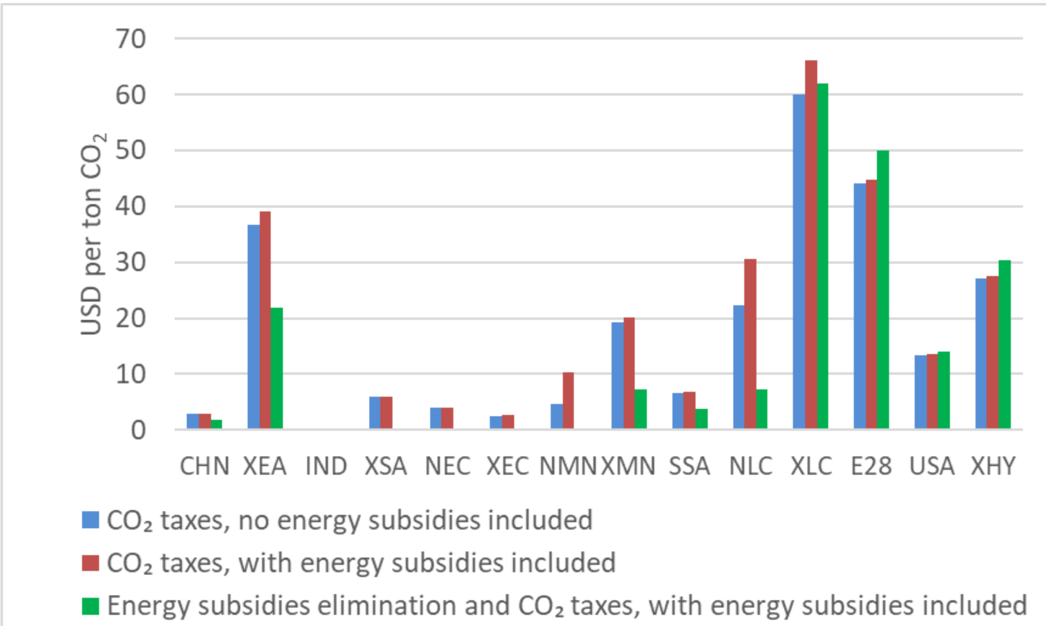


Figure 8. CO_2 taxes required to reach NDC targets.

Source: Authors calculations.

The inclusion of energy subsidies slightly reduces the welfare losses in the NDC policy experiment (Figure 9). This is because there are some large negative production taxes when energy subsidies are included and the carbon tax reduces the distortionary impacts of these taxes by reducing energy consumption. However, if the elimination of pre-tax fossil-fuel consumption subsidies is used as a policy instrument, then not only much lower CO_2 taxes are required, but also global welfare losses are reduced by over 95%from $90 billion to $3 billion (Figure 9, secondary axis) under higher global CO_2 emissions reduction. At the same time, even for regions that exceed their NDC targets after the elimination of energy subsidies (e.g. energy producers in MENA (NMN)), welfare costs per ton of CO_2 emissions reduced are lower than in the first two scenarios.

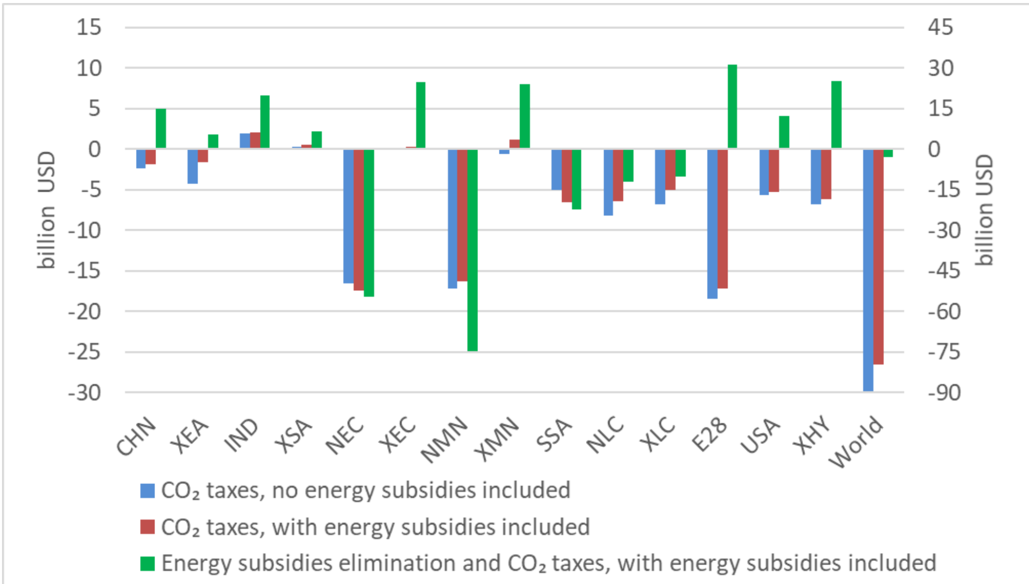


Figure 9. Welfare changes under NDC targets implementation with no global emission permits trade.

