

Zombie Energy: Climate benefits of ending subsidies to fossil fuel production

WORKING PAPER



Ivetta Gerasimchuk
Andrea M. Bassi
Carlos Dominguez Ordonez
Alexander Doukas
Laura Merrill
Shelagh Whitley
February 2017



© 2017 The International Institute for Sustainable Development
Available under a Creative Commons Attribution-NonCommercial-NoDerivs
3.0 Unported (CC BY-NC-ND 3.0)

Published by the International Institute for Sustainable Development.

International Institute for Sustainable Development

The International Institute for Sustainable Development (IISD) is one of the world's leading centres of research and innovation. The Institute provides practical solutions to the growing challenges and opportunities of integrating environmental and social priorities with economic development. We report on international negotiations and share knowledge gained through collaborative projects, resulting in more rigorous research, stronger global networks, and better engagement among researchers, citizens, businesses and policy-makers.

IISD is registered as a charitable organization in Canada and has 501(c)(3) status in the United States. IISD receives core operating support from the Government of Canada, provided through the International Development Research Centre (IDRC) and from the Province of Manitoba. The Institute receives project funding from numerous governments inside and outside Canada, United Nations agencies, foundations, the private sector, and individuals.

About GSI

The IISD Global Subsidies Initiative (GSI) supports international processes, national governments and civil society organizations to align subsidies with sustainable development. GSI does this by promoting transparency on the nature and size of subsidies; evaluating the economic, social and environmental impacts of subsidies; and, where necessary, advising on how inefficient and wasteful subsidies can best be reformed. GSI is headquartered in Geneva, Switzerland, and works with partners located around the world. Its principal funders have included the governments of Denmark, Finland, New Zealand, Norway, Sweden, Switzerland and the United Kingdom, as well as the KR Foundation.

Overseas Development Institute

The Overseas Development Institute (ODI) is the UK's leading independent think tank on international development and humanitarian issues. Our mission is to inspire and inform policy and practice which lead to the reduction of poverty, the alleviation of suffering and the achievement of sustainable livelihoods in developing countries. We do this by locking together high quality applied research, practical policy advice, and policy-focused dissemination and debate. We work with partners in the public and private sectors, in both developing and developed countries.

Zombie Energy: Climate benefits of ending subsidies to fossil fuel production

February 2017

Ivetta Gerasimchuk, Andrea M. Bassi, Carlos Dominguez Ordonez,
Alexander Doukas, Laura Merrill and Shelagh Whitley

Head Office

111 Lombard Avenue, Suite 325
Winnipeg, Manitoba
Canada R3B 0T4

Tel: +1 (204) 958-7700

Website: www.iisd.org

Twitter: @IISD_news

GSI

International Environment House 2,
9 chemin de Balexert
1219 Châtelaine
Geneva, Switzerland

Tel: +1 (204) 958-7700

Website: www.iisd.org/gsi

Twitter: @globalsubsidies

ODI

Overseas Development Institute
203 Blackfriars Road
London SE1 8NJ

Tel: 44 (0) 207 922 0351

Website: www.odi.org

Twitter: @ODIdev



Table of Abbreviations

APEC	Asia-Pacific Economic Cooperation
ASCM	Agreement on Subsidies and Countervailing Measures
CGE	Computable General Equilibrium
DCF	Discounted cash flow
FID	Final investment decision
GHG	Greenhouse gases
GSI	Global Subsidies Initiative
IEA	International Energy Agency
IPCC	Intergovernmental Panel on Climate Change
IISD	International Institute for Sustainable Development
IRR	Internal rate of return
LNG	Liquefied natural gas
MW	Megawatts
NGO	Non-governmental organization
NPV	Net present value
OCI	Oil Change International
ODI	Overseas Development Institute
OECD	Organisation for Economic Co-operation and Development
OPEC	Organization of Petroleum Exporting Countries
PP	Payback period
PRB	Powder River Basin
PV	Present value
SEI	Stockholm Environment Institute
SOE	State-owned enterprise
URR	Ultimately recoverable resources
WACC	Weighted average cost of capital
WTO	World Trade Organization



Acknowledgements

The authors would like to thank the William and Flora Hewlett Foundation and the KR Foundation for their generous support of this research project and publication. The authors are grateful to the following peer reviewers for their invaluable feedback and suggestions on earlier drafts of this paper:

- Elisabeth Bast, Managing Director at Oil Change International (OCI)
- Han Chen, International Climate Advocate, Natural Resources Defense Council (NRDC)
- Peter Erickson, Senior Scientist, Stockholm Environment Institute
- Mark Fulton, Founder, Energy Transition Advisors Pty Ltd and Advisor to the Carbon Tracker Initiative
- Lucy Kitson, Research Officer – Economist at International Institute for Sustainable Development (IISD)
- Doug Koplow, Founder at Earth Track, Inc.
- Michael Lazarus, U.S. Centre Director and Co-leader, Initiative on Fossil Fuels and Climate Change, Stockholm Environment Institute
- Greg Muttitt, Senior Advisor at Oil Change International (OCI)
- Sam Pickard, PhD
- Ronald Steenblik, Senior Counsellor, Fossil-Fuel Subsidy Reform at the Organisation for Economic Co-operation and Development (OECD)
- Radoslaw Stefanski, PhD, Lecturer at the University of St. Andrews
- Christina Timiliotis, Junior Economist at the Organisation for Economic Co-operation and Development (OECD)
- Peter Wooders, Group Director, Energy, International Institute for Sustainable Development (IISD)
- Pål I. Davidsen, Professor of System Dynamics, University of Bergen, Norway

The opinions expressed and the arguments employed in this report do not necessarily reflect those of the funders and peer reviewers, nor should they be attributed to them.



