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Phase-out of fossil fuel subsidies: implications for emissions, GDP and public budget

By ***Elisa Delpiazzo***
Fondazione CMCC – Centro Euro-Mediterraneo sui Cambiamenti Climatici, FEEM - Fondazione Eni Enrico Mattei
elisa.delpiazzo@cmcc.it

Ramiro Parrado
Fondazione CMCC – Centro Euro-Mediterraneo sui Cambiamenti Climatici, FEEM - Fondazione Eni Enrico Mattei
ramiro.parrado@cmcc.it

Gabriele Standardi
Fondazione CMCC – Centro Euro-Mediterraneo sui Cambiamenti Climatici, FEEM - Fondazione Eni Enrico Mattei
gabriele.standardi@cmcc.it

SUMMARY In this study we assess the potential benefits of removing fossil fuel subsidies around the world using a Computable General Equilibrium approach. Results confirm the win-win nature of the policy. World GDP increases and emissions decrease compared to the baseline scenario in 2030. In addition to the previous studies, the model allows the evaluation of the economic consequences for the public finance. Fiscal benefits can be observed all around the world, especially for Middle East, North Africa and former Soviet Union where public debt and deficit reduce substantially over the years. In these regions fossil fuel subsidies represent a not negligible burden for public budget.

Keywords: Fossil Fuel subsidies, climate change mitigation, general equilibrium.

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SUMMARY

1. INTRODUCTION

The phase-out of fossil fuel subsidies, which distort the consumption and production choices in favor of negative environmental externality generating activities, ranks high amongst mitigation options according to many international institutions such as World Bank (WB), the Organization for Economic Cooperation and Development (OECD), the International Monetary Fund (IMF) and the International Energy Agency (IEA).

Indeed, in line with the G20 commitment to phase out inefficient Fossil-Fuel subsidies, G20 countries and Friends countries could include Fossil Fuel subsidies reforms in their respective Intended Nationally Determined Contributions (INDCs) [1] and use the emission reduction achieved through these policies as part of their commitment (Merrill et al., 2015).

From a theoretical point of view, this policy is a *win-win* option for both the economic and the environmental systems. On the one hand, it eliminates a price distortion and accordingly increases efficiency in resource allocation. On the other hand, by making the use of fossil fuel more costly, contributes to the reduction of the negative environmental externality associated to greenhouse gases emissions. Moreover the removal of these subsidies alleviates the fiscal burden for the government freeing public resources which can be used for other scopes. It is also worth to notice that fossil fuel subsidies can decrease the competitiveness of key low carbon industries. Their removal offers the opportunity to tackle environmental and public budget problems at the same time (Whitley et al, 2015; Merrill et al., 2015).

However, environmental benefits contrast with social acceptability as these subsidies still provide an important support to the firms production activities and households especially in developing countries enhancing domestic production and energy access (Whitley et al, 2015; Merrill et al., 2015).

In fact, until now the subsidy phase-out has encountered much political resistance, especially in developing countries where subsidies are still high. As said, there are many reasons for that. In developing countries subsidies are used as a policy instrument to reduce poverty and facilitate the energy access of low and middle-income households; they favors not only households, but sometimes also strong industrial lobbies which can understandably oppose their removal; they are finally a way for policy making to maintain support or at least relieve social tensions in situations of widespread corruption and lack of institutional capacity (IMF, 2013).

[1] Friends of Fossil Fuel Subsidy Reform is an informal group of non-G20 countries aiming to build political consensus on the importance of fossil fuel subsidy reform. Current members of the Friends group are Costa Rica, Denmark, Ethiopia, Finland, New Zealand, Norway, Sweden and Switzerland.

The purpose of this study is adding to the standard analysis on economic welfare effects and environmental benefits of fossil fuels removal, the assessment of impacts on public finance. We focus our attention on economic consequences at the global and multi-regional level.

The analysis is developed using a global recursive-dynamic Computable General Equilibrium (CGE) model: ICES (Intertemporal Computable Equilibrium System), developed in Bosello et al., (2007); Eboli et al., (2010); Parrado and De Cian, (2014). As standard in CGE models, it allows an economic and environmental (i.e. impacts on emissions) assessment of different mitigation policies considering all the economic interactions across sectors within and between national/regional economic systems. The explicit representation of national and international trade and endogenous price mechanisms equating demand and supply enable CGE models to capture direct and indirect economic effects triggered by the mitigation policy under scrutiny.

In order to improve the capacity of the model to inform on public budget dynamics, ICES has been extended with a more realistic description of the public sector. This upgraded version of the model, ICES-XPS (Intertemporal Computable Equilibrium System – eXtended Public Sector) follows Del Piazzo et al., (forthcoming).

The report is organized as follows. In the next section we offer some basic background information on fossil fuel subsidies and the main methodologies to derive them. In section 3 we briefly survey the main studies addressing subsidy removal using global/multi-regional models. In section 4 we sketch the model and lay out the experiment design. Section 5 presents and discusses the results. Section 6 concludes.

2. OVERVIEW OF FOSSIL FUEL SUBSIDIES

When fossil fuel subsidies are concerned, one of the biggest challenges stems from data limitations. To date, a complete, consistent and globally extended dataset on fossil fuel subsidies does not exist. Opacity characterizes the data in many developing countries, where governments are not willing to provide easily this type of information even though for research purposes. Unfortunately, developing countries are also those who use most extensively fossil fuel subsidy as policy tool.

Table 1 reports the main and most recent approaches to compute fossil fuel subsidies (Whitley et al, 2015). In particular, the OECD approach eventually estimates both consumption and production subsidies, but is based on scrutiny of specific government programs (identification and estimation). This introduces evident biases as the most transparent states tend to depict higher figures than those who do not report all policies. Thus, there is a lack of cross-country comparability in OECD data because of different definitions, accounting and disclosure rules (Adolf et al, 2014).

IEA estimates on the other hand, analyze only consumption subsidies but use a more general methodology, the so called price-gap approach (Koplow, 2009). Basically, the subsidies are computed as the difference between the observed end-user consumer price (paid by both households and firms) and a given reference price. For tradable energy vectors the reference price is their international price. For a non-traded energy vector, like electricity, the reference price is the supply cost “cleaned” of internal margins, taxes and excise duties. This method presents some limitations. Firstly, a huge variability can be noted in international energy vector prices due to a multiplicity of factors like e.g. speculative pressures, market power of suppliers etc. This makes the estimated values and the analyses based on them very time dependent. Secondly, as for subsidies, also reliable data on taxes and transport costs are not always available and this can cause non-negligible distortions in the computation of the reference price. Despite these caveats, the price-gap methodology enables easier inter-country comparisons. It is thus also the starting point for the IMF estimation. IMF integrates the IEA approach with tax expenditure information and includes 153 countries in the world to estimate consumption and production subsidy.

Figure 1 ranks countries in term of share of fossil-fuel consumption subsidies over GDP (IEA, 2015). In 2014, they amounted worldwide to $ 493 billion, $ 39 billion less than the previous year, in part due to the drop in international energy prices, with subsidies to oil products representing over half of the total.