Source: Authors calculations.

To compare our assessment with the existing literature on the reform of global fossil-fuel subsidies (IEA, 1999; OECD, 2012, IMF, 2015; Burniaux and Chateau, 2014; Magne et al., 2014), we also consider an additional policy simulation. In this scenario, fossil-fuel subsidies are eliminated without CO_2 taxes. According to our results, the elimination of global fossil-fuel subsidies reduces global CO_2 emissions by 4.2%. Our estimate is somewhat lower compared to other studies that predict global CO_2 emissions to fall between 4.6% (IEA, 1999) and 10% (OECD, 2009; Burniaux and Chateau, 2014), with some estimates in between (OECD, 2012; Magne et al., 2014). A likely reason for such difference is that we use a static model and mid-term assessment timeframe, while most other studies provide a long-term assessment using dynamic models.

6. Discussion

This paper highlights the importance of including pre-tax fossil-fuel consumption subsidies in the GTAP Data Base and provides an important step forward in achieving this objective. Nonetheless, the approach raises some issues and is not without limitations:

1) The current methodology addresses only market prices and commodity tax rates, leaving energy export and import prices unchanged. In some cases, this may result in significant differences between international and domestic market prices. Following the usual definition of subsidies these prices should not diverge by much. Therefore, one of the potential improvements of the GTAP Data Base energy module should include an update of fossil-fuel export and import prices, as well as their harmonization with updated market prices after inclusion of the subsidies.
2) The current approach uses a single tax instrument to address both reference commodity taxes and the introduced subsidy rates. As a result, the GTAP Data Base with energy subsidies included does not include explicit representation of the subsidy rates as they are aggregated with commodity taxes by estimating the net fossil-fuel consumption tax rate. Thus, one future improvement could include the introduction of an additional tax instrument, which would directly represent the subsidy rates.
3) Due to data limitations, we assume uniform subsidy rates for intermediate and final users, as well as across activities.[29] There are some country/commodity cases that contradict this assumption, especially in the case of the electricity sector, but the publicly available global energy subsidy databases, including both the IEA (2015) and IMF (2015) data, do not contain enough information to represent such cases.[30]
4) Finally, the approach used in this paper, could be challenged on methodological grounds. As described in Section 3, we take international energy market prices as a reference and introduce energy subsidy rates relative to their levels. Some could argue that the reference price should be based on the production cost, which may significantly differ from the international market price in the case of energy-abundant economies. The counter-argument is that such an approach would result in an economically inefficient resource allocation and hinder economic development in the long run (IEA, 2017).

[29] USD per toe tax rates are assumed uniform, while ad valorem rates may differ.

[30] For example, in the case of the Ukrainian electricity sector, residential consumers are charged below the market price (i.e., benefit from subsidies), while industrial users pay above the market price (are the source of subsidy), thus there is cross subsidization (Chepeliev, 2015).

We have not addressed the important issue of the high uncertainty around international energy market prices and its corresponding feedback into the uncertainty around fossil-fuel subsidy values, especially for non-traded country/commodity cases. Nonetheless, as far as we are concerned, high uncertainty around energy reference price estimates does not mean that fossil-fuel subsidies should be set to zero and it is not a valid reason for ignoring or misrepresenting them.

7. Conclusion

Though widely used as a policy tool and amounting to almost $500 billion worldwide, pre-tax fossil-fuel consumption subsidies are not explicitly represented in national accounts, input-output tables or global economic databases. In this paper, we contribute towards the inclusion of pre-tax fossil-fuel consumption subsidies to the GTAP 9.2 Data Base, which covers 141 regions and 57 sectors. We do it in a straightforward manner by updating fossil-fuel commodity tax rates and market prices for four energy products—coal, petroleum products, natural gas and electricity, leaving tax-paid prices faced by energy users unchanged.

Despite some limitations associated with our methodology, which are discussed in Section 6, the updated GTAP Data Base provides several benefits for energy and environmental policy simulations. In particular, it provides an additional, and potentially economically significant policy instrument. Our simulations suggest this additional policy instrument is more efficient (less costly) than greenhouse gas taxation in meeting emissions reduction targets. The GTAP Data Base with energy subsidies included also provides a more consistent representation of relative energy prices, which can influence simulation outcomes even if policies do not directly involve subsidies elimination. As our policy simulations show, explicit representation of energy subsidies in the GTAP Data Base requires higher emission taxes to meet regional NDC targets than when energy subsidies are not included and results in lower regional welfare losses.