About This Report

This report sheds light on the potential climate benefits of the removal of fossil fuel production subsidies in terms of both greenhouse gas (GHG) emission reductions and the oil, gas and coal reserves that could become uneconomical to produce. The paper explains how different production subsidies currently unlock “zombie energy” from fossil fuel deposits that would not be commercially viable to produce without government support. It also presents new modelling of the global removal of certain subsidies to fossil fuel production. In doing so, the report builds on the dataset from the previous Overseas Development Institute (ODI) and Oil Change International (OCI) report “Empty Promises: G20 Subsidies to Oil, Gas and Coal Production” (Bast, Doukas, Pickard, van der Burg, L., & Whitley, 2015) as well as research by the Global Subsidies Initiative (GSI) on both the scale and impacts of various fossil fuel subsidies.

The report is structured as follows:

- Chapter 1 explains why fossil fuel production subsidies matter for climate change. The chapter also defines and categorizes fossil fuel production subsidies.
- Chapter 2 outlines how different subsidies influence investment decisions related to fossil fuel production.
- Chapter 3 discusses modelling of a removal of fossil fuel production subsidies and inputs of the GSI-IF (p) global model.
- Chapter 4 presents results of new modelling that shows how much coal, oil and gas could become uneconomical to produce—and the GHG emission reductions that would result—if certain fossil fuel production subsidies are removed globally.

The report concludes with a summary of the findings as well as opportunities for further research on the climate benefits of fossil fuel subsidy removal.

Glossary

Carbon lock-in: Once certain carbon-intensive development pathways are chosen and capital-intensive investments are made, fossil fuel dependence and the carbon emissions that come with it can become “locked in,” making a transition to lower-carbon development pathways difficult and increasing the risk of exceeding climate limits (Erickson, 2015).

Fossil fuel production subsidies: For the purpose of this report, subsidies include direct spending and tax breaks to support fossil fuel production (see Chapter 1).

Fossil fuel production: Production of oil, natural gas, or of solid fuels (peat, lignite, sub-bituminous or brown coal, bituminous or black coal or anthracite). For the purposes of this report, this term includes such stages of fossil fuel project lifecycles as gaining access, exploration and appraisal, field development, extraction, transportation of fossil fuels, construction and operation of refineries, and decommissioning of fossil fuel facilities (see Figure 3).

Unburnable carbon: Fossil fuels that cannot be burned if global warming is to be kept below 2°C. According to the Intergovernmental Panel on Climate Change (IPCC) and the International Energy Agency (IEA), three quarters of existing proven fossil fuel reserves must be left in the ground to meet the internationally agreed goal of holding a global average temperature rise to no more than 2°C (IPCC, 2014).

Zombie energy: Fossil fuels that are only able to be produced as a result of subsidies. Their extraction would not be economically viable without government support. The term builds on the financial community’s conversations on zombie banks and zombie companies in many economic sectors, including energy (“What is a zombie bank?”, n.d.; Wildau, 2016).



Executive Summary

Ending subsidies to fossil fuel production is often a missing piece of comprehensive climate action plans. To implement the 2015 Paris Agreement and keep climate change well below 2°C, the world needs both supply-side policies (such as removal of fossil fuel production subsidies, moratoriums and “no-go zones” or coal phase-out) and demand-side policies (such as carbon pricing, removal of fossil fuel consumption subsidies, or fuel and energy efficiency standards).

This report is a first-of-its-kind attempt to shine a light on how global removal of subsidies to the production of coal, oil and gas (a key supply-side policy) could contribute to climate change mitigation and leaving unburnable carbon in the ground.

Our objective is to help close a significant gap in understanding the scale, scope and—in particular—the climate impact of current fossil fuel production subsidies and assist those concerned with the issue in three ways. First, the report brings together both quantitative and qualitative knowledge on fossil fuel production subsidies and highlights their negative implications for the climate. Second, as a proof of concept, it undertakes a thought experiment by modelling a global removal of fossil fuel production subsidies using the best available bottom-up data and a set of conservative assumptions. Third, it provides recommendations for further steps in overcoming data limitations and further research on the impact of removing fossil fuel subsidies.