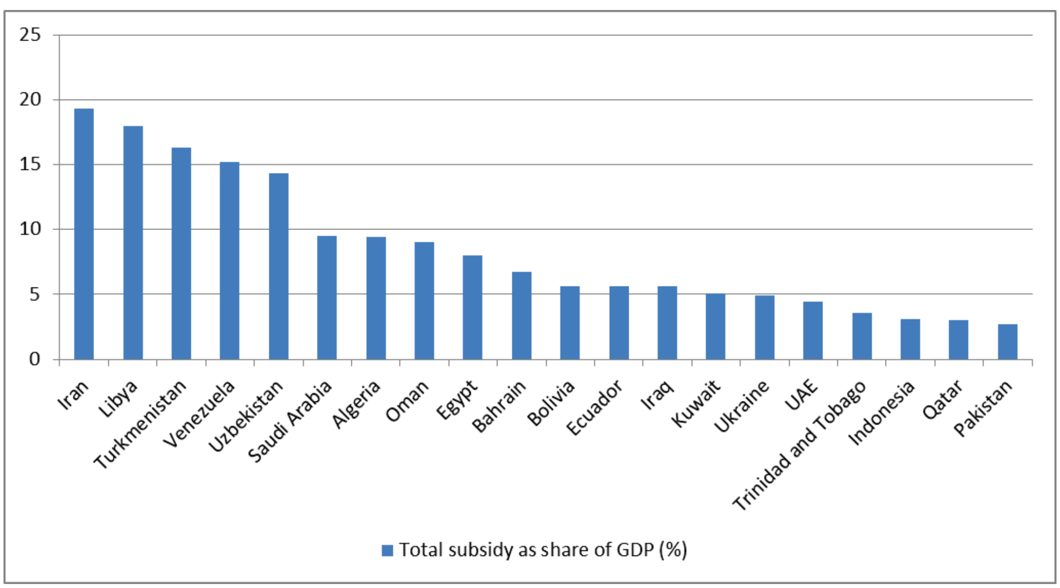
The biggest regional shares pertain to Middle East and North Africa (7 countries out of 10 in the first positions of the ranking belong to this geographical area) where subsidies are common in both net oil exporting and importing countries. In Latin America, Venezuela accounts for the highest share, where they amount to roughly 15 per cent of total GDP, but also Ecuador and Bolivia show not negligible shares. Fossil fuel subsides are also substantial in some countries of the Former Soviet Union, notably Ukraine, Uzbekistan and Turkmenistan where the support is strong in the gas sector.

Table 1: summary on international initiatives to identify and estimate subsidies

Initiative	Years	Subsidies covered	Type of analysis	Countries
IEA (International Energy Agency)	2012-2014	Consumption	Price-gap analysis	40 developing countries
IMF (International Monetary Fund)	2013	Consumption and production	Price-gap analysis combined with modelling of tax expenditure	153 countries
OECD (Organization for Economic Cooperation and Development)	2007-2014	Consumption and production	Identification and estimation	All 34 OECD members 6 emerging G20 economies (Brazil, China, India, Indonesia, Russia and South Africa)

Source: Whitley et al, 2015

Figure 1: ranking of countries in 2014



Source: IEA

3. LITERATURE REVIEW OF PREVIOUS STUDIES

Until now, the empirical literature on fossil fuel subsidy phase-out at the global or multi-regional level has focused on welfare effects and CO2 reductions. Table 2 provides a compact literature list, while respective results are reported in Table 3. The studies differ in terms of geographical/sectoral coverage, time frame, model calibration year, model underlying economic assumptions, experiment design and implementation.[2] All of them except one are CGE analyses and contrast policy outcome against a business as usual "without policy" scenario. Then subsidies are removed from the baseline and results are shown in differences between the policy and the baseline. All studies use the price-gap methodology to compute subsidies.

Table 2: main contributions to the literature of fossil-fuel subsidy removal

Study	Methodology	
Bosello and Standardi (2013)	General equilibrium	Phase-out in a static framework
Burniaux et al. (2011, 2014)	General equilibrium	Gradual phase out over the period 2013-2020
Burniaux et al. (2009)	General equilibrium	Gradual phase out over the period 2013-2020
OECD (2000)	General Equilibrium	Phase out over the period 1996-2010
Saunders and Schneider (2000)	General equilibrium	Gradual phase out over the period 2001-2005
IEA (1999)	Partial equilibrium	Phase-out in a static framework
Burniaux et al. (1992)	General equilibrium	Gradual phase out over the period 1990-2000
Larsen and Shah (1992)	General equilibrium	Phase-out over the period 1990-2020

Source: Ellis (2010), Bosello and Standardi (2013) and Merrill et al. (2015)

[2] For an extensive review on the earlier six contributions see Ellis (2010), for the two most recent refer to Bosello and Standardi (2013).

Table 3: results of the main contributions for global fossil-fuel subsidy removal

Study	Change in Income or GDP (Global)	Change in CO2 emissios (Global)
Bosello and Standardi (2013)	0.13% lower in 2050	1.63% below base case by 2050
Burniaux et al. (2011,2014)	0.3% higher in 2050	10.0% below base case by 2050
Burniaux et al. (2009)	0.2% higher in 2050	13.0% below base case by 2050
OECD (2000)	0.1% higher in 2010	6.2% below base case by 2010
Saunders and Schneider (2000)	NA	1.1% below base case by 2010
IEA (1999)	NA	4.6% decrease
Burniaux et al. (1992)	0.7% per year to 2050	6% below base case by 2000 18% below base case by 2050
Larsen and Shah (1992)	NA	5% below base case by 2020

Source: Ellis (2010), Bosello and Standardi (2013)and Merrill et al. (2015)

3.1 LARSEN AND SHAH (1992)

The first study includes 13 regions (Former Soviet Union, China, Poland, India, South Africa, Czechoslovakia, Mexico, Brazil, Argentina, Venezuela, Indonesia, Saudi Arabia and Egypt). The model is calibrated in 1987 and simulates until 2020. The price-gap method is used to estimate fossil fuel consumption subsidies in 1987. The policy analyzed consists in a full removal of existing fossil fuel subsidies from 1990 to 2020.

Ultimately, CO2 global emissions decrease by 5 per cent in 2020 while GDP in non-OECD countries increases by 1.8 per year from 1990 to 2020 compared to the no policy baseline. Impacts on world GDP are not reported.

3.2 BURNIAUX, MARTIN AND OLIVEIRA-MARTINS (1992)

In this study the authors apply the OECD GREEN model (Burniaux, Nicoletti and Oliveira-Martins, 1992), a multi-region multi-fuel dynamic general-equilibrium model to assess the effects of subsidy removal in both OECD and non-OECD countries. The model considers twelve regions: four OECD regions (U.S., Japan, EU-15 and other OECD) and eight non-

OECD regions (the Former Soviet Union, Eastern Europe, China, India, Brazil, Energy-Exporting Lesser-Developed Countries, Dynamic Asian Economies and the Rest of the World). The model base year and price-gap data refer to 1985. The simulated policy consists in a total removal of fossil fuel consumption subsidies in 2000 implemented through a gradual phasing out between 1990 and 2000. Policy effects are however assessed on the longer term, until 2050. Effects on the world GDP are positive, 0.7 per cent per year over the period 1990-2050, Co2 emissions are 18 per cent less compared to the baseline scenario by the end of 2050.

3.3 SAUNDERS AND SCHNEIDER (2000)

In the third study Saunders and Schneider apply the multi-region, multi-sector dynamic general-equilibrium, Global Trade and Environment Model (GTEM), of the Australian Bureau of Agricultural and Resource Economics (ABARE). It depicts 17 macro-regions (Australia, Canada, U.S., Japan, European Union, Former Soviet Union, Eastern Europe, China, Indonesia, Korea, Thailand, India, South Africa, Middle East, Mexico, Argentina and the rest of the world) and 15 main industries (among which the most energy-intensive likely to be affected by subsidy changes).

Instead of applying directly the price gap approach, Saunders and Schneider use 1995 World Bank estimates of energy consumption subsidies. In the policy scenarios, it is assumed that fossil-fuel consumption subsidies are removed over the five-year period 2001-2005. Results show that global Co2 emissions reduce by 1.1 per cent in 2010 compared to the baseline.

3.4 OECD (2000)

The OECD assessment (2000) also uses the Green model. In this version the price-gap data stem from 1996 IEA estimates (IEA, 1999). The geographical aggregation is the same of Burniaux et al. (1992) but the base year is 1996. The temporal horizon covers the period 1996-2010. Co2 emissions fall by 6.2 per cent in 2010. Looking at welfare gain, the GDP increase is small, only 0.1 per cent in 2010 compared to the baseline.

3.5 BURNIAUX, CHATEAU, DELLINK, DUVAL AND JAMET (2009)

Burniaux et al. (2009) use the OECD computable general equilibrium model ENV-Linkages, which is the upgraded version of the old GREEN model. The model database is GTAP (Global Trade Analysis Project) 8 (Narayanan et al., 2012). This work analyzes four non-OECD countries (China, India, Brazil and Russia), two non-OECD macro-regions (Oil exporting countries and non-EU Eastern European Countries) and the Rest of the World). 2007 IEA *price-gap* estimates (IEA, 2008) are included in the database for the base year 2005. The simulation period is extended to 2050, the subsidy removal takes place between 2013 and 2020. Results show that the world CO2 emissions are reduced by 13 per cent in 2050 compared to the baseline. The increase in the global GDP is tiny, about 0.2 per cent in 2050.