Acknowledgements

The authors acknowledge the valuable comments from two anonymous reviewers.

References

Aguiar, A., Narayanan, B., and McDougall, R. 2016. An Overview of the GTAP 9 Data Base. *Journal of Global Economic Analysis*, 1(1):181-208. DOI: http://dx.doi.org/10.21642/JGEA.010103AF

Alshehabi, O. H. 2011. Fuel Subsidies and Unemployment: A CGE Model Applied to Iran. USAEE-IAEE WP 11-074. http://ssrn.com/abstract=1821644

Barany, A., Grigonyte, D. 2015. Measuring Fossil Fuel Subsidies. European Commission. ECFIN Economic Brief. Issue 40, March 2015. http://ec.europa.eu/economy_finance/publications/economic_briefs/2015/pdf/eb40_en.pdf

Biausque, V. 2010. The Value of Statistical Life: A Meta Analysis. Organization for Economic Co-operation and Development. ENF/EPOC/WPNEP(2010)/FINAL. http://www.oecd.org/officialdocuments/publicdisplaydocumentpdf/?cote=ENV/EPOC/WPNEP(2010)9/FINAL&doclanguage=en

Burniaux, J.M. and Chateau J. 2014. Greenhouse Gases: Mitigation Potential and Economic Efficiency of Phasing-Out Fossil Fuel Subsidies. International Economics 140: 71–88.

Burniaux, J.M. and Truong, T.P. 2002. "GTAP-E: an energy-environmental version of the GTAP model." GTAP Technical Papers No. 16. http://docs.lib.purdue.edu/cgi/viewcontent.cgi?article=1017&context=gtaptp

Chepeliev, M. 2014. Simulation and economic impact evaluation of Ukrainian electricity market tariff policy shift. Economy and forecasting, 1(1), 1-24. https://papers.ssrn.com/sol3/papers.cfm?abstract_id=2608980

Chepeliev, M. 2015. Coal Production Subsidies Elimination in Ukraine: A CGE Analysis. https://ssrn.com/abstract=2609315

Chepeliev, M. and van der Mensbrugghe, D. 2017. Global energy subsidies reform: inclusive approaches to welfare assessment. Presented at the 20th Annual Conference on Global Economic Analysis, West Lafayette, USA. https://www.gtap.agecon.purdue.edu/resources/res_display.asp?RecordID=5299

Cline, W.R. 2011. Carbon Abatement Costs and Climate Change Finance. Peterson Institute for International Economics. July 2011. Washington D.C., USA.

Coady, D., Parry, I., Sears L., Shang, B. 2015. How Large are Global Energy Subsidies? IMF Working Paper WP/15/105. http://www.imf.org/external/pubs/cat/longres.aspx?sk=42940.0

Corong, E.L., Hertel, T.W., McDougall, R.A., Tsigas, M.E., and van der Mensbrugghe, D. 2017. The Standard GTAP Model, Version 7. *Journal of Global Economic Analysis*, 2(1):1-119. DOI: http://dx.doi.org/10.21642/JGEA.020101AF

Ellis, J., 2010. The Effects of Fossil-Fuel Subsidy Reform: A review of modelling and empirical studies. International Institute for Sustainable Development. http://search.iisd.org/gsi/sites/default/files/effects_ffs.pdf

Gerasimchuk, I., Bridle, R., Beaton, C., Charles, C. 2012. State of Play on Biofuel Subsidies: Are policies ready to shift? http://www.iisd.org/gsi/sites/default/files/bf_stateplay_2012.pdf

Hertel, T.W., editor. 1997. Global Trade Analysis: Modelling and Applications, Cambridge University Press.