What We Definitely Know About Fossil Fuel Production Subsidies

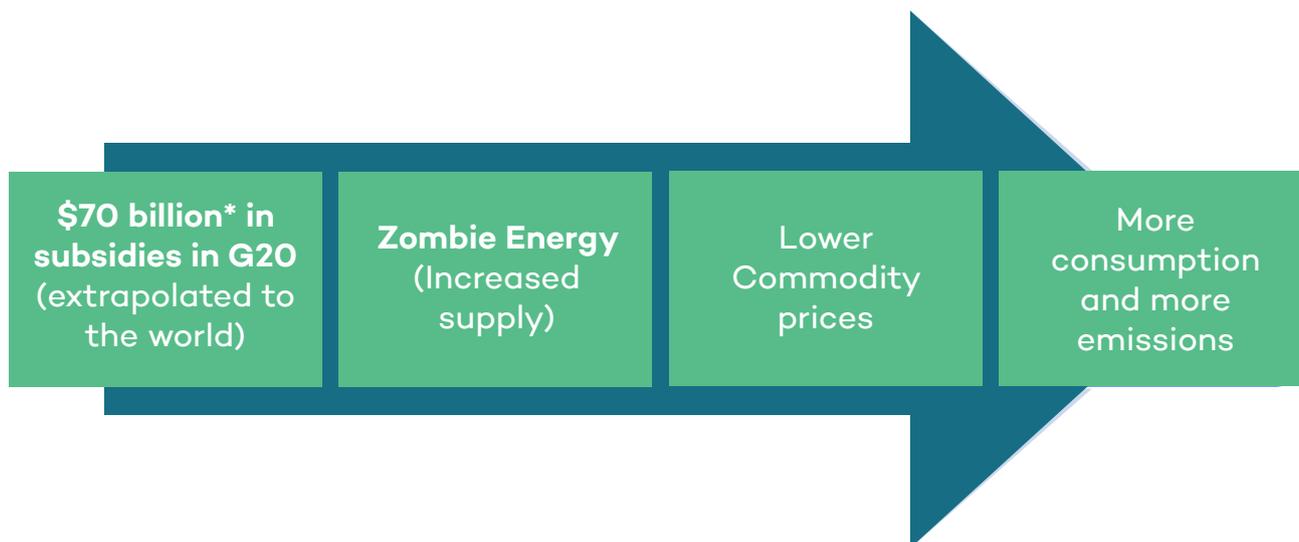
Fossil fuel production subsidies are significant. A recent estimate of direct spending and tax breaks to fossil fuel production in the G20 countries alone placed the figure at USD 70 billion per year on average in 2013 and 2014 (Bast et al., 2015).¹ Fossil fuel production subsidies are especially sizable in the countries that are major producers of oil, gas, and coal (in this report, we disregard production of fossil fuel-based electricity). These subsidies undermine climate action in three ways.

First, they create **zombie energy**, i.e., production from fields that would be economically unviable without government support. IPCC data show that, if we are to have a reasonable chance to keep climate change within 2°C, three quarters of proven reserves of coal, oil, and natural gas are unburnable and have to stay in the ground (IPCC, 2014a). The oil, gas, and coal in already-producing fields and mines are more than we can afford to burn while keeping likely warming below 2°C (Muttitt, 2016). Yet governments continue to spend billions of dollars developing additional fossil fuel supply that cannot be burned.

Second, production subsidies **skew energy markets**—they act as a negative carbon tax, artificially lowering the cost of producing more oil, coal and gas, that can be passed through in the form of lower market prices, encouraging more fossil fuel consumption and emissions (Figure ES1). These market distortions can in turn make investment in energy efficiency and clean alternatives seem less competitive. Government backing also acts as a confidence trick: without it, fossil fuel projects would be less attractive for private investment.

Third, government support to fossil fuel production **locks in fossil dependency** by giving strong signals to investment decision makers. It is especially critical to the success of major development and infrastructure projects that anchor the fossil fuel-based energy systems and are both capital-intensive and long-lived. Once investments are made, there is a strong incentive for producers to continue production to recoup them (Erickson, 2015). After capital costs are sunk, a field or a plant is likely to continue operating as long as the income from production covers the ongoing operating costs.

¹ In addition, G20 countries provided USD 286 billion in state-owned enterprise investment and USD 88 billion in public finance, but the concessional element of these is difficult to quantify due to lack of data.



* Incomplete, but best available dataset (Bast et al., 2015) for direct spending and tax breaks to fossil fuel production by G20 countries on annual average in 2013 and 2014, also excluding estimated:
 ✓ USD 286 billion in SOE investment ✓ USD 88 billion in public finance

Figure ES1. How fossil fuel production subsidies lead to more emissions (first-order impacts)

Source: Authors' diagram.

Potential Climate Benefits of a Global Production Subsidies Removal

To the best of the authors' knowledge, this study pioneers the analysis of both first- and second-order impacts of a removal of subsidies to fossil fuel production at the global level with the use of the System Dynamics approach and GSI-IF (p) model.

For this modelling, we use the best available data set on subsidies to the production of coal, oil and gas (covering the G20 countries)—including subsidies to refining, but excluding subsidies to the generation of fossil fuel-based electricity (Bast et al., 2015, drawing on OECD, 2015). On a per-unit-of-production basis, we extrapolated the G20 data to a global level. We also had to make conservative assumptions where empirical data were missing. The subsidy removal is modelled as instantaneous around the globe, and the modelling period is 2017–2050. We outlined the resulting impacts in terms of both emissions and reserves that would become uneconomical to produce.



Impacts of Removing Fossil Fuel Production Subsidies on GHG Emissions

Subsidy removal pulls a chain of first-order impacts: increases in production costs and decreases in fossil fuel supply relative to the baseline lead to increases in prices and hence lower consumption and lower emissions (Figure ES1). This, however, triggers a chain of second-order impacts whereby market forces push fossil fuel prices, supply and, ultimately consumption and emissions in the opposite direction (Figure ES2).

