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# Unlocking Supply and Locking in Carbon:

## The paradox of determining which fossil fuel subsidies are the worst for the climate

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Fossil-fuel subsidy reform can be described as a low-hanging, but prickly fruit with respect to climate change mitigation. Low-hanging, because fossil fuel subsidy reform saves both public money and avoids dangerous GHG emissions. And prickly because of its political economy challenges and barriers. This paper focuses on the impact of subsidies on fossil fuel supply and, where necessary, touches upon the related, but more researched area of subsidies to fossil fuel consumption. The authors seek to answer the questions that many experts and policy makers are asking: a) which subsidies to fossil fuels are the worst in terms of climate change impacts?; and b) are these the same subsidies that should be phased out first under the commitment of G20 and APEC leaders to "phase out inefficient fossil fuel subsidies that encourage wasteful consumption"?

In sum, we find that it is possible to identify those subsidies to fossil fuels that are likely to have the greatest climate impacts, through supporting lock-in of high carbon assets. The paradox is that, even leaving aside political economy challenges, prioritizing certain "heavy climate impact" subsidies for phase-out is not an effective solution from the viewpoint of keeping unburnable carbon in the ground. Because of fossil fuel substitution effects and transboundary leakage of capital and emissions, an incomplete subsidy phase-out will result in the continued unlocking of emissions elsewhere. The only effective policy consistent with the Paris agreement is the phase-out of all subsidies to all fuels, on both production and consumption side, and by all countries, provided complimentary policies are put in place to protect the vulnerable.

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## 1. Different climate impacts of different subsidies on fossil fuel production

Subsidies[2] to fossil fuel production[3] come in many forms and are likely to have different impacts, depending on their incidence and mechanism. All producer subsidies reduce the industry's costs, but these costs can be different and incurred in different ways over fossil fuel project lifecycles. For example, climate impacts of government support to exploration or field development are likely to differ from those of government spending on rehabilitation of abandoned extraction sites.

Subsidies that have the most negative climate impacts are those that lock in fossil fuel energy choices not just for the short-term, but for many years and even decades to come. All subsidies to fossil fuel production can be divided into three groups, depending on their potential climate impacts: a) subsidies that give a long-term signal to the fossil-fuel industry and therefore influence investment decisions and support lock-in of high carbon assets; b) subsidies that reduce fossil-fuel industry's costs on a short-term basis and, in particular, may enable the continued operation of high-carbon assets where it would not be otherwise economically viable; c) subsidies that do not materially reduce costs of the industry and have no direct impact on high carbon assets.

## 2. Which subsidies have which impacts on carbon lock-in?

In order to judge which subsidies have which impacts on lock-in of investment in high carbon assets, we need to go to a micro level and unpack how the fossil-fuel industry takes final investment decisions (FIDs).

Normally, the fossil-fuel industry, especially in the private sector, relies on short-term or midterm plans rather than long-term strategies. The industry remains opportunistic and very sensitive to the main decision-making factor: the price for energy commodities on the world markets. The

[2] There are different definitions of subsidies (also called "measures of government support"), but in this paper we follow the definition coined by the Agreement on Subsidies and Countervailing Measures (ASCM) of the World Trade Organization (WTO) that is legally binding for the 164 members of the WTO. Under the ASCM, subsidies" can be grouped as follows:

- direct transfers of funds from the budget to energy producers and consumers (e.g. grants, support of energy purchases by low-income households);
- tax expenditure and other government revenue foregone (e.g. reduction or exemptions of certain taxes, such as VAT or excise taxes on fuel consumption);
- induced transfers (import tariffs, below market electricity/heat prices, cross-subsidies in the electricity sector);
- transfer of risk to government (e.g. low interest loans, loan guarantees).