International Energy Agency (IEA). 1999. World Energy Outlook Insights. Looking at Energy Subsidies: Getting the Prices Right. http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.168.1604&rep=rep1&type=pdf

International Energy Agency (IEA). 2005. Energy Statistics Manual. https://www.iea.org/publications/freepublications/publication/statistics_manual.pdf

International Energy Agency (IEA). 2015. IEA fossil-fuel subsidies database. OECD/IEA. http://www.worldenergyoutlook.org/resources/energysubsidies/

International Energy Agency (IEA). 2016. World Energy Outlook 2016: Executive Summary. https://www.iea.org/Textbase/npsum/WEO2016SUM.pdf

International Energy Agency (IEA). 2017. Fossil-fuel subsidies – methodology and assumptions. http://www.worldenergyoutlook.org/resources/energysubsidies/methodology/

International Institute for Sustainable Development (IISD). 2014. Comparison of Fossil-Fuel Subsidy and Support Estimates. https://www.iisd.org/gsi/comparison-fossil-fuel-subsidy-and-support-estimates

International Monetary Fund (IMF). 2015. Energy Subsidies Template. http://www.imf.org/external/np/fad/subsidies/

James, M., and R. McDougall. 1993. "FIT: An input-output data update facility for SALTER." Industry Commission, Canberra, SALTER working paper No. 17. http://www.pc.gov.au/research/supporting/salter-model/workingpaper17.

Kojima, M., Koplow, D. 2015. Fossil Fuel Subsidies: Approaches and Valuation. Policy Research Working Paper No. 7220. World Bank Group, Washington, DC. World Bank.

Magne, B., Chateau, J., Dellink, R. 2014. Global implications of joint fossil fuel subsidy reform and nuclear phase-out: an economic analysis. Climatic Change (2014) 123:677-900.

McDougall, R. and Lee, H.-L. 2006. GTAP 6 Data Base Documentation – Chapter 17: An Energy Data Base for GTAP. https://www.gtap.agecon.purdue.edu/resources/download/2934.pdf

McDougall, R. and Golub, A. 2007. "GTAP-E: A revised energy-environmental version of the GTAP model." GTAP Research Memorandum 15. https://www.jgea.org/resources/download/4212.pdf

Morgan, T. 2007. Energy Subsidies: Their Magnitude, How they Affect Energy Investment and Greenhouse Gas Emissions, and Prospects for Reform. United Nations Framework Convention on Climate Change Secretariat. http://unfccc.int/files/cooperation_and_support/financial_mechanism/application/pdf/morgan_pdf.pdf

Malcolm, G. 1998. Adjusting Tax Rates in the GTAP Data Base. GTAP Technical Paper No. 12. http://docs.lib.purdue.edu/gtaptp/15

Malcolm, G. and Truong, T.P. 1999. The Process of Incorporating Energy Data into GTAP. http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.548.9675&rep=rep1&type=pdf

Nordhaus, W. 2014. Estimates of the Social Cost of Carbon: Concepts and Results from the DICE-2013R Model and Alternative Approaches. Journal of the Association of Environmental and Resource Economists. March/June 2014. http://www.journals.uchicago.edu/doi/abs/10.1086/676035

Organisation for Economic Co-operation and Development (OECD). 2005. Environmentally harmful subsidies: Challenges for reform. Paris.

Organisation for Economic Co-operation and Development. 2009. The Economics of Climate Change Mitigation: Policies and Options for Global Action Beyond 2012. http://www.oecd-ilibrary.org/docserver/download/9709011e.pdf?expires=1490655327&id=id&accname=ocid194779&checksum=4247BE18AA0E5141ADE2E384C326D031

Organisation for Economic Co-operation and Development (OECD). 2012. OECD Environmental Outlook to 2050. OECD Publishing. http://dx.doi.org/10.1787/9789264122246-en

Organisation for Economic Co-operation and Development (OECD). 2015. OECD Companion to the Inventory of Support Measures for Fossil Fuels 2015. http://www.oecd-ilibrary.org/docserver/download/2215011e.pdf?expires=1490126987&id=id&accname=ocid194779&checksum=1C398D7491A67C07464B32859997B2DC

Organisation for Economic Co-operation and Development (OECD). 2017. OECD analysis of budgetary support and tax expenditures. http://www.oecd.org/site/tadffss/data/

Peters, J., 2016a. The GTAP-Power Data Base: Disaggregating the Electricity Sector in the GTAP Data Base. Vol. 1, No. 1, pp. 209-250. DOI: http://dx.doi.org/10.21642/JGEA.010104AF

Peters, J., 2016b. GTAP-E-Power: An Electricity-detailed Economy-wide Model. Journal of Global Economic Analysis, Vol. 1, No. 2, pp. 156-187. DOI: http://dx.doi.org/10.21642/JGEA.010204AF

Saunders, M., Schneider, K. 2000. Removing energy subsidies in developing and transition economies. ABARE Conference Paper, 23rd Annual IAEE International Conference, International Association of Energy Economics, June

7-10, Sydney. https://earthtrack.net/sites/default/files/Saunders_Schneider.pdf

Sovacool, B.K. 2017. Reviewing, Reforming, and Rethinking Global Energy Subsidies: Towards a Political Economy Research Agenda. Ecological Economics 135, 150-163.