On balance, the pull factor from subsidy removal is stronger than the push back from market forces, because higher fossil fuel prices encourage more energy efficiency and substitution of fossil fuels with alternative energy, thus resulting in net emission reductions. Against the IEA Current Policies scenario,² a global removal of fossil fuel production subsidies results in estimated GHG emissions reduction of up to 37 Gt of CO₂ equivalent. This translates into up to 6 per cent of the reduction³ needed to reach the 2°C target with a 66 per cent chance of success, or 4 per cent of the reduction that we need to reach the 1.5°C target with a 50 per cent chance.

This cumulative reduction of up to 37 Gt of CO₂ over 2017–2050 averages at approximately 1.1 Gt of CO₂ per year, or 2 per cent relative to the Current Policies baseline in the period 2017–2050. This would be roughly equivalent to eliminating all emissions from the aviation sector.⁴

Importantly, the GHG emissions reductions relative to the baseline are highly sensitive to the price assumptions. In particular, if we only change one factor in the IEA Current Policies scenario,⁵ namely fix the fossil fuel prices at the level of 2015–2016 (approximately USD 50 per barrel for oil), the aggregate CO₂ emissions reduction would be as high as 175 Gt over 2017–2050. This is equivalent to 29 per cent of the reduction needed to reach the 2°C target with a 66 per cent chance of success, or 17 per cent of the reduction that we need to reach the 1.5°C target with a 50 per cent chance.

Thus, depending on fossil fuel prices, the GHG emission reductions from a removal of production subsidies can be anywhere between 37 and 175 Gt of CO₂, and—provided that demand for fossil fuels follows the baseline—the lower market prices for fossil fuels will be, the greater the climate benefits of a production subsidy removal.

² Our modelling uses the IEA Current Policies scenario as a baseline: this scenario assumes a price of up to USD 145 per barrel of oil by 2050 and takes the climate change to above 5°C in the longer term.

³ Under the IEA Current Policies scenario, the projected emissions over 2017–2050 will amount to 1,395 Gt. Compared with the carbon budgets presented in Table 1, this means an overshoot of 1,045 Gt over the target compatible with a 50 per cent chance of 1.5°C, and an overshoot of 595 Gt over the target compatible with a 66 per cent chance of 2°C.

⁴ According to business-as-usual projections, between 2016 and 2050 global aviation would generate an estimated 43 Gt of CO₂ emissions (Pardee, 2015).

⁵ See Footnote 2. This is a hypothetical scenario where we only fix fossil fuel prices at the 2015–2016 level, while demand for fossil fuels continues to grow and all other parameters and assumptions remain the same as in the IEA Current Policies scenario.

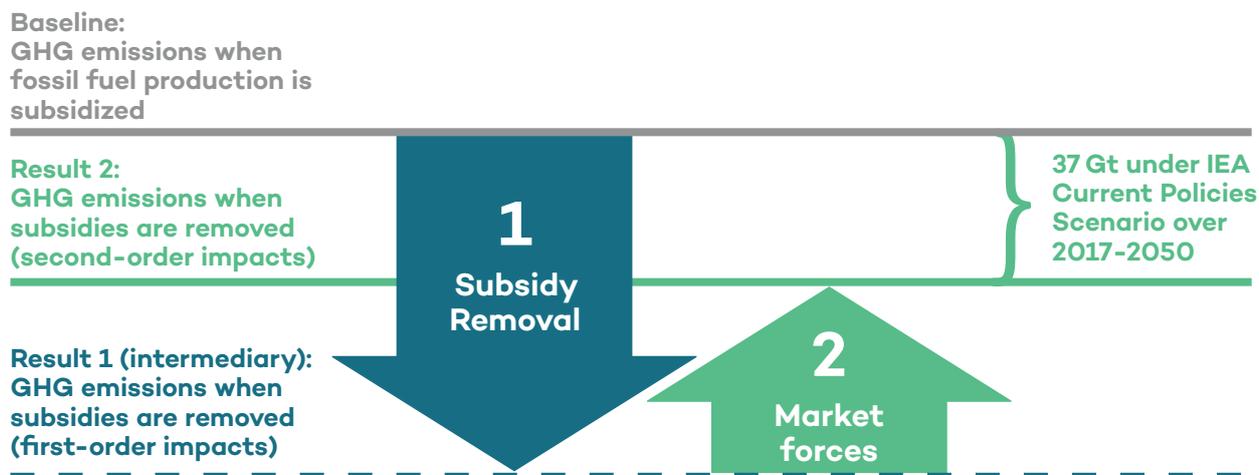


Figure ES2. Change in GHG emissions as a result of production subsidy removal: First- and second-order impacts

Source: Authors' diagram.

Impacts of Removing Fossil Fuel Production Subsidies on Economic Viability of Fossil Fuel Reserves

The reserves of fossil fuels that would be uneconomical to produce as a result of subsidy removal amount to 120–138 Gt of CO₂ over 2017–2050. This is equivalent to 13–15 per cent of all reserves in the existing and under-construction oil and gas fields, and coal mines in 2015 (942 Gt of CO₂; see Muttitt, 2016).