3.6 BURNIAUX AND CHATEAU (2011, 2014)

Burniaux and Chateau (2011, 2014) use the ENV-Linkages model (Chateau et al., 2014). Twelve regions are considered: China, India, Brazil, Russia, Oil exporting countries, Former Soviet Union Countries, Japan, Canada, USA, EU27 and the macro-region made up of Australia and New Zealand. The economic context is based on long-term economic growth scenario described in Duval and de la Maisonneuve (2010), the price-gaps are those estimated by the IEA in 2008 for 37 non-ECD countries (IEA, 2009). These estimates are introduced in the model as subsidies on final consumption of households and intermediate consumption of firms. The baseline scenario assumes constant subsidies (in percent) at the 2005 levels until 2050. The subsidy reform implies a gradual phasing-out over the period 2013 to 2020. The policy causes a world Co2 emission reduction of 10 per cent in 2050 relative to the baseline. The new baseline now considers the world financial and economic crisis and therefore lower global emission levels. Turning to the income effects, the Equivalent Variation (EV) income increases by about 0.3 for the word as a whole in 2050 with respect to the baseline.

3.7 BOSELLO AND STANDARDI (2013)

They impose the same geographical/sectoral aggregation and the same shocks on subsidies as in Burniaux and Chateau (2011, 2014), mimicking as far as possible the reference scenario and the policy implementation. The aim is more methodological trying to understand the main drivers which guide the different results between Env-Linkages and ICES model which has been used by the authors. Compared to the baseline scenario results show a Co2 emission reduction of around 1.63 per cent by the end of 2050 and a slight decrease in global income around 0.1%.

4. SIMULATING PHASING OUT OF FOSSIL FUEL SUBSIDIES WITH ICES-XPS

In this section we simulate a gradual, but complete fossil fuel subsidies removal within the period 2015-2020. The aim is testing not only, as standard in the literature, effects on GDP and emissions, but also to analyze the implications for public finance. As said, we use the ICES-XPS model (Del Piazzo et al, forthcoming) which has been developed with the purpose to capture government budget effects. In the next two sections we briefly present the main characteristics of the extended model, describe the baseline scenario and the policy implementation.

4.1 THE ICES-XPS MODEL

4.1.1 FIRMS

The ICES-XPS model uses a Walrasian perfect competition paradigm to simulate market adjustment processes. Industries are modeled through a representative price-taker firm that minimizes its production costs in each sector and region. The production tree of the ICES-XPS model is illustrated in Figure 2.

The production functions are specified via a series of nested Constant Elasticity of Substitution (CES) functions. At the top level the output for the representative firm is a Leontief function between value added and intermediate inputs. The intermediate inputs can be domestic and foreign. They are imperfect substitutes, according to the Armington assumption. At a lower level the technological process is modelled through a capital-energy nest which allows for substitution between capital and the energy bundle. The energy bundle, in turn, links electric and non-electric composite. The latter puts together fossil fuels (oil, coal, gas and petroleum products) and the former electricity stemming from fossil fuels, renewables and nuclear. The final aim of this modelling is the possibility to substitute fossil fuels with capital and/or renewables mimicking a de-carbonization pathway after the implementation of a mitigation policy.

Table 4 reports the values of the key elasticities starting from the upper level of capital/energy nest to the lowest nests of the energy tree in the model.

Figure 2: the production structure used in the ICES-XPS experiment

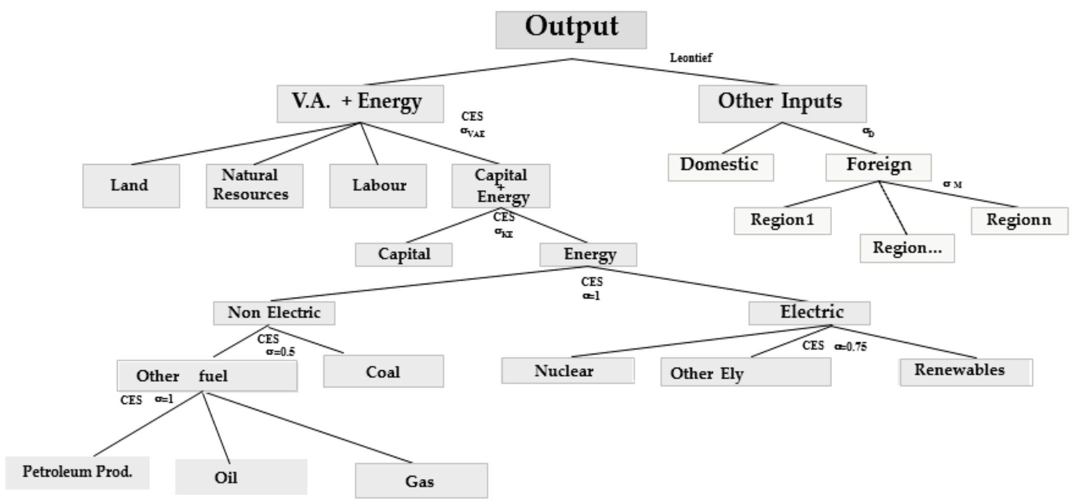


Table 4: key elasticity values of ICES-XPS

	ICES
Capital / Energy elasticity	0.5
Electric / Non Electric el.	1
Coal / Other fossil fuels el.	0.5
Remaining fossil fuels el.	1
Renewables/ nuclear /fossil fuels el.	0.75

4.1.2 HOUSEHOLDS

Looking at the demand side, a private representative household in each region receives income ($\mathrm{YH_r}$), defined as the service value of national primary factors (natural resources, land, labor, capital)[3], transfers and interest payments.

Equation (1) describes private income respect to sources. It is composed of four main elements: (i) factor use remuneration (divided into labor and capital income, $\mathrm{YHL_r}, \mathrm{YHK_r}$ respectively); (ii) social transfers from the government ($\mathrm{YHTR_r}$); (iii) the net of other transfers between private households and government ($\mathrm{YHOGI_r}, \mathrm{YHOGE_r}$) which is functional to the balancing of the base year; (iv) income from interest on public debt ($\mathrm{YHI_r}$).

$$\mathrm{YH_r} = \mathrm{YHL_r} + \mathrm{YHK_r} + \mathrm{YHTR_r} - \mathrm{YHOGI_r} + \mathrm{YHOGE_r} + \mathrm{YHI_r} \qquad (1)$$

Where:

$$\mathrm{YHTR_r} = \alpha_{\mathrm{TR,r}} \cdot \mathrm{YG_r} \qquad (2)$$

$$\mathrm{YHOGI_r} = \alpha_{\mathrm{OGI,r}} \cdot \mathrm{YH_r} \qquad (3)$$

$$\mathrm{YHOGE_r} = \alpha_{\mathrm{OGE,r}} \cdot \mathrm{YG_r} \qquad (4)$$

$$\mathrm{YHI_r} = \mathrm{INTD_r} + \mathrm{INTI_r} \qquad (5)$$

Transfers are fixed shares of the income of the agent paying out the transfer. For instance, social transfers from government to the private household (equation (2)) are a fixed share ($\alpha_{\mathrm{TR,r}}$) of the government income. Similarly, other expenditures (equations (3)-(4)) are respectively fixed shares of government and household income (according to shares $\alpha_{\mathrm{OGE,r}}$ and $\alpha_{\mathrm{OGI,r}}$). Interest income to households (equation (5)) is the sum of interest paid from the domestic government ($\mathrm{INTD_r}$) and interest from abroad ($\mathrm{INTI_r}$).