The World Bank. 2017. GDP (current US$). http://data.worldbank.org/indicator/NY.GDP.MKTP.CD

United Nations Framework Convention on Climate Change (UNFCCC). 2017. INDCs as communicated by parties. http://www4.unfccc.int/Submissions/INDC/Submission%20Pages/submissions.aspx

United States Energy Information Administration (EIA). 2016. International Energy Outlook 2016. https://www.eia.gov/outlooks/ieo/ieo_tables.php

Appendix A. Energy commodities mapping

Table A.1. Mapping from IMF database energy commodities to GTAP sectors

IMF energy commodity	GTAP 9 sectoral code	GTAP sector description
Gasoline	P_C	Coke oven products, refined petroleum products, processing of nuclear fuel
Diesel	P_C	
Kerosene	P_C	
Coal	COA	Mining and agglomeration of hard coal lignite and peat
Natural gas	GAS	Extraction of crude petroleum and natural gas (part), service activities incidental to oil and gas extraction excluding surveying (part)
Electricity	ELY	Production, collection and distribution of electricity

Source: Authors.

Appendix B. Regional aggregation

Table B.1. Mapping from the GTAP 9.2 regions to aggregate regions

No.	Aggregate regions	GTAP 9.2 regions
1	**China, P.R. (CHN)**	China (CHN)
2	**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)
3	**India (IND)**	India (IND)
4	**Rest of South Asia (XSA)**	Bangladesh (BGD), Nepal (NPL), Pakistan (PAK), Sri Lanka (LKA), Rest of South Asia (XSA)
5	**Energy producers in Europe and Central Asia (NEC)**	Russian Federation (RUS), Kazakhstan (KAZ), Tajikistan (TJK), Azerbaijan (AZE)
6	**Rest of Europe and 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)
7	**Energy producers in Middle East and North Africa (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)
8	**Rest of Middle East and North Africa (XMN)**	Jordan (JOR), Turkey (TUR), Egypt (EGY), Morocco (MAR), Tunisia (TUN)
9	**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)
10	**Energy producers in Latin America and Caribbean (NLC)**	Mexico (MEX), Bolivia (BOL), Colombia (COL), Ecuador (ECU), Venezuela (VEN)
11	**Rest of Latin America and 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)
12	**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)
13	**Unites States (USA)**	United States of America (USA)
14	**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)

Source: Authors.

Appendix C. Pre-tax fossil-fuel consumption subsidy rates in 2011

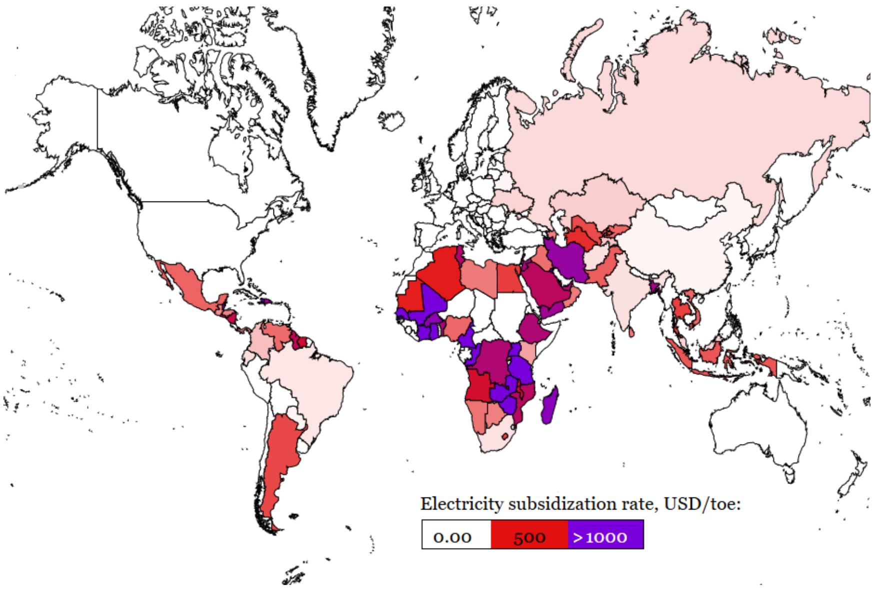


Figure C.1. Electricity consumption subsidy rates by countries in 2011, USD per toe.

Source: Developed by authors using *openheatmap.com*.