[3] Fossil-fuel production here is understood as all phases involved into supply of fossil-fuel energy, including fossil-fuel based electricity: field exploration, appraisal, development, exploitation and decommissioning, construction, exploitation and decommissioning of refineries and fossil fuel based power plants, transportation of fossil fuels. There are different expert opinions on where to draw the line between activities and infrastructure related to energy supply and those linked to energy demand.

sector goes through investment cycles. Companies manage their production via a portfolio of extractive projects that is diversified over type of fields, level of development and depletion as well as jurisdictions (Arora, 2012; Johnston, 2003). Worth noting is that in order to achieve maximum profitability, companies often try to influence governments and ask for policy amendments that favor certain business developments, including through subsidies.

In their turn, many governments have long-term strategies of economic, sectoral or regional development that span ten to twenty years ahead. In order to implement such strategies and achieve the stated policy objectives over both long term and short term, governments use different tools to influence the private sector, including the distribution of fossil fuel assets developed and maintained by companies. Various forms of subsidies are widely used to this end. Some of them perpetuate and remain in force longer than strategic government considerations that provided rationale for subsidy introduction.

Thus corporate decision-making and government's strategic planning are inter-linked, and the outcome of these interlinkages is that companies take certain government policies as signals for investments, in particular, investments that lock in high carbon assets for many years to come. Frequently such investments also have the opportunity cost of a foregone chance to use equivalent funds for development of energy efficiency and alternative energy solutions.

The list of subsidies that influence final investment decisions in the fossil-fuel sector is rather long. First, this list includes all subsidies that reduce capital costs (capex subsidies). Second, subsidies that reduce operating costs (opex subsidies) can influence investment decisions if they are conferred on a long-term basis and be less relevant to them if they have a temporary nature. Third, consumption subsidies also contribute to carbon lock-in. Finally, a limited number of subsidies can be qualified as having no impact on investment decisions.  These four groups are described in more detail below. Table 1 provides specific examples of subsidies in each category, based on subsidy typologies developed and applied by OECD (OECD, 2015), World Bank (Kojima & Koplow, 2015), and other expert organisations (Lang, 2010; Bast, et al., 2015).

### *2.1. Subsidies to capital expenditure*

The fossil-fuel industry is very capital-intensive and it operates in a capital-scarce environment. The capital investments have to be made, normally, at early stages of extractive projects' lifecycle. In particular, capex subsidies reduce companies' expenditure on exploration[4], research and development, feasibility studies, as well as infrastructure such as ports and roads leading to extraction sites and pipelines from oil and gas fields.

Therefore every policy that reduces or enables a write-off of capital costs against taxable income of companies carries a lot of weight. The costs of developing new oil, gas and coal fields or constructing an electricity plant are in the range of several billions US dollars. In many cases, capital costs represent the majority of the expenditure to be recovered by investors over a

[4] Government support to exploration has been described as a subset of subsidies which are particularly inconsistent with climate goals (Bast et al., 2014).

project's lifecycle, whereas operational costs are normally low once the field has been brought on stream. Further, capital in this sector has a long lifetime. Therefore if the capital costs have already been incurred, production from the developed fields will continue even during the years in which the market price is below the breakeven price of the field.

For example, Snohvit, a large natural gas site offshore Norway, has been granted specific tax benefits in the form of accelerated depreciation and uplift that assisted Statoil's final investment decision on its development and construction of a related LNG plant (EconPöyryManagementConsulting, et al., 2012). Yamal LNG project in Russia has received support through about USD 6 billion of government funding of transport infrastructure around the site (sea port facilities, dredging, support of icebreaker fleet), that has commercialized the otherwise economically unviable project (Lunden & Fjaertoft, 2014).

Meanwhile, not all capex subsidies are the same. They differ in size and the ways they impact project economics. In addition to the bulk capex expenditure at the development stage, some, though normally smaller, capital investments need to be made throughout later project cycle, for instance for equipment replacement and site decommissioning. The impact of capex subsidies is also not limited to the direct reduction of the costs of fossil fuel projects' development. Capital subsidies, especially co-funding by the state or provision of government loans and loan guarantees on preferential terms de-risks investments and further reduces the cost of capital to companies. If synced, different capex subsidies can amplify the impact of each other on lock-in of high carbon assets. What is common between all capex subsidies is that they lock in high carbon assets through impacting long-term investment decisions.