We note that these quantities are not necessarily permanently left in the ground. How much would be permanently left in the ground depends solely on demand response and would equal emission reductions from avoided consumption. In turn, demand response and emission reductions from avoided consumption are sensitive to price assumptions as described above. Other things equal, the lower the price of fossil fuels, the greater the impact of production subsidy removal in terms of carbon permanently left in the ground, and vice versa. In particular, in our modelling, the reserves that would become uneconomical to produce as a result of ending fossil fuel production subsidies could be potentially produced and consumed before 2050 if the prices go above the levels assumed in the IEA Current Policies scenario (USD 145 per barrel in 2050). Depending on the price scenario, these reserves could also still be available and could be exploited after 2050.

In this sense, the effect of production subsidy removal can be compared with a temporary moratorium on marginal fossil fuels. Meanwhile, we could reasonably expect that the quantity of fossil fuels produced would be much lower than today if the world successfully meets the Paris Agreement commitments. For example, the fossil fuels temporarily rendered uneconomical to produce might never become economical if production subsidy removal is coupled with the removal of consumption subsidies and other demand-side policies.



Next Steps: Further analysis of the impact of removing fossil fuel production subsidies

These findings are just the tip of the iceberg. A lack of transparency in government reporting, and even more hidden subsidies channelled through public loans, guarantees and state-owned enterprises obscure the full extent of government support to fossil fuels. In addition, due to a lack of data our analysis does not include subsidies to power generation. Governments should work together to establish a reporting system for all fossil fuel subsidies, starting by expanding the current OECD inventory to include all countries. This can also be expanded by peer reviews building on examples of the China and United States' voluntary peer review of fossil fuel subsidies published under G20 in 2016.

More research is necessary to fill in the gaps as well as to take the modelling to a new level, including through:

- Assessing climate benefits using baseline scenarios consistent with globally agreed climate action (instead of using the IEA Current Policies scenario) to illustrate the full potential of a given mitigation action such as fossil fuel subsidy removal.
- Developing and consolidating better data sets on national subsidies to fossil fuel producers, ideally based on more comprehensive bottom-up inventories in key producing countries, including those outside of G20, particularly for large producers including Iran, Iraq, Venezuela, Columbia and Norway.
- Developing and consolidating better data sets and understanding of the subsidy component (concessional elements) of public finance and state-owned enterprise investment that promote current and future production of fossil fuels.
- Improving understanding of the wider effects of government support to fossil fuel production on investment decisions. Subsidies leverage private capital both directly (in projects that receive subsidies) and more broadly in terms of risk perception, and a global subsidy phase-out might trigger a certain amount of wider private divestment from fossil fuels.
- Expanding the scope of modelling to include production subsidies through support to fossil fuel-based electricity generation—in G20 alone, at least USD 8.5 billion in annual subsidies went to fossil fuel-based power production in 2013–2014. These subsidies were only excluded from this analysis due to methodological limitations.
- Expanding the scope of modelling to include the removal of both consumption and production subsidies to fossil fuels and explore the potential of their partial reallocation to support renewable energy and energy efficiency.
- Continued assessments of subsidy removal on a project-, policy- and country-specific basis such as Erickson, Down, Lazarus, & Koplou (2017).



Similarly to “shared, but differentiated” climate change responsibility, discussions around keeping fossil fuels in the ground and ending production subsidies must take into account equity considerations (Kantha, 2016). This is because governments may use production subsidies to attract investment into fossil fuels, often with the objective of using royalties and other revenues for development. In addition, assessments of supply-side climate policy options including through ending subsidies, must learn lessons from broader conversations in the field of natural resource policies and management such as on the “green paradox,”⁶ “resource curse,” “Dutch disease” and many more.

It would be also important for policy-makers to see the modelling results for impacts beyond climate benefits, in particular, impacts on public budgets, employment and the wider economy. Fossil fuel subsidy phase-out (both upstream and downstream) is an important enabling condition for the transition to a green economy. However, it is important to understand how it relates to other enabling conditions and green economic policies on the demand side (for instance, carbon pricing, removal of fossil fuel consumption subsidies, or fuel and energy efficiency standards) and supply side (for example, phase-out of coal-fired electricity generation or moratoriums on new production) (Harris, Beck, & Gerasimchuk, 2015; Lazarus, Erickson, & Tempest, 2015). The scope of analysis for selection of the most sustainable policies can become very broad, and the art of policy assessments lies in 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.

The urgency to reduce emissions in order to comply with the Paris Agreement is huge. The removal of production subsidies would have a significant impact, but it is only one of a number of policies that need to be implemented, i.e., fossil fuel consumption subsidy reform, the phase-out of coal-fired power plants and support for technology innovation. Production subsidy removal is not in competition with these—it is an essential part of the necessary policy package.

⁶ The “green paradox” is the observation that policies aimed at curbing fossil fuel supply and demand can act like an announced expropriation for the owners of fossil fuel resources, encouraging them to accelerate resource extraction and hence to accelerate global warming (Sinn, 2008).