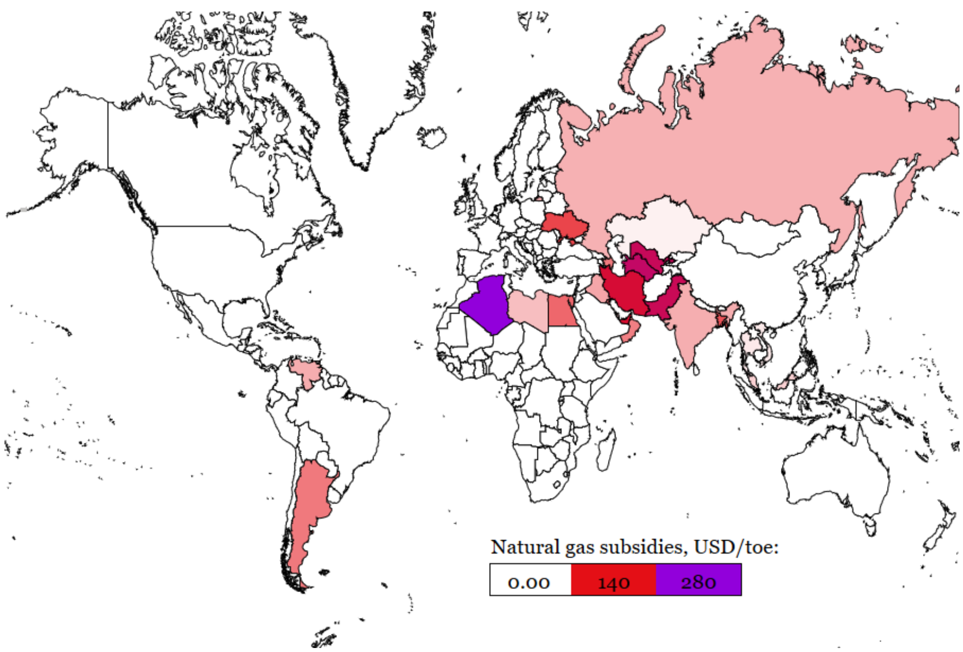


Figure C.2. Pre-tax natural gas consumption subsidy rates in 2011, USD per toe.

Source: Developed by authors using *openheatmap.com.*

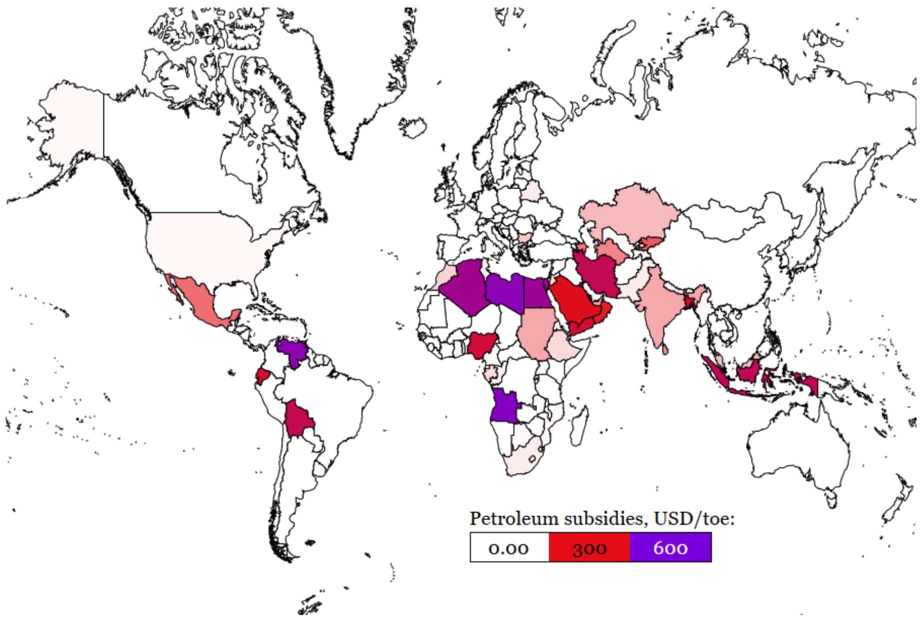


Figure C.3. Pre-tax petroleum products consumption subsidy rates in 2011, USD per toe.

Source: Developed by authors using *openheatmap.com.*

Appendix D. Comparison of the aggregate Social Accounting Matrixes for the GTAP 9.2 and 9.2es Data Bases[1]

Table D.1. Aggregated SAM for major net energy exporting regions in GTAP 9.2es, bn USD.