### *2.2. Subsidies to operating expenditure*

The second large group of subsidies are policies that reduce operational expenditures (opex) of fossil fuel producers. These subsidies reduce operational costs of fossil fuel extraction once the project already starts producing. Opex subsidies either make extraction of oil, gas and coal more profitable or enable their producers to reduce sales prices, for instance, at the government requirement, in competition with each other, or in competition with alternative forms of energy.

If opex subsidies are provided on a long-term basis and become part of a taxation system, they can be capitalized and have direct influence either on companies' final investment decisions about new projects, or on continued exploitation of depleted sites. For instance, over the past decades support for domestic coal production in different countries included obligations on power producers to purchase local coal, import prohibitions or high import tariffs that shielded domestic production from foreign competition. Historically, such policies were maintained over the long term in such countries as the UK and Germany (Steenblik & Coroyannakis, 1995), though they were later on phased out in Europe. Such opex subsidies allow firms to remain operating that would otherwise have exited the marketplace. Moreover, such policies encourage investment in new capital equipment and in fixed infrastructure. For instance, in China coal subsidies have created overcapacity and overdependence on coal (ChinaDialogue, 2016). Such wide-spread opex subsidies as royalty reduction on specific new or mature oil fields at national and subnational level in Canada, US, Russia and many other countries have the same long-term effect of locking in high carbon assets.

In contrast, other opex subsidies are not designed to influence investment decisions. The temporary tax and fee relief on coal companies in China's provinces of Shanxi, Inner Mongolia and Shaanxi has, at least by design[5], little direct impact on creation of new high carbon assets since the measure has been provided to assist coal mine closure and restructuring of the coal industry. At the same time it is a subsidy that companies can recycled in coal mining business to improve profitability on a short-term basis.

Understanding whether or not an opex subsidy to fossil fuel producers sends a long-term signal to companies requires a high degree of familiarity with policies in question. Experts and policy makers interested in limiting the carbon lock-in should screen opex subsidies on an individual basis.

### *2.3. Fossil-fuel consumer subsidies*

In terms of impacts on final investment decisions, consumer subsidies have a lot in common with opex subsidies: some of them send long-term signals, others are short-lived and are perceived as such.

On the one hand, fossil fuel producers often object to subsidies to consumers in the form of price caps, since these eat up their margins (Beaton, et al., 2013). On the other, consumer subsidies drive up demand for fossil fuels and often create a guaranteed market for them, making them more competitive over alternative energy choices (IMF, 2013) (Merrill, et al., 2015). In particular, the influence of subsidized fossil fuel prices can be tracked down to urban sprawl and wasteful energy consumption in transport and buildings in many countries (New Climate Economy, 2014).

Therefore experts and policy makers have to consider the impacts of consumer subsidies on lock-in of high carbon assets and, in particular, analyze which of them send long-term signals that influence final investment decisions.

### *2.4. Other subsidies*

There can be a case made that while the absolute majority of subsidies have influence on energy production and consumption choices, other government support measures pursue different objectives and therefore have no impact on shifting production, carbon lock-in and emissions. In particular, the measures that can fall into this category are subsidies to assist social transitions in communities where a lot of jobs depend, or used to depend, on extraction of fossil fuels. For instance, such subsidies include government contributions for early retirement or retraining of coal miners in Mexico and Germany and aid packages for formerly coal-producing regions in Europe (Bast, et al., 2015), (Gass, et al., 2016). Government support

[5] Whatever the stated policy objectives and the intended design of a subsidy, almost in every instance there are unintended beneficiaries and unexpected impacts of such policies (Beaton, et al., 2013).

to extractive sites' rehabilitation and compensation of investors for the shut-down of coal plants also appears to have no direct impact on fossil fuel supply.

However, each such case requires analysis of not only direct, but also indirect impacts. Subsidies often have unintended effects and beneficiaries.