Table of Contents

Introduction	1
CHAPTER 1. What Are Subsidies to Fossil Fuel Production, and Why Do They Matter for the Climate?	3
1.1 Defining Subsidies.....	3
1.2 Defining Fossil Fuel Production	4
1.3 How Subsidies to Fossil Fuel Production Contribute to Climate Change.....	6
CHAPTER 2. Production Subsidies as a Key Driver of Investment in Fossil Fuel Supply	9
2.1 How Final Investment Decisions Are Made at the Project Level.....	9
2.2 How Final Investment Decisions Are Made Beyond the Project Level.....	13
2.3 Reading Signals of Production Subsidies	15
2.4 Which Subsidies Have Which Impacts on Carbon Lock-In?	18
CHAPTER 3. Modelling Removal of Fossil Fuel Production Subsidies	22
3.1 Algorithm for Modelling a Global Removal of Fossil Fuel Production Subsidies.....	23
3.2 Model Input: Characteristics of subsidies.....	25
3.3 Model Input: Characteristics of projects receiving subsidies	30
3.4 Model Input: All other factors	31
3.5 GSI-IF (p) Model	34
CHAPTER 4. Climate Benefits of Ending Fossil Fuel Production Subsidies:	
Findings from modelling	35
4.1 Results of GSI-IF(p) Simulations: Reserves that would become uneconomical to produce	35
4.2 Results of GSI-IF(p) Simulations: Emission reductions	38
Key Conclusions and Recommendations	41
Summary of Findings.....	41
Next Steps: Further analysis into the impact of removing fossil fuel production subsidies.....	43
References	46
ANNEX A. Existing Research on the Climate Impact of Removing Fossil Fuel Subsidies	56
ANNEX B. Approach and Findings From Modelling a Global Removal of Fossil Fuel Production Subsidies	61



List of Figures and Tables

Figure ES1. How fossil fuel production subsidies lead to more emissions (first-order impacts).....	v
Figure ES2. Change in GHG emissions as a result of production subsidy removal: First- and second-order impacts	vii
Figure 1. Stages of fossil fuel production.....	5
Table 1. The overshoot of fossil fuel reserves earmarked for extraction in comparison with global carbon budgets for a safe climate	7
Figure 2. Undiscounted and discounted cash flow of the same hypothetical oil and gas project over its lifecycle	11
Figure 3. Signals that subsidies give to investment decision makers.....	16
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.....	16
Figure 4. Undiscounted and discounted cash flow of the same hypothetical oil and gas project over its lifecycle, with and without subsidy.....	17
Table 3. Classification of subsidies based on the signal they send for lock-in of investment into fossil fuels: subsidies to capex, opex, consumption and other examples	20
Figure 5. Algorithm for modelling a global removal of fossil fuel production subsidies	24
Figure 6. Disaggregation of the USD 70 billion worth of G20 fossil fuel production subsidies by fuel, shares on annual average basis in 2013–2014	27
Table 4. Multipliers for capex subsidies and their equivalents of targeting subsidy at a portion of producing reserves if applied as model inputs: 2013–2014 data from the inventory by Bast et al. (2015)	29
Figure 7. Oil price in real terms under Current Policies scenario: Production subsidy removal and baseline.....	32
Figure 8. Schematic representation of the cost curve, indicating the impact of production subsidy removal.....	33
Table 5. Carbon equivalent of energy reserves that would be uneconomical to produce as a result of ending subsidies to fossil fuel production	36
Table 6. Oil and natural gas that would become uneconomical to produce as a result of production subsidy removal over 2017–2050	36
Table 7. Coal that would become uneconomical to produce as a result of production subsidy removal over 2017–2050	37
Table 8. Emissions from energy combustion avoided as a result of fossil fuel production subsidy removal over 2017–2050	39
Table A1. Emissions reductions scenarios from removal of fossil fuel consumption subsidies, existing research.....	57
Table A2. Emissions reductions scenarios from removal of fossil fuel production subsidies, existing research	59
Figure B1. Schematic representation of the cost curve, with an indication the impact of production subsidy removal.	64



Figure B2. Medium-term impact of subsidy removal on viable and unviable reserves, including demand effects	64
Figure B3. Share of oil production that is obtained from natural gas and gas-condensate fields, breakeven price range USD/boe 45-50 and total production.....	66
Figure B4. Cumulative resources and share of annual production, by breakeven price bracket (years 2000 and 2050)	67
Table B3. Subsidies to oil in select G20 countries, annual averages for 2013–2014.....	69
Table B4. Subsidies to natural gas in select G20 countries, annual averages for 2013–2014.....	70
Table B5. Subsidies to coal in select G20 countries, annual averages for 2013–2014.....	71
Figure B5. Share of production by breakeven price, 2000 and 2016.....	72
Figure B6. Long-term oil supply curve – combined global conventional and unconventional oil reserves and resources.....	75
Figure B7. Liquid fuel supply potential and production costs.....	75
Figure B8. Mapping cumulative production and annual breakeven price (2000–2050).....	76
Figure B9. Supply cost curves for oil, years 2000 and 2050.....	77
Figure B10. Mapping cumulative production and annual breakeven price (2000–2050).....	78
Figure B11. Supply cost curves for natural gas, years 2000 and 2050.....	79
Figure B12. Global coal supply cost curve (2007 and 2050), hard coal.....	80
Figure B13. Global coal supply cost curve (2007 and 2050), lignite/brown coal.....	80
Figure B14. Australia export thermal breakeven price (Sep. 2014), subsidy at USD 4 per tonne of coal	81
Figure B15. Powder River Basin (PRB) domestic thermal breakeven price (Sep. 2014), subsidy at USD 4 per tonne of coal	81
Figure B16. Causal Loop Diagram representing the main feedback loops influencing fossil fuel (oil) exploration, discovery and recovery.....	83
Figure B17. Oil supply module, main building blocks.....	84
Figure B18. Global emission reduction due to production subsidy removal, relative to the baseline scenario, 2015–2050	88
Figure B19. Oil prices, percent change relative to the baseline scenario, 2015–2050	89
Figure B20. Gas prices, percent change relative to the baseline scenario, 2015–2050.....	90
Figure B21. Coal prices, percent change relative to the baseline scenario, 2015 - 2050.....	90
Figure B22. Oil recoverable reserves, 2015–2050.....	91
Figure B23. Oil reserves that become uneconomical to produce, 2015–2050	92
Figure B24. Natural Gas recoverable reserves, 2015–2050	92
Figure B25. Natural Gas reserves that become uneconomical to produce, 2015–2050	93
Figure B26. Coal recoverable reserves (AUS scenario), 2015–2050.....	94
Figure B27. Coal recoverable reserves (PRB scenario), 2015–2050.....	94
Figure B28. Coal reserves that become uneconomical to produce (PRB scenario), 2015–2050.....	95