Income is then used to finance aggregate household consumption ($\mathrm{PRIV\_EXP_r}$) and household savings ($\mathrm{PRIV\_SAV_r}$). The expenditure and saving shares are fixed ($\beta_{\mathrm{PEXP,r}}$ and $(1 - \beta_{\mathrm{PEXP,r}})$, respectively), which means that the top-level utility function has a Cobb-Douglas specification. Formally, equation (6) defines the private income equation respect to uses; equations (7) and (8) isolate the Cobb-Douglas structure between consumption and savings.

$$\mathrm{YH_r} = \mathrm{PRIV\_EXP_r} + \mathrm{PRIV\_SAV_r} \qquad (6)$$

[3] Capital and labor are perfectly mobile domestically, but immobile internationally. Land and natural resources, on the other hand, are industry-specific.

$$PRIV\_EXP_r = \beta_{PEXP,r} \cdot YH_r \tag{7}$$

$$PRIV\_SAV_r = (1 - \beta_{PEXP,r}) \cdot YH_r \tag{8}$$

The functional specification for private consumption is the Constant Difference in Elasticities (CDE) form: a non-homothetic function, which is used to account for differences in income elasticities for the various consumption goods. Given this, Equations (9) is the decomposition of the private expenditure into prices and quantities, while equation (10) represents the budget constraint for the representative household:

$$PRIV\_EXP_r = PPRIV_r \cdot QPRIV_r \tag{9}$$

$$PPRIV_r \cdot QPRIV_r = \sum_i PP_{i,r} \cdot QP_{i,r} \tag{10}$$

4.1.3 THE GOVERNMENT

The government is a separate actor, which is the major advancement of the ICES-XPS model together with the representation of public expenditures, compared to the standard ICES model in which the government, as typical in global CGE models, behaves as an household.

Government receives income from four main sources: (i) tax revenues ($TTAX_r$); (ii) the net transfers with private households ($YHOGI_r - YHTR_r - YHOGE_r$); (iii) net interest payments to resident and non- resident households (YGI_r); (iv) net foreign transfers among governments ($AIDI_r - AIDO_r$). Government income is used for consumption (GOV_EXP_r) and savings (SAV_GOV_r). Equations (11) and (12) represent the government income respect to sources and uses, while equation (13) defines the different taxes in the economy. The government tax revenue equation simply sums the revenues from each different tax instrument for each region: (i) import duties ($MTAX_r$); (ii) export subsidies ($XTAX_r$); (iii) sales taxes ($STAX_r$), as the sum of final uses taxes; (iv) production taxes ($PTAX_r$); (v) factor use taxes ($FTAX_r$); (vi) household income tax ($YTAX_r$).

$$YG_r = TTAX_r - YHTR_r + YHOGI_r - YHOGE_r - YGI_r + AIDI_r - AIDO_r \tag{11}$$

$$YG_r = GOV\_EXP_r + SAV\_GOV_r \tag{12}$$

$$TTAX_r = MTAX_r + XTAX_r + STAX_r + PTAX_r + FTAX_r + YTAX_r \tag{13}$$

Where:

$$YGI_r = INTD_r + INTO_r \tag{14}$$

$$AIDO_r = \alpha_{AIDO,r} YG_r \cdot aidout_r \tag{15}$$

$$\mathrm{AIDI_r} = \overline{\mathrm{AIDI_r}} \cdot \mathrm{aidin_r} \qquad (16)$$

Equations (14)-(16) define the new variables. $\mathrm{YGI_r}$ is the total amount of interest paid by a government (so it is the sum of payment to residents $(\mathrm{INTD_r})$ and non-residents $(\mathrm{INTO_r})$). Outflows of grants $(\mathrm{AIDO_r})$ are a fixed share of government income, multiplied by a scaling parameter $(\mathrm{aidout_r})$ which reflects the change in the global amount of grants to be allocated. Inflows of grants $(\mathrm{AIDI_r})$, are simply rescaled considering the initial level.

Since there is no bilateral matrix to track international transfers (i.e. grants), we use the approach described in McDonald and Sonmez (2004), where an artificial accounting agent (named “Globe”) collects all outflows and distribute them to the countries. This leads to a clearing condition (equation (17)) in the global market of aid of this kind:

$$\sum_r \overline{\mathrm{AIDI_r}} \cdot \mathrm{aidin_r} = \sum_r \overline{\mathrm{AIDO_r}} \cdot \mathrm{aidout_r} \qquad (17)$$

Government income is used to consume and save according to equation (12). Regional real government expenditures are a fixed share of real regional GDP (equation (18)), while nominal expenditures are the sum of the single commodity consumption (equation (19)).

$$\mathrm{QGOV_r} = \beta_{\mathrm{GEXP,r}} \cdot \mathrm{QGDP_r} \qquad (18)$$

$$\mathrm{PGOV_r} \cdot \mathrm{QGOV_{r_r}} = \sum_i \mathrm{PG_{i,r}} \cdot \mathrm{QG_{i,r}} \qquad (19)$$

Total regional investments are modeled through a Cobb-Douglas function of private and public investments. Formally, regional investment net of depreciation $(\mathrm{NETINV_r})$ is split into public $(\mathrm{GOV\_INV_r})$ and private investments $(\mathrm{PRIV\_INV_r})$ according to fixed shares (equation (20)).

$$\mathrm{NETINV_r} = \mathrm{GOV\_INV_r} + \mathrm{PRIV\_INV_r} \qquad (20)$$

Where:

$$\mathrm{GOV\_INV_r} = \varepsilon_r \cdot \mathrm{NETINV_r} \qquad (21)$$

$$\mathrm{PRIV\_INV_r} = (1 - \varepsilon_r) \cdot \mathrm{NETINV_r} \qquad (22)$$

The gap between public savings and public investments is the amount of borrowing the government requires. This gap is financed by private households. Both domestic and foreign households supply a homogenous saving commodity. Therefore, equation (23) is satisfied in each time period of the simulation:

$$\mathrm{I\_GOV_r} = \mathrm{SAV\_GOV_r} + \mathrm{GBOR_r} \qquad (23)$$

Note that a positive value of the variable $\mathrm{GBOR_r}$ means a deficit, thus the government is borrowing, while a negative sign means a surplus so that the government is a lending resources.

Investment is internationally mobile: regional savings (private plus public) from all regions are pooled and subsequently investment is allocated to achieve equality of expected rates of return to capital in the long term. Savings and investments are equalized at the world, but not at the regional level. Therefore, each region could have an imbalance between disposable savings and investment demand, which is closed by a surplus/deficit in foreign transactions (considered as the sum of trade surpluses/deficits and the net inflows of international transfers). An important role is played by government borrowing since it reduces the availability of regional savings with a consequent increase in saving prices which are negatively correlated to the rate of return to capital. Therefore, a country can attract more investment and increase the rate of growth of its capital stock when its GDP and its rate of return to capital are relatively higher than those of the other countries, or its government necessitates a lower level of borrowing.

The ICES-XPS model is a recursive dynamic model, thus each year is linked to the previous one via capital accumulation. The structure of the debt accumulation for the government is close to the capital accumulation. There is a stock from the previous simulation year ($\mathrm{GDEBT_{t-1,r}}$) which is increased by government's borrowing in the current simulation year ($\mathrm{GBOR_{t,r}}$). Denoting the current simulation year as t and the previous year as t-1, we have the following accumulation rule:

$$\mathrm{GDEBT_{t,r} = GDEBT_{t-1,r} + GBOR_{t,r}} \tag{24}$$

Then, we split the accumulation rule to consider the repayment of debt for domestic and foreign households according to a fixed share $\mathrm{fdshr_r}$, defined as the share of foreign debt on total debt in region r in the base year. So equation (24) becomes:

$$\mathrm{GDDEBT_{t,r} = GDDEBT_{t-1,r} + (1 - fdshr_r) \cdot GBOR_{t,r}} \tag{25}$$

$$\mathrm{GFDEBT_{t,r} = GFDEBT_{t-1,r} + fdshr_r \cdot GBOR_{t,r}} \tag{26}$$

Interest payments on government's domestic and foreign debt stocks ($\mathrm{INTD_{t,r}}, \mathrm{INTF_{t,r}}$) are defined as an exogenous interest rate ($\mathrm{ir_r}$) multiplied by the related previous year debt stock (equations (27)-(28)). This means that interest payments are a consequence of the level of indebtedness:

$$\mathrm{INTD_{t,r} = ir_r \cdot GDDEBT_{t-1,r}} \tag{27}$$

$$\mathrm{INTF}_{t,r} = \mathrm{ir}_r \cdot \mathrm{GFDEBT}_{t-1,r} \qquad (28)$$