***Table 1. Classification of subsidies based on how they lock in long-term investment into fossil fuels: subsidies to capex, opex, consumption and other examples***

| **Group of subsidies** | **Stages of project development** | **Examples of subsidies** |
|---|---|---|
| Capex subsidies | Mostly early stages of project lifecycle, particularly exploration and field development or plant construction. Other capex subsidies apply throughout later stages | • Direct funding of industry-specific R&D and tax breaks stimulating it<br>• Direct and indirect funding of fossil fuel companies at a project level, including preferential loans and loan guarantees<br>• Direct funding of exploration and exploration cost write-offs against payable taxes<br>• Funding of industry-specific infrastructure development (roads, ports, pipelines)<br>• Accelerated depreciation of fixed assets<br>• Tax breaks beneficial for development and construction such as fuel tax reduction for heavy machinery or waivers for import duties and VAT on equipment<br>• Direct funding of site rehabilitation and rehabilitation cost write-offs against payable taxes |
| Opex subsidies | Start once the field or plant become operational | • Direct and indirect funding of fossil fuel companies at a corporate level, including preferential loans and loan guarantees<br>• Bailout in case of operational losses<br>• Relief on royalties<br>• Tax holidays, tax credits and other tax breaks during project operation with respect to income tax, property tax, pollution and other taxes<br>• Prices and fees for input factors regulated at below-market level (e.g. for land, water, railroads, ports, pipelines)<br>• Prices of output regulated or stimulated at above-market level, including through market protection<br>• Liability caps and insufficient environmental regulations |
| Consumption subsidies | Apply at an industry-level rather than project-level, influence final investment decisions when calculating revenue from sales | • Conditional and unconditional cash transfers to fuel consumers<br>• Compensation to suppliers for selling fuels under regulated prices<br>• Fuel distribution and rationing on preferential terms<br>• Domestic market obligations for suppliers<br>• Consumer prices regulated at below-market level<br>• Cross-subsidies between different categories of consumers<br>• Tax relief on consumer side (exemptions from VAT, excise tax, etc) |
| Other subsidies | Various | • Labor and pension debt subsidies<br>• Aid packages to regions that depend or formerly depended on fossil fuel extraction<br>• Compensations to investors for the shut-down of coal plants |

Source: Authors' summary with the use of subsidy typologies developed and applied by OECD (OECD, 2015), World Bank (Kojima & Koplow, 2015) and other expert organisations (Lang, 2010; Bast, et al., 2015)

## 3. The challenges of quantifying the difference in subsidies with respect to the lock-in of high carbon assets

Although it is clear that different fossil fuel subsidies work in different ways and therefore their impacts on the carbon lock-in and emissions are not the same, capturing this differences in measurable terms is challenging. Yet, quantitative assessments of differences in fossil fuel subsidies present a practical interest to both policy makers and researchers interested in the implications of different subsidy scenarios.

This section is an attempt to outline how such quantification challenges may be overcome through assumptions. In most cases, such assumptions have to be rough and therefore can be subject to criticism. They form a basis for a thought experiment and a proof of concept at an early stage of gaining knowledge in this policy area. Further research is required to develop each of the assumptions in the future.

### *3.1. Overcoming the lack of fossil fuel subsidy data*

By far, lack of fossil fuel subsidy data is the main challenge in terms of evaluating the impacts of these policies on the lock-in of high carbon assets.

OECD and several NGOs, including GSI, OCI and ODI publish bottom-up inventories of subsidies to fossil-fuel production. These inventories estimate fossil fuel producer subsidies at USD 100 billion a year (GSI, n.d.) as a minimum on a global level, of which at least USD 70 billion are in G20 countries (Bast, et al., 2015). However, these numbers are underestimates given the lack of government reporting on subsidies and methodological difficulties quantifying many important subsidy schemes. Further, the existing inventories cover only a subset of countries, with no quantitative estimates of upstream fossil fuel subsidies available for such major producers as the Gulf countries, Mexico and Nigeria.

To overcome this challenge, one has to take the available estimates as a minimum and assume that the structure and the magnitude of upstream subsidies in less researched countries is about the same as for the countries for which subsidy inventories are more detailed, for instance, US, Canada or Russia.