Introduction

The Paris Agreement has set an ambitious goal of striving to limit anthropogenic climate change to 1.5°C above pre-industrial levels, while firmly committing to limit temperature increase to well below 2°C (United Nations Framework Convention on Climate Change [UNFCCC], 2015). This creates a need for rapid climate change mitigation compared with what governments have committed to so far, since planned policies (under Nationally Determined Contributions) fall very far short of these goals (UNFCCC, 2015; United Nations Environment Programme [UNEP], 2015). IPCC data show that as of 2014 nearly three quarters of proven reserves of coal, oil, and natural gas are “unburnable” to maintain a reasonable chance of keeping warming below 2°C (IPCC, 2014). And recent research has found that the oil, gas, and coal in already-producing fields and mines are more than we can afford to burn while keeping likely warming below 2°C (see Muttitt, 2016 and Table 1).

This is a significant challenge. While climate policy discussions have historically focused on managing energy demand as a mitigation tool, there is only recently a growing awareness of the need to complement demand-side measures with supply-side policies—that is, climate policies focused on restraining fossil fuel supply (Lazarus, et al., 2015; Mendelevitch, 2015; Kretzmann, 2015) (See FAQ #2).

This disconnect between demand-side and supply-side climate policy conversations is worrisome. The entire carbon accounting system is skewed toward managing demand. While countries can get credit for restricting emissions from consumption of fossil fuels, they also can continue exporting fossil fuels to other markets, making their combustion a mitigation problem for other economies. In order to overcome this disconnect, policy-makers need to start thinking in terms of “unburnable carbon” and support the adoption of new accounting approaches that make it easier for countries to measure and be recognized for supply-side actions (Erickson & Lazarus, 2013).

Against this backdrop of lack of action in terms of supply-side climate policy, governments have continued to provide subsidies for fossil fuel exploration, production and consumption. This support has taken place despite previous commitments to phase out subsidies for fossil fuels, and in the face of mounting risks of carbon lock-in and stranded assets (Bast, et al., 2015). Moreover, this support has given an artificial life to fossil fuel production that would not be viable without subsidies. Using the financial community’s terminology, these subsidy-driven fossil fuel projects are zombies (see FAQ # 2).

As with most climate change policies, activities addressing fossil fuel subsidies have also focused on subsidies to consumption, rather than to the production of coal, oil and gas. The IEA estimates a 10 per cent reduction in energy sector emissions by 2030 from accelerating the partial phase-out of subsidies to fossil fuel consumption. Global estimates range from a 3 per cent emissions reduction by 2020 from removal of consumption subsidies, upwards to an 18 per cent reduction from the removal of subsidies and appropriate taxation of fossil fuels (see Annex A, Part I for a review of the existing literature).



FAQ #1. WHAT IS ZOMBIE ENERGY?

For the purposes of this report, the term “zombie energy” describes fossil fuels that are only able to be produced as a result of subsidies. Their extraction would not be economically viable without government support. The term builds on the financial community’s conversations on zombie banks and zombie companies in many economic sectors, including energy. While there is no unified definition of “zombie companies” or “zombie banks,” these terms are often used to describe operations that are not economically viable and would not continue without government support (“What is a zombie bank?”, n.d.) For example, in China inefficient state-owned companies and other “walking dead” businesses are seen to have been kept afloat largely through loans from government-controlled banks (Wildau, 2016).

FAQ #2. WHICH POLICIES ARE MORE EFFECTIVE: SUPPLY-SIDE OR DEMAND-SIDE?

It’s a false dilemma. We need both supply-side policies (such as removal of fossil fuel production subsidies, moratoria and “no-go zones” or coal phase-out) and demand-side policies (such as carbon pricing, removal of fossil fuel consumption subsidies, or fuel and energy efficiency standards). The climate challenge is so urgent, that we need all tools available. As with government attempts to fight other threats, such as illegal arms, action is required along the entire chain from production to consumption.