Similarly to the case of international grants, there is a clearing condition (equation (29)) also in the world market for interest payments. This condition ensures that the total amount of interests governments pay to non- residents equals the total amount of interest payments from abroad. This does not mean that there is a balance in outflows and inflows of foreign interest payments but each country could face a positive or negative net value.

$$\sum_r \mathrm{INTI}_{r,t} = \sum_r \mathrm{INTF}_{r,t} \qquad (29)$$

Moreover, each country receives an amount of interests from abroad that depends on the value of the interest collected in the world market scaled weighted by a parameter ($\mathrm{psavshr}_{r,t-1}$) which represents the country contribution to world private saving in the previous year (equation 30).

$$\mathrm{psavshr}_{r,t-1} = \frac{\mathrm{SAV\_PRIV}_{r,t-1}}{\sum_r \mathrm{SAV\_PRIV}_{r,t-1}} \qquad (30)$$

This share reflects by how much private households in each country contribute to finance total world debt. Since public and private savings are homogenous goods, private households lend a fraction of their savings to governments. As a consequence, the public agent pays interests to the household. If households save more, they could devote a higher fraction of their savings to finance public debt. This means that at time t+1 they obtain higher interest payments. Therefore, foreign interest inflows become:

$$\mathrm{INTI}_{r,t} = \mathrm{INTAVI}_r \cdot \mathrm{psavshr}_{r,t-1} \qquad (31)$$

Finally, when the public agent is introduced in a Computable General Equilibrium model, the modeler has to choose how to close the sector, in other words, he has to decide the causality among income, expenditures and savings (Robinson, 2003). There are essentially two alternatives: (i) endogenous government savings and the other components exogenous, or (ii) the other way round with exogenous government savings. Since we want to use the ICES-XPS model to assess the budgetary effects of removing fossil fuels subsidies, we follow the first approach. Therefore, taxes have exogenous tax rate, expenditures (both recurrent and investments) are fixed exogenously and as a consequence the model calculates the final savings (or public borrowing) as the gap between revenues and expenditures. However, there are no projections for government expenditures up to 2050. Some estimates are in IMF's World Economic Outlook (IMF, 2015) up to 2020 but there is no clear and unique correspondence between its aggregate "general government total expenditures" and the ICES-XPS variables. Therefore, to project these variables in the baseline we do two assumptions: (i) real recurrent expenditures are a fixed share of real GDP (Chateau et al. 2014); (ii) real government investments are a fixed share of total regional investments, so that public and private investments are a Cobb-Douglas function respect to total (depreciated) regional investments.

4.2 EXPERIMENT DESIGN

The first step of the analysis is to build a baseline scenario for the period 2007-2030. 2007 is the calibration year of ICES-XPS which, on its turn, is based on the GTAP 8 database (Narayanan et al., 2012). The reference period represents a reasonable compromise between the very long run time horizon of the climate policy and the medium time horizon which usually represents the basis to study the issue of public deficit and debt.

Macro-economic drivers of the baseline are those of the Shared Socioeconomic Pathway (SSP) 2 (O'Neill et al., 2015). Essentially this means that the model replicates the GDP and population of this scenario for the chosen regional and sectoral aggregation reported in Table 5.

SSP2 is a middle of the road scenario where the social, economic, and technological trends do not shift markedly from historical patterns. Emerging countries gradually catch up with developed countries in terms of per capita income and demographic behavior. Macroeconomic trends are reported in Figures 3 and 4.

Figure 3: population trends in the SSP2 (% Ch. wrt 2007)

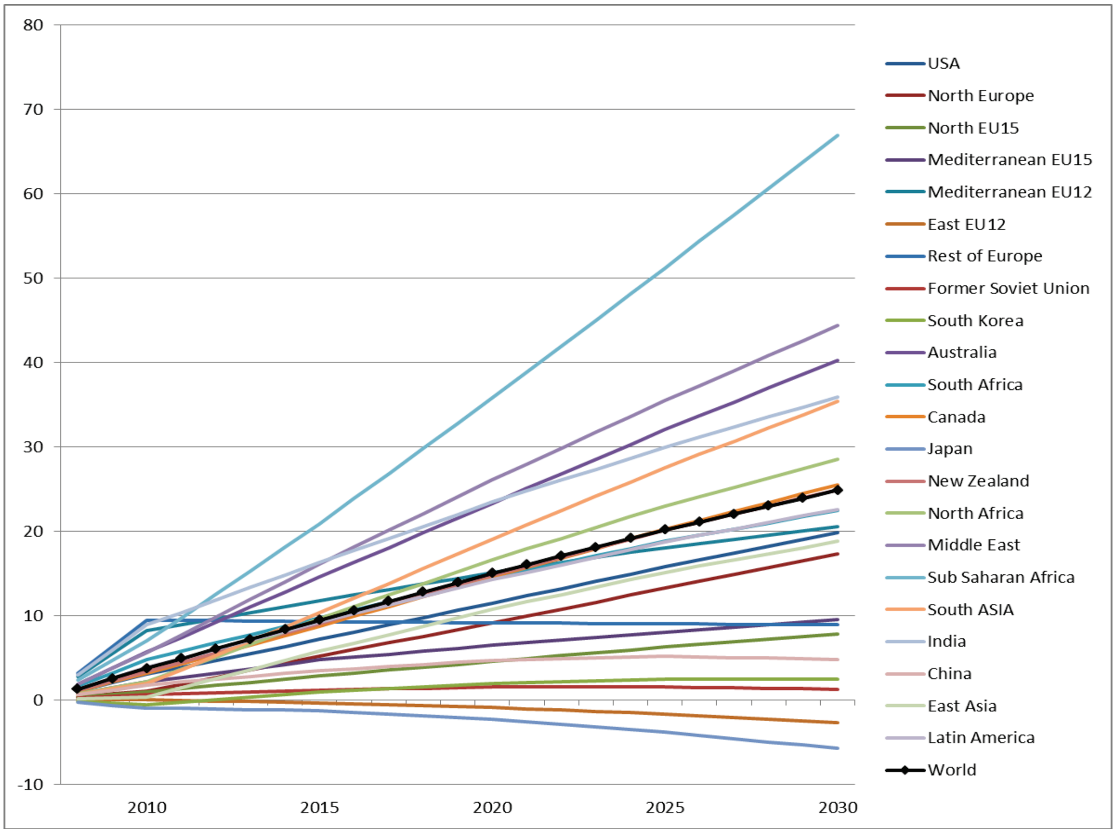


Figure 4: GDP trends in the SSP2 (% Ch. wrt 2007)