### *3.2. Estimating long-term versus short-term impacts*

Above we discussed how different subsidies vary in the mechanics of impacting the lock-in of high carbon assets, with important nuances. The nuance that lends itself more easily to a straightforward quantification is time value of money, or more exactly, time value of reduced costs to companies due to various subsidies. Adding up Present Values of cash inflows and outflows over an extractive project's lifecycle allows companies to calculate the entire project's Net Present Value (NPV)[6] , which is one of the key tools in making final investment decisions[7].

Discounting of a nominal value of cash inflow or outflow in the future to its present value reflects the business perception that a dollar today is worth more than a dollar tomorrow. As a rule of thumb, the industry applies discount rates varying between 8% and 12% (Kasriel & Wood, 2013). One discount rate widely cited as a hurdle rate in the extractive industry is 10% (Lunden & Fjaertoft, 2014) (Arora, 2012). In reality, discount rates also depend on the project and country in question and can be higher or lower depending on those characteristics. Sometimes a lower discount rate of 8% can be used for de-risked or longer-term projects. Overall, discount rates of 10% and 8% seem to be the most conservative for considering the impact of subsidies on project cash flow.

Figure 1 illustrates a typical project cash flow in the oil and gas industry in absolute, undiscounted terms. In this generalized approach it is assumed that exploration, appraisal, development production and abandonment stages of an extractive project have the same duration for all fuels (Chassin, 2014), (Shafiee, et al., 2009)[8]. It is assumed that the pre-production period comprising exploration, appraisal and development is five years, the production period is twenty years, and the final year is for the site decommissioning. In total, the project lifecycle is 26 years, though in reality lifecycle for projects can be shorter and longer.

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[6] NPV is calculated the following way: each cash inflow or outflow is discounted back to its Present Value (PV). Then they are summed. If NPV is positive, this means a project is profitable.

PV is calculated according to the following formula:

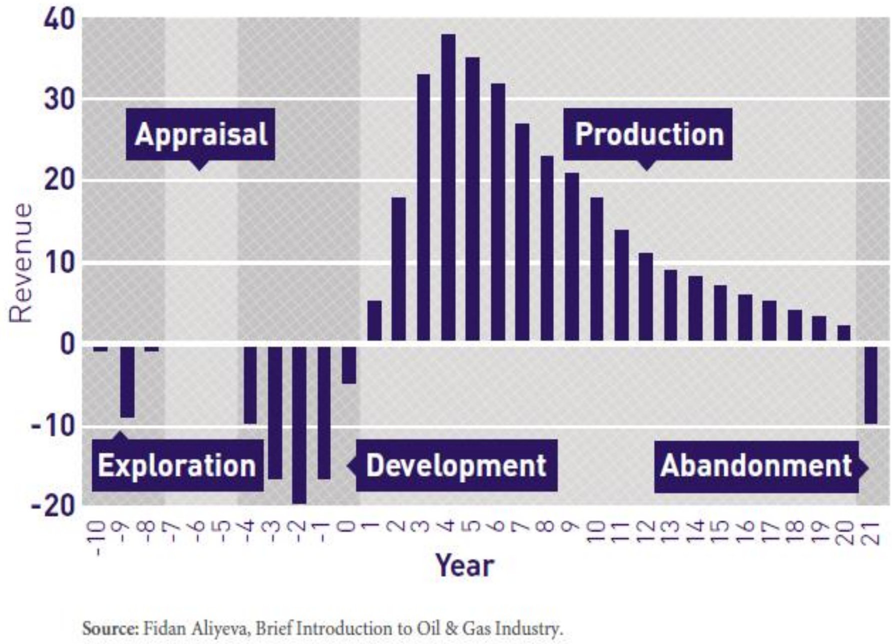
$$PV = \frac{C_t}{(1+r)^t}$$

where
t – the time of the cash inflow or outflow
r – the discount rate
$C_t$ – the value of cash inflow or cash outflow, at time t.

[7] Another important tool is internal rate of return (IRR) that can also be impacted by subsidies. IRR demonstrates how the project is expected to perform against such benchmarks as profitability of other projects and weighted average cost of capital attracted to develop the projects.