Since the inception of the international climate regime under the UNFCCC, policy-makers have focused mainly on demand-side policies, yet it has not been enough to divert the world from a trajectory toward dangerous climate change. The political economy is also very different for the two sets of policies: demand-side management often requires policies that need to be accepted by a large number of actors, while on the supply side there are fewer key players in each country. In this case, executive decisions like coal phase-out or “no-go zones” can sometimes be more acceptable. For an overview of the strengths and challenges of different supply-side policies, see Lazarus et al. (2015).

Combining supply-side climate policies—like the removal of subsidies to fossil fuel production—and demand-side climate policies that reduce consumption can be a more efficient and cost-effective way of getting to net zero emissions than using either approach in isolation. A 2013 analysis by Statistics Norway illustrates this point, indicating that, in Norway’s case, combining supply and demand-side climate policy could deliver global emissions reductions at one-third the cost of using demand-side measures alone (Fæhn Hagem, Lindholt, Mæland, & Rosendahl, 2013).

The expert and policy community has only recently started connecting the dots between fossil fuel production subsidies and climate change (see Annex A, Part I for a review of sources). Meanwhile, in their voluntary peer reviews released with the G20 process in September 2016, the world’s two largest emitters (the United States and China), listed several significant subsidies to fossil fuel production (G20, 2016a, 2016b). This is one of the first cases where governments officially put the removal of subsidies to fossil fuel supply on the table of required policy changes.

However, there is a significant gap in understanding the scale, scope, and in particular the climate impact of current fossil fuel production subsidies. This report seeks to close this gap in three ways. First, it brings together both quantitative and qualitative knowledge on fossil fuel production subsidies and highlights their negative implications for the climate. Second, as a proof of concept, it undertakes a thought experiment by modelling a global removal of fossil fuel production subsidies using the best available bottom-up data and a set of conservative assumptions. Third, it provides recommendations for further steps in overcoming data limitations and further research on the impact of removing fossil fuel subsidies.



CHAPTER 1. What Are Subsidies to Fossil Fuel Production, and Why Do They Matter for the Climate?

Fossil fuel subsidy removal can be described as a low-hanging, but prickly fruit with respect to climate change mitigation. Low-hanging, because ending fossil fuel subsidies saves both public money and brings immediate climate benefits through reduction of fossil fuel production and consumption. Yet it is also prickly because of its political economy challenges and barriers (see Whitley & van der Burg, 2015). This chapter defines and categorizes fossil fuel production subsidies. It also outlines their current role in driving dangerous climate change.

1.1 Defining Subsidies

Although governments have made high-level commitments in a number of international forums to “phasing out inefficient fossil fuel subsidies that encourage wasteful consumption” (including via the G7, G20,⁷ Asia-Pacific Economic Cooperation (APEC), United Nations Sustainable Development Goals, and the Addis Ababa Action Agenda [United Nations, 2015]), they have not set a definition for these subsidies. Individual countries and international organizations use different definitions—and include different types of subsidies—in their current estimates (International Institute for Sustainable Development [IISD], n.d.; Whitley & van der Burg, 2015). For example, “The UK defines fossil fuel subsidies as government action that lowers the pre-tax price to consumers to below international market level” (UK Department of Energy and Climate Change, 2015), a definition that at first sight excludes subsidies directed toward fossil fuel production. At the same time, the voluntary peer reviews of fossil fuel subsidies that the United States and China released under China’s G20 presidency in 2016 have focused primarily on production subsidies (G20, 2016a, 2016b).

Nonetheless, though not all-encompassing, there is an internationally agreed definition of subsidies. In its Agreement on Subsidies and Countervailing Measures (ASCM), the World Trade Organization (WTO) defines a subsidy as follows (WTO, 1994):

“a financial contribution by a government or any public body within the territory of a Member [...] where:

- (i) a government practice involves a direct transfer of funds (e.g., grants, loans, and equity infusion), potential direct transfers of funds or liabilities (e.g., loan guarantees);
- (ii) government revenue that is otherwise due is foregone or not collected (e.g., fiscal incentives such as tax credits);
- (iii) a government provides goods or services other than general infrastructure, or purchases goods;
- (iv) a government makes payments to a funding mechanism, or entrusts or directs a private body to carry out one or more of the type of functions illustrated in (i) to (iii) above which would normally be vested in the government and the practice, in no real sense, differs from practices normally followed by governments;”

This definition of subsidy has been accepted by the 164 member states of the WTO, and we have used this in our analysis as a basis for identifying subsidies to the production of coal, oil and gas.

⁷ The G20 have committed every year since 2009 to phase out “inefficient fossil fuel subsidies that encourage wasteful consumption,” but its member countries have taken only limited action to address them. Ahead of the G20 leaders’ summit in Hangzhou in September 2016, more than 200 NGOs from 45 countries and a group of insurers with USD 1.2 trillion under management urged G20 leaders to phase out subsidies for fossil fuels by 2020 (Lewis, 2016; “Insurers call on G20,” 2016).



FAQ #3. WHAT IS THE DIFFERENCE BETWEEN SUBSIDIES AND INCENTIVES?

Subsidies and incentives are the same policies, only viewed from different perspectives. “Subsidy” is a legal term, though it can be defined differently in different documents. “Incentive” is a term often used by companies arguing that governments need to introduce or maintain subsidies to promote their business, especially in high-cost environments. Subsidies to fossil fuels are often