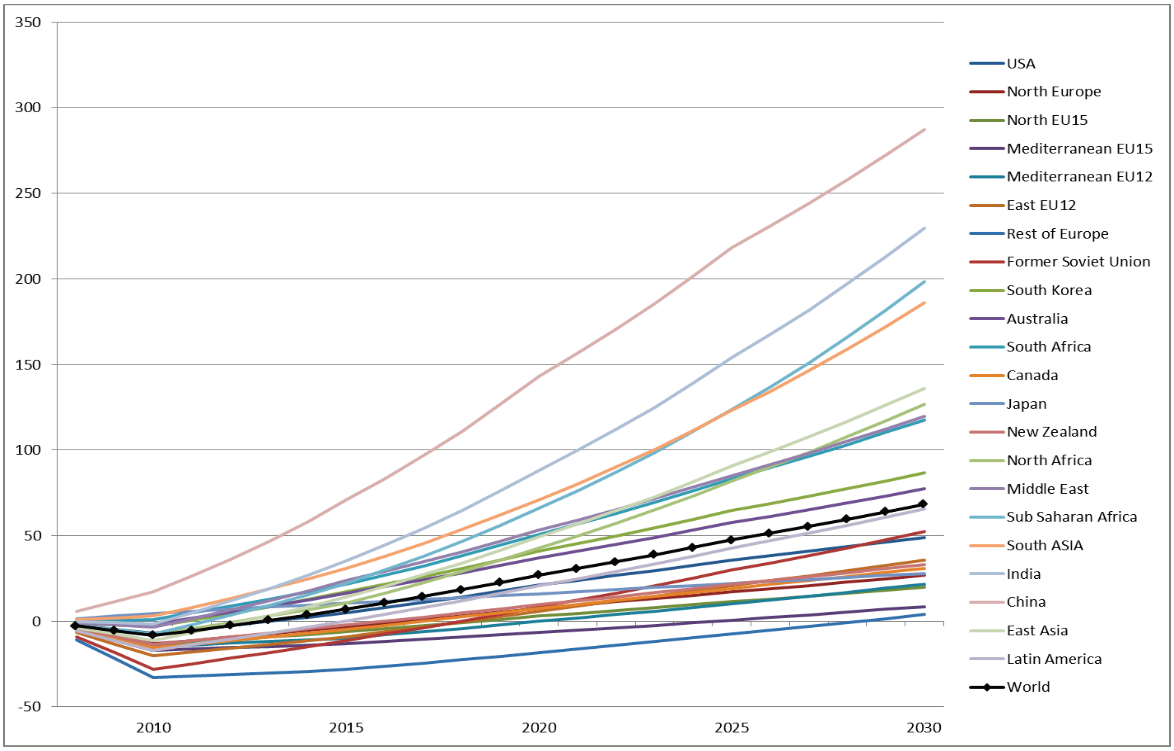

350
300
250
200
150
100
50
0
-50
2010
2015
2020
2025
2030
USA
North Europe
North EU15
Mediterranean EU15
Mediterranean EU12
East EU12
Rest of Europe
Former Soviet Union
South Korea
Australia
South Africa
Canada
Japan
New Zealand
North Africa
Middle East
Sub Saharan Africa
South ASIA
India
China
East Asia
Latin America
World

Table 5: sectoral and regional aggregation

No.	Sectors	No.	Regions
1	Rice	1	USA
2	Wheat	2	North Europe
3	Cereal Crops	3	North EU15
4	Vegetable Fruits	4	Mediterranean EU15
5	Livestock	5	Mediterranean EU12
6	Coal	6	East EU12
7	Oil	7	Rest of Europe
8	Gas	8	Former Soviet Union
9	Nuclear Fuel	9	South Korea
10	Oil Products	10	Australia
11	Electricity Nuclear	11	South Africa
12	Electricity Renewables	12	Canada
13	Electricity Other	13	Japan
14	Energy Intensive industy	14	New Zealand
15	Other industry	15	North Africa
16	Construction	16	Middle East
17	Road Transport	17	South Saharan Africa
18	Other Transport	18	South ASIA
19	Commerce	19	India
20	Water	20	China
21	Market Services	21	East Asia
22	Public Services	22	Latin America

Once the baseline has been set, the policy implemented consists in a linear phase-out of fossil fuel subsidies reaching 100% by 2020, starting in 2015.

It is worth to describe at this stage, how subsidy removals have been introduced. What has to be considered first is the peculiar representation of fiscal data in the GTAP (and accordingly in the ICES-XPS) database. In practice, prices embed an *ad valorem* “net” fiscal component (rx) which does not disentangle the tax and subsidy part. This originates the following after tax/subsidy price P*:

$$P^{*}_{i,r} = [1 + rx_{i,r}]P_{i,r} \qquad (32)$$

where P is the pre-tax/subsidy price, i represents the relevant (in our case fossil fuel) sector index (i.e. coal, oil, gas and electricity), r the region index.

The *ad-valorem* rate rx is the net result of complex interactions between taxes and subsidies. To be clearer, the rate rx is made up of two components, subsidy and tax, according to the following equations:

$$P^*_{i,r} = [1 + trx_{i,r} - srx_{i,r}]P_{i,r} \qquad (33)$$

$$rx_{i,r} = trx_{i,r} - srx_{i,r} \qquad (34)$$

where trx is the ad valorem tax rate and srx is the ad valorem subsidy rate.

Should the tax component prevail the rate rx is positive, should the subsidy component prevail the rate rx is negative. Without detailed (and in practice unavailable) information, it is not possible to unequivocally identify whether rx is positive or negative in the reality.

We simplify the problem implementing the phasing-out policy in the form of an *ad valorem* tax (thus mimicking a negative subsidy) over the fossil fuel price P*. This tax is exactly the (negative) *ad valorem* subsidy reported by Burniaux and Chateau (2011, 2014) rearranged according to our geographical aggregation. These values represent the average subsidy rate over the total demand for each type of fuel (coal, oil, gas, electricity) and region (Table 6).

Even if this methodology entails some simplifications because we do not include the actual monetary values of subsidies in the database, it represents the most reliable and easy way to implement the policy. Furthermore, it is consistent with the empirical evidence that taxes and subsidies coexist in the same sector to determine the final price.

Applying this procedure it emerges (Table 6) that Middle East and North Africa have strong subsidies for oil while Former Soviet Union has a high level of subsidies for gas. This reflects the sectoral specialization and reserves of the three macro regions. All the three macro-regions also show important fossil fuels support in the electricity sector.

Table 6: % *ad valorem* subsidy rate in the reference year 2007

Regions	Coal	Gas	Oil	Electricity
Former Soviet Union	0.00	-20.10	-0.14	-21.58
North Africa	-0.22	-10.61	-26.85	-34.20
Middle East	-0.28	-10.40	-24.91	-31.78
Sub Saharan Africa	-0.90	-8.20	-4.10	-5.80
South Asia	-0.90	-8.20	-4.10	-5.80
India	0.00	-32.20	-20.40	-1.70
China	-1.20	-7.10	-1.70	-1.70
East Asia	-0.62	-9.21	-13.66	-17.73
Latin America	-0.53	-5.47	-4.42	-5.96

Source: our elaboration rescaling Burniaux and Chateau inputs (2011)

5. RESULTS

The results of the policy are expressed in percent changes with respect to the baseline scenario for GDP and CO2 emissions and reported in Figures 5 and 6 over the period 2007-2030. Table 7 summarizes the numerical values for the final year 2030.

At the world level the “double gain” of the policy in terms of welfare gain and emission reduction (Figures 5 and 6) which is common to most of the studies, is confirmed. CO2 emissions to decline with the beginning of the phase out in 2015 up to 2020 and then tend to stabilize (in fact they slightly decrease further). In 2030 they are 2.32 % lower than in the baseline. World GDP remains roughly constant along the implementation period 2015-20, but then becomes higher than in the baseline (Table 7).

The regional picture is highly differentiated featuring winners and losers from the policy. Not surprisingly, the regions experiencing the highest economic losses are North Africa, Middle East, Former Soviet Union and East Asia which are strong net oil and gas exporters. The subsidy removal translates into an increase of the fossil fuel prices contributing to a generalized contraction of domestic economic activity and a the deterioration exports, especially if they are net fossil fuel exporters. International trade shifts toward the remaining regions which show GDP gains. This last dynamics highlights an interesting undesired side effect of the policy. Albeit removal of subsidies reduces emissions in the formerly subsidizing countries (the biggest CO2 reductions can be observed in Former Soviet Union with its nearly -17% in 2030, followed by North Africa and Middle East similar to what found in Burniaux and Chateau (2011, 2014) and Bosello and Standardi (2013)), other countries, experiencing GDP expansions would tend to emit more. This raises an important issue of international coordination of the policy, calling for a control of emissions also in those regions where subsidies are absent.