[8] It is noteworthy that on average coal projects are less capital extensive than oil and gas projects while they have higher operational costs, in particular for labor (though again a lot depends on each project in question).

***Figure 1. Schematic representation of a company's revenues from an oil and gas producing project over its lifecycle*** *(5 years for pre-production, 20 years for production, and 1 year for post-production)*




Source: as reproduced in (Chassin, 2014)

For pre-production, the discounted value of costs, which are overwhelmingly capital costs, – as well as subsidies that reduce them - is close to present value since they are not that far out in the future. In contrast, for the costs related to the production stage as well as related subsidies, the discounted value is significantly lower, since they are much farther out in the future. At the production stage most costs are normally opex. The costs and subsidies related to the decommissioning, or post-production stage, are capex, but their discounted value is the lowest since they occur at the end of the project's lifetime. For simplicity, it is possible to merge production and post-production costs based on their low net present value.

Using the PV formula[9] and the discount rate of 8%, the PV of any cost (regardless if it is capex or opex) during the pre-production phase of the project (the first five years) is 2.5 times higher than the PV of any cost during the production and decommissioning phase of the project (years six to twenty-six). If we use the discount rate of 10%, the difference becomes three times. These multipliers are listed in Table 2.

[9] See footnote 6.

**Table 2. Multipliers based on the average Present Value of subsidies reducing costs of fossil fuel extraction projects during the pre-production, production and post-production stages**

| Discount rate | Average PV of subsidies during pre-production stage (first five years of a project) | Average PV of subsidies during production and post-production stages (years six to twenty six of a project) |
|---|---|---|
| 8% | 1 | 2.5 |
| 10% | | 3 |

Source: Authors' presentation

In other words, based solely on the time value of money perspective of final investment decisions, $1 of subsidies to a fossil fuel project during its pre-production stage locks in as much investment in fossil fuel extraction as $2.5 - $3 of subsidies during the production and post-production stages. It is further possible to generalize that these multiplier of 2.5 and 3 apply mostly to such types of subsidies as capex since the costs and subsidies at the pre-production stage are overwhelmingly capex subsidies (e.g. exploration write-offs, accelerated depreciation allowance, deduction of capital expenses from taxable profits, etc.), which thus have the highest impact on lock-in of high carbon assets.

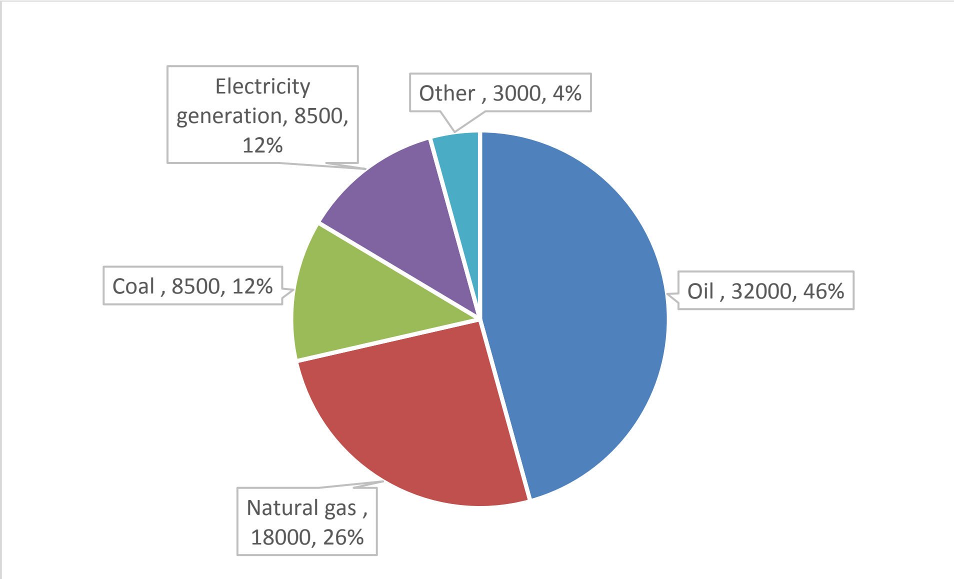
### *3.3. Disaggregation of cross-cutting subsidies*

In practice, many subsidies are cross-cutting:
- through fuels;
- through stages of project development;
- through both capex and opex costs.