		Sectors		*Taxes*			*Other*			*Total*
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	
Sectors	*1. Energy*	*855*	*564*	*0*	*0*	*0*	*0*	*264*	*1562*	*3245*
	2. Non-energy	*478*	*3400*	*0*	*0*	*0*	*0*	*5521*	*858*	*10256*
Taxes	*3. Sales tax for energy*	***-33***	***-116***	*0*	*0*	*0*	*0*	***-55***	*0*	*-204*
	4. Sales tax for non-energy	*3*	*55*	*0*	*0*	*0*	*0*	*184*	*0*	*242*
	5. Other taxes	*221*	*418*	*0*	*0*	*0*	*487*	*0*	*0*	*1126*
Other	*6. Factors*	*1618*	*4338*	*0*	*0*	*0*	*0*	*0*	*0*	*5956*
	7. RA	*0*	*0*	***-204***	*242*	*1126*	*5469*	*5801*	*-721*	*11713*
	8. Row	*103*	*1597*	*0*	*0*	*0*	*0*	*0*	*80*	*1780*
	Total	*3245*	*10256*	*-204*	*242*	*1126*	*5956*	*11713*	*1780*	

Notes: Major net energy exporting regions include NEC, LMN and NLC (see Appendix C for country mappings).

Source: Authors.

Table D.2. Aggregated SAM for major net energy exporting regions in GTAP 9.2, bn USD.

		Sectors		*Taxes*			*Other*			*Total*
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	
Sectors	*1. Energy*	*795*	*486*	*0*	*0*	*0*	*0*	*229*	*1562*	*3073*
	2. Non-energy	*432*	*3410*	*0*	*0*	*0*	*0*	*5484*	*858*	*10183*
Taxes	*3. Sales tax for energy*	***27***	***26***	*0*	*0*	*0*	*0*	***17***	*0*	*69*
	4. Sales tax for non-energy	*2*	*56*	*0*	*0*	*0*	*0*	*183*	*0*	*241*
	5. Other taxes	*218*	*415*	*0*	*0*	*0*	*476*	*0*	*0*	*1109*
Other	*6. Factors*	*1496*	*4194*	*0*	*0*	*0*	*0*	*0*	*0*	*5690*
	7. RA	*0*	*0*	***69***	*241*	*1109*	*5214*	*5801*	*-721*	*11713*
	8. Row	*103*	*1597*	*0*	*0*	*0*	*0*	*0*	*80*	*1780*
	Total	*3073*	*10183*	*69*	*241*	*1109*	*5690*	*11713*	*1780*	

[1] a) the "Energy" sector includes sectors No. 2-17 (see Appendix E); b) "Non-energy" aggregation corresponds to sectors No. 1, 18-20 (Appendix E); c) Sales taxes include both domestic and import-related taxes; d) "RA" label represent households, government and capital goods accounts; and e) "Row" label corresponds to the Rest of the world account.

Source: Authors.

Table D.3. Aggregated SAM for other subsidizing regions[2] in GTAP 9.2es, bn USD.

		Sectors		***Taxes***			***Other***			***Total***
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	
Sectors	*1. Energy*	*1523*	*1506*	*0*	*0*	*0*	*0*	*468*	*546*	*4043*
	2. Non-energy	*512*	*21056*	*0*	*0*	*0*	*0*	*17544*	*4554*	*43666*
Taxes	*3. Sales tax for energy*	***-8***	***19***	*0*	*0*	*0*	*0*	***49***	*0*	*61*
	4. Sales tax for non-energy	*17*	*773*	*0*	*0*	*0*	*0*	*949*	*0*	*1738*
	5. Other taxes	*94*	*1005*	*0*	*0*	*0*	*1097*	*0*	*0*	*2196*
Other	*6. Factors*	*974*	*14973*	*0*	*0*	*0*	*0*	*0*	*0*	*15947*
	7. RA	*0*	*0*	***61***	*1738*	*2196*	*14850*	*16473*	*164*	*35483*
	8. Row	*931*	*4334*	*0*	*0*	*0*	*0*	*0*	*274*	*5539*
Total		*4043*	*43666*	*61*	*1738*	*2196*	*15947*	*35483*	*5539*	

Notes: Other subsidizing regions include CHN, XEA, IND, XSA, XEC, XMN, SSA, XLC (see Appendix C for country mappings).

Source: Authors.

Table D.4. Aggregated SAM for other subsidizing regions in GTAP 9.2, bn USD.