Figure 5. GDP: % Ch. wrt the baseline scenario

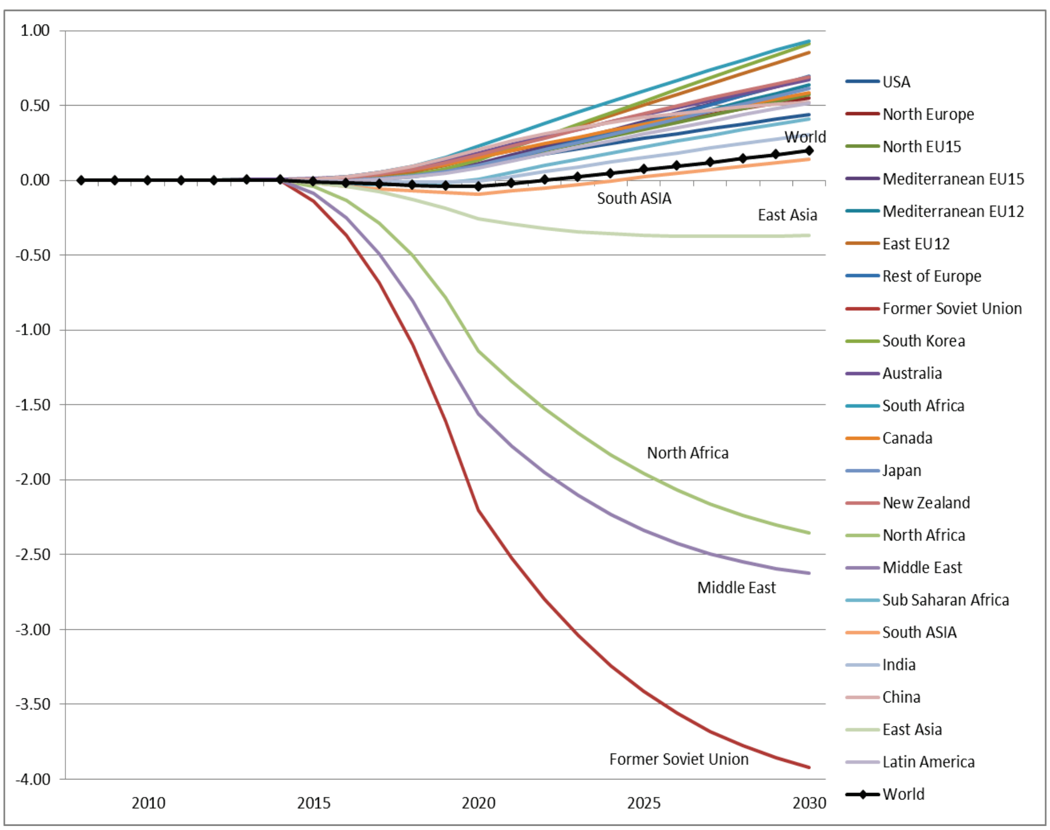
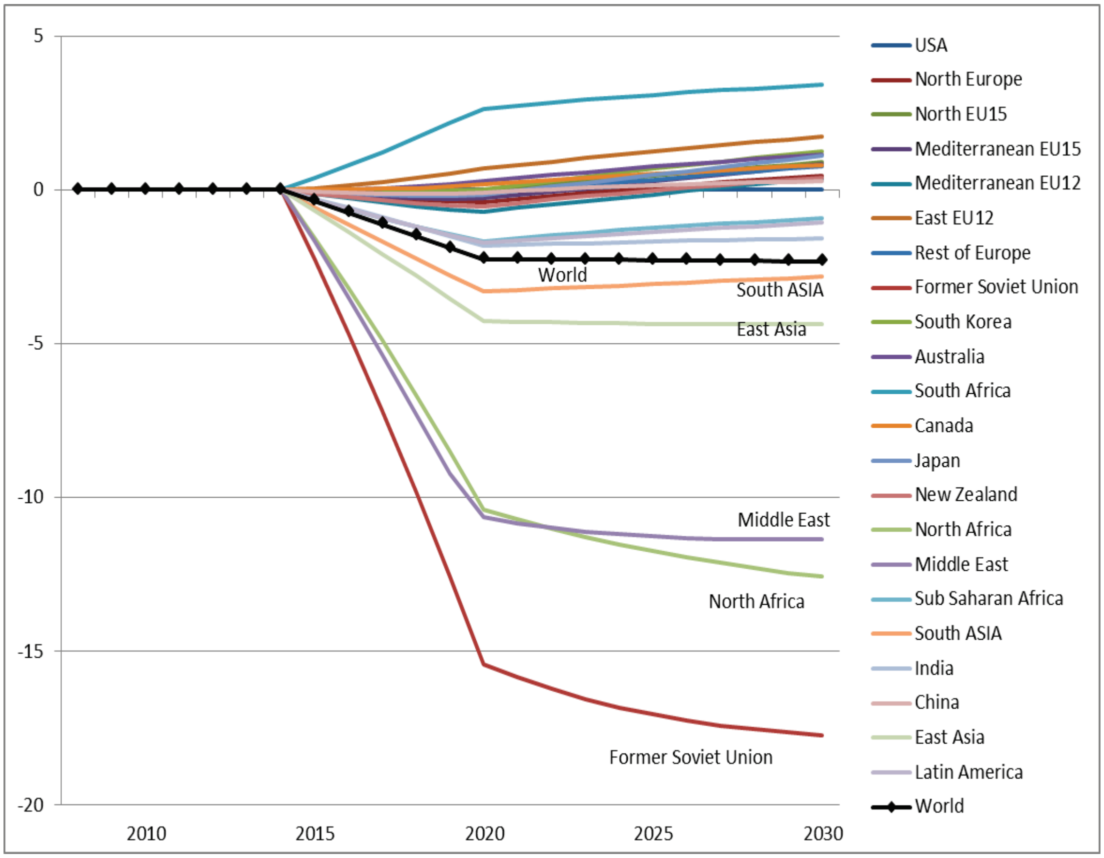


Figure 4. CO2 emissions: % Ch. wrt the baseline scenario



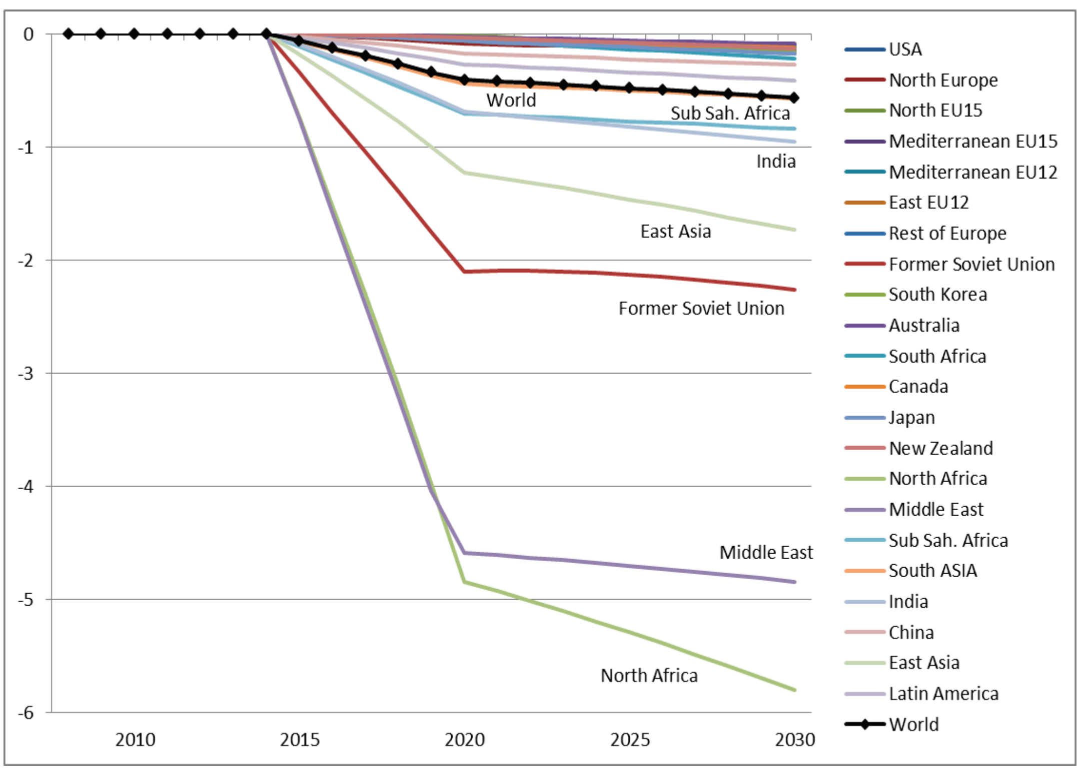
A further analysis possible with ICES-XPS is to verify the economic consequences of the policy on public budgets. The results are expressed as absolute changes with respect to the baseline for % deficit GDP ratio and % debt GDP ratio in Figures 7 and 8. Table 7 summarizes the numerical values for the final year 2030.