A detailed knowledge of each subsidy is required to put it into one of the groups suggested above in order to classify its likely impacts on carbon lock-in. In some cases, attribution has to be based on assumptions. For example, for subsidies that apply to several types of fuels, attribution can be made based on each fuel's role in domestic primary energy production expressed in kilotonnes of oil equivalent.

Figure 2 presents results of the authors' disaggregation of the total of $70 billion reported as national subsidies to fossil fuel production in the G20 inventory (Bast, et al., 2015). $32 billion were for subsidies for oil, $18 billion – for gas, $8.5 billion for coal, and $8,5 billion for electricity. $3 more billion were subsidies to the fossil fuel sector, but not directly attributable to companies in the sense of carbon lock-in, given their social assistance nature (see point 2.4 above).

**Figure 2. Disaggregation of G20 fossil fuel production subsidies by fuel, million USD and shares on annual average basis in 2013-2014.**




Source: Author's calculations based on (Bast, et al., 2015)

Disaggregation of subsidies by stages of project development and their type – pre-production, production or post-production, opex or capex, short-term or long-term – is even more challenging. The G20 inventories by ODI and OCI made the first effort to single out exploration subsidies (Bast, et al., 2014) and to describe which subsidies are opex or capex (Bast, et al., 2015), but found out that many measures are mixed. For instance, such subsidy worth almost $4 billion a year as Corporate Tax Exemption for Master Limited Partnerships in the USA applies to all stages and types of activities by fossil fuel companies. Any hypotheses about disaggregating such subsidies can be subject to criticism, but for the proof of concept it is possible to assume that 50% of a mixed subsidy sends a long-term signal to investors and 50% is perceived as a short-term policy.

## 4. How do climate impacts of subsidies depend on specific fuels and projects?

The discussion above has been scoped around the difference in carbon lock-in implications of various subsidy designs at the providing end. Meanwhile, the differences in carbon lock-in will of course equally depend on the specifics at the subsidy receiving end – which fuel and which type of project are subsidized. This other group of factors is outside of the scope of this paper and the authors explore it in a separate forthcoming report that employs a systems analysis model of the world energy supply.

For the purposes of this document, two things are worth stressing in light of some frequently asked questions. In particular, it is common knowledge that fossil fuels have different carbon intensity of emissions from their combustion, with coal being the most carbon-intensive, followed by oil and then natural gas. However, this does not mean that in general subsidies to coal result in more carbon extraction than subsidies to oil, and subsidies to natural gas will have the least impact.

In reality, all depends on the percentage of extraction costs offset by subsidies, and physical characteristics of an extractive project. The importance of subsidies is higher for marginal production that would not be commercially viable without them. Since global reserves of relatively cheap coal are further from depletion than global reserves of affordable oil and gas, the cost curves for each fuel have different shapes, and the same $1 of subsidies will impact these curves in a different way. This discussion is further complicated by the need to make assumptions about which projects received subsidies – all projects, or only marginal ones (since the marginal nature of certain projects is often used as a basis for subsidy application).

## 5. The paradox of prioritization: why a partial phase-out of fossil fuel subsidies is not effective for climate action

Some subsidies appear to contribute to lock-in of high carbon assets more than others. However, this does not mean that reformers should focus just on them and classify other fossil fuel subsidies as more efficient and less harmful.

First, for both consumer subsidy reform as a demand-side mitigation policy and producer subsidy reform as a supply-side mitigation policy, there are concerns about leakage[10]. If subsidies are eliminated and carbon lock-in is avoided in one place, due to mobility of capital and opportunistic behavior of energy companies carbon lock-in can occur where subsidies have remained. The only way to avoid such leakage at all is to undertake the reform of all types of fossil fuel subsidies simultaneously in all countries of the world.