		Sectors		***Taxes***			***Other***			***Total***
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	
Sectors	*1. Energy*	*1498*	*1442*	*0*	*0*	*0*	*0*	*438*	*546*	*3924*
	2. Non-energy	*477*	*21115*	*0*	*0*	*0*	*0*	*17523*	*4554*	*43669*
Taxes	*3. Sales tax for energy*	***22***	***130***	*0*	*0*	*0*	*0*	***99***	*0*	*252*
	4. Sales tax for non-energy	*16*	*775*	*0*	*0*	*0*	*0*	*949*	*0*	*1740*
	5. Other taxes	*88*	*1006*	*0*	*0*	*0*	*1095*	*0*	*0*	*2189*
Other	*6. Factors*	*892*	*14867*	*0*	*0*	*0*	*0*	*0*	*0*	*15759*
	7. RA	*0*	*0*	***252***	*1740*	*2189*	*14664*	*16473*	*164*	*35483*
	8. Row	*931*	*4334*	*0*	*0*	*0*	*0*	*0*	*274*	*5539*
Total		*3924*	*43669*	*252*	*1740*	*2189*	*15759*	*35483*	*5539*	

Source: Authors.

Appendix E. Sectoral aggregation

Table E.1. Mapping from the GTAP-E-Power 9.2 sectors to aggregate sectors

No.	Sector code	Sector description	GTAP-E-Power sector
1	Agriculture	Grains and crops, livestock, forestry, fishing	pdr wht gro v_f osd c_b pfb ocr ctl oap rmk wol frs fsh
2	Coal	Coal	coa
3	Oil	Oil	oil
4	Gas	Gas	gas gdt
5	Oil_Pcts	Petroleum and coal	p_c
6	TnD	Electricity transmission	TnD
7	NuclearBL	Nuclear power	NuclearBL
8	CoalBL	Coal-fired power	CoalBL
9	GasBL	Gas-fired power in base load	GasBL
10	WindBL	Wind power	WindBL
11	HydroBL	Hydro power in base load	HydroBL
12	OilBL	Oil-fired power in base load	OilBL
13	OthBL	Other power in base load	OtherBL
14	GasP	Gas-fired power in peak load	GasP
15	HydroP	Hydro power in peak load	HydroP
16	OilP	Oil-fired power in peak load	OilP
17	SolarP	Solar power	SolarP
18	En_Int_Ind	Energy intensive industries	omn crp nmm i_s nfm
19	Oth_Ind	Other industries	cmt omt vol mil pcr sgr ofd b_t tex wap lea lum ppp fmp mvh otn ele ome omf
20	Services	Transport and communication, other services	trd otp wtp atp cmn wtr cns ofi isr obs ros osg dwe

Source: Authors.

Appendix F. CO_2 emission changes without trading in international emissions permits

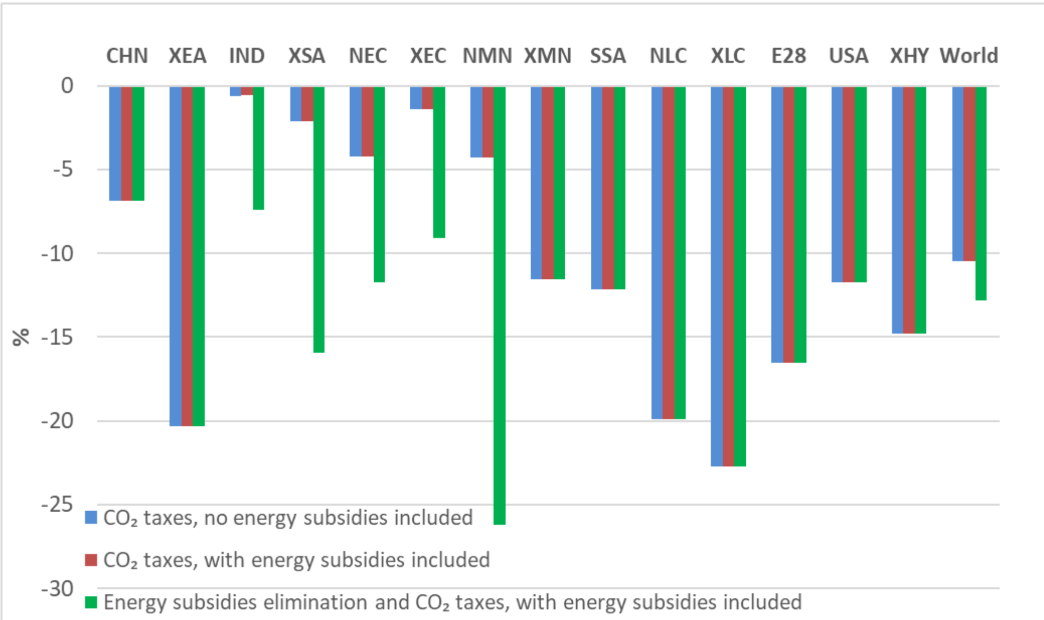


Figure F.1. CO_2 emission changes without trading in international emissions permits.

Source: Authors calculations.