At the global level the % Deficit GDP ratio decreases by more than 0.5 (Table 7) points in 2030 compared to the baseline. Results are even stronger for the % Debt GDP ratio where the reduction is more than 6 points (Table 7). It is possible to notice that the world deficit GDP ratio is decreasing in the implementation period 2015-2020 and then tends to stabilize (Figure 7). As expected the world Debt GDP ratio is decreasing in the entire period 2007-2030 because the stock of public debt takes into account the deficit reductions taking place in the previous years (Figure 8).

More interesting are the regional results. The policy is undoubtedly beneficial for public finances in all the countries/regions considered, and in particular for those exhibiting the highest level of fossil fuels support such as the Former Soviet Union, Middle East, North Africa, South Asia and East Asia reducing both the deficit/GDP and the debt/GDP ratios. The reductions of the debt GDP ratio is particularly pronounced in the couple Middle East and North Africa achieving absolute changes of more than 56 points (Table 7).

In principle, these results are expected as the simulation eventually consists in adding a new tax. Under standard circumstances,[4] an additional source of revenues determines lower deficits and debts. Results would be more informative if the subsidy component were explicitly disentangled from the fossil fuel prices, which is a matter for future research. Nonetheless, what is still interesting to note is that declines in deficit and debt /GDP ratios are experienced even though GDP declines. This means that in formerly subsidizing countries both deficits and debts are decreasing more steeply than GDP, and emphasizes, albeit indirectly, the particularly distortionary nature of subsides in these countries.

Figure 7. Deficit/GDP ratio: absolute changes wrt the baseline scenario



[4] That is without the presence of "Laffer curve" phenomena.

Figure 8. Debt/GDP ratio: absolute change wrt the baseline scenario

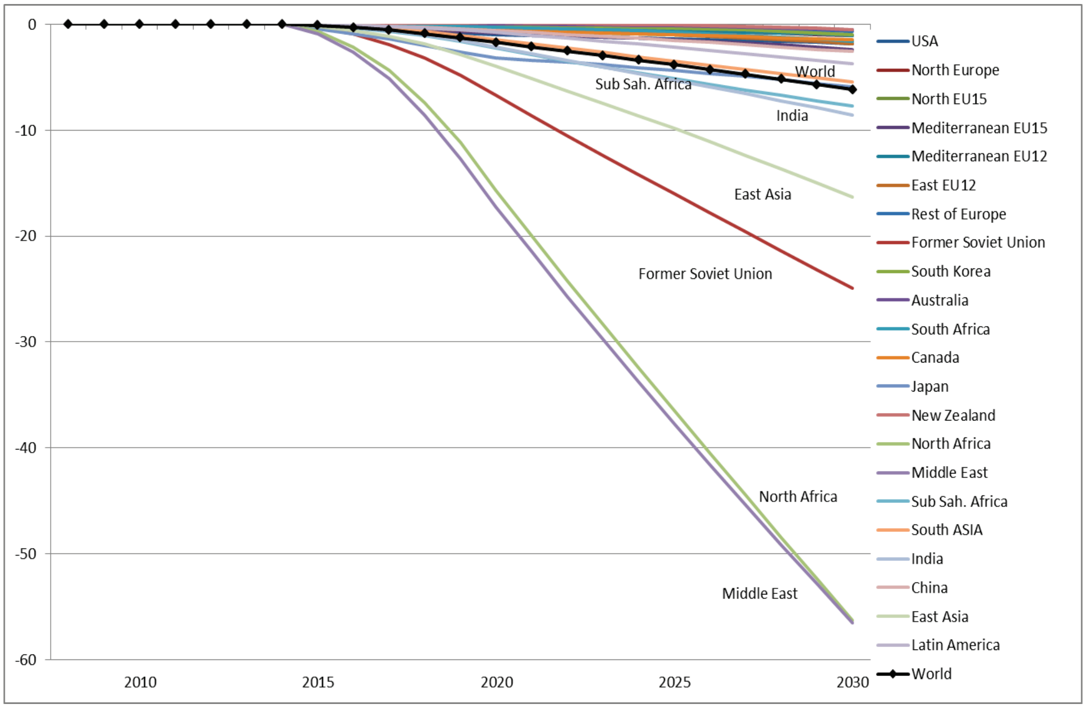


Table 7: % changes and absolute changes with respect to the baseline in 2030

	GDP % Ch.	Co2 % Ch.	% Def/GDP abs. Ch.	% Debt/GDP abs. Ch.
USA	0.44	0.01	-0.10	-1.85
North Europe	0.55	0.48	-0.15	-1.10
North EU15	0.57	0.90	-0.12	-1.65
Mediterranean EU15	0.69	0.84	-0.17	-2.38
Mediterranean EU12	0.64	0.38	-0.12	-1.05
East EU12	0.85	1.75	-0.17	-1.88
Rest of Europe	0.70	0.79	-0.14	-0.72
Former Soviet Union	**-3.92**	**-17.72**	**-2.26**	**-24.96**
South Korea	0.91	1.26	-0.15	-0.97
Australia	0.67	1.15	-0.09	-0.52
South Africa	0.93	3.42	-0.22	-1.61
Canada	0.59	0.81	-0.12	-1.51
Japan	0.62	1.10	-0.18	-5.95
New Zealand	0.69	0.39	-0.13	-0.52
North Africa	**-2.35**	**-12.58**	**-5.80**	**-56.30**
Middle East	**-2.62**	**-11.34**	**-4.84**	**-56.50**
Sub Saharan Africa	0.41	-0.93	-0.84	-7.72
South ASIA	0.14	-2.82	-0.57	-5.48
India	0.30	-1.58	-0.96	-8.58
China	0.52	0.29	-0.27	-2.60
East Asia	-0.37	-4.37	-1.73	-16.35
Latin America	0.52	-1.07	-0.41	-3.76
World	**0.20**	**-2.32**	**-0.57**	**-6.19**

Finally, offering a quick comparison of our results with the existing literature (contrasting Tables 3 and 7), it can be seen that our GDP results are similar to Burniaux and Chateau (2011, 2014) while emissions are more in line with Saunders and Schneider (2000) and a previous study by Bosello and Standardi (2013). However, this latter, using a static version of the ICES model and without the more realistic public sector description of ICES-XPS predicted a slight decrease of the global income as a result of the policy. In the current study, global GDP declines negligibly until 2020 and then increases. This can be explained by the interaction of two factors: the presence of the recursive dynamics and the new structure of public expenditure. The removal of subsidies, that in our case consists in an additional tax, produces new revenues which decrease the deficit, debts and the payment of debt services. Thus additional resources are “freed” for private investment, and this has a positive effect on capital accumulation and on the long-run economic growth.

6. CONCLUSIONS

This study analyses the economic, environmental (CO2 emissions) and public budget consequences of the complete phase-out of fossil fuel subsidies to be achieved in the ideal period 2015-2020, by using a world Computable General Equilibrium model featuring an improved description of the government role and of its expenditure structure.

Results show that this policy is effective in achieving global GDP gains and emission reductions at the same time (emissions decline the 2.32% in 2030 compared with the baseline). The global picture however hides important asymmetries. In particular, the removal of subsidies translates into an increase of the fossil fuel prices in formerly subsidizing countries contributing to a generalized contraction of domestic economic activity and a deterioration of exports especially if the country is a net fossil energy exporter. International trade shifts toward the remaining regions that, on the contrary, show GDP gains and a slight increase in emissions. In other words, also the removal of fossil fuel subsidies may induce the well-known leakage effect.

This said, the phasing-out is successful in reducing the Deficit GDP ratio and the Debt GDP ratio in all the countries that can thus consolidate their public budgets. Considering that in the simulation the subsidy removal is achieved imposing a new tax, the result may seem not totally unexpected. However, what remains interesting to note is that declines in deficit and debt /GDP ratios are experienced under GDP declines induced by the removal policy. This means that in formerly subsidizing countries both deficits and debts are decreasing more steeply than

GDP, and emphasizes, albeit indirectly, the particularly distortionary nature of subsides in these countries.

The next step of the present research would consists in disentangling explicitly the subsidy component in the fossil fuel price. This would allow to better capture the welfare effects of the removal and possibly also a different impact on emissions. This however requires to fully characterize the fiscal component of fossil fuel prices which is particularly challenging for developing countries which are also those where subsidies are more widespread.

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