Second, capital in the sector is very mobile and highly concentrated within a few multinational companies that can recycle any type of subsidies that they receive. Some subsidies can appear less pernicious than the others, but their existence means subsidization of the fossil fuel sector as a whole. For instance, subsidies to natural gas can be presented as subsidies for a cleaner fuel. But in reality, oil and gas are often co-produced by the same companies, and a subsidy to natural gas means subsidization of oil as well. Another example is carbon capture and storage that despite the perceived climate benefits perpetuates the fossil fuel industry and has the opportunity cost of foregone investments into alternative energy.

Third, if certain subsidies are given green light, this creates a political opportunity for lobby groups to demand more and more subsidies to be seen as exceptions. Moreover, it is not uncommon for governments to replace one type of fossil fuel subsidy with another.

[10] Leakage is a concern for many policies that seek to mitigate climate change, including carbon pricing or introduction of stricter pollution standards. In particular, there have been long debates about leakage of emissions from the EU to other countries as a result of the Emissions Trading Scheme, which might have triggered some emissions-intense businesses to move their operations from the EU to countries with no carbon pricing. Leakage is hardly observable, but modellable.

It is therefore important for all government to eliminate all types of fossil fuel subsidies, but in a well-planned way that will protect the vulnerable by policies mitigating the possible negative effects of the reform.

## 6. Conclusions and recommendations for further research

This paper has laid out some of the principles based on which further research can evaluate the impacts of different fossil fuel subsidies on the lock-in of high-carbon assets. A forthcoming publication by the authors will complement this qualitative discussion with a quantitative assessment using a systems analysis model of the global energy system.

Subsidies that are most dangerous for the climate are those that lock-in investment into the extraction of fossil fuels on a long-term basis, in particular subsidies to exploration and field development such as write-offs of these expenses against taxable income. Based on the time value of money, $1 of subsidies that reduce expenditure at the pre-production stage of a project (for example, accelerated depreciation) can lock in three times as much investment into fossil fuels as $1 of subsidies that apply at production and post-production stages (for instance, royalty relief for extraction, subsidies to fossil fuel consumption, support to field decommissioning).

Meanwhile, much more research is needed to assess the impacts of subsidies to fossil fuel supply on the lock-in of high carbon assets and climate change in general. The angles that need to come under further research and discussion are:

- Better data and better disaggregation with respect to national subsidies to fossil fuel producers, ideally based on more comprehensive bottom-up inventories in key producing countries;
- More assessments of how subsidies to fossil fuel supply impact carbon lock-in on a project-, policy- and country- specific basis.
- Better understanding of possible assessment avenues with respect to wider effects of government support to fossil fuel production on investment decisions. Subsidies leverage private capital and it is quite likely that subsidy removal can trigger a certain amount of private divestment from fossil fuels. Divestment can have its own dynamics given investors' common "herd behavior" and a possible snowball effect;

Similarly to "shared, but differentiated" climate change responsibility, discussions around "unburnable carbon" and fossil fuel producer subsidy reform also raise a lot of questions about equity, since developing countries use subsidies to attract investment into fossil fuels often with the objective of using royalties and other revenues for projects to development. Assessments of supply-side mitigation options also plug into much broader conversations on the "green paradox", "resource curse", "Dutch disease", energy security and more policy debates on natural resource policies and management.

For policy-makers it is also always highly important to see how the benefits of fossil fuel subsidy reform compare with its impacts beyond the climate, in particular, impacts on public budgets, employment and the wider economy. Fossil fuel subsidy reform both upstream and downstream is an important enabling condition for the transition to green economy, but it is also necessary to understand how it relates to other enabling conditions and green economic policies on the demand-side (for instance, carbon pricing, fuel and energy efficiency standards) and supply-side (for example, full or partial phase-out of coal-fired electricity generation as recently implemented in Ontario and Germany, "no go" zones for oil extraction such as Lofoten Islands in Norway and Bristol Bay in the USA). The scope of analysis for selection of the most sustainable policies can become really broad, and the art of policy assessments is finding the right balance between the breadth and complexity of feedback loops, on the one hand, and policies within realistic reach of governments, on the other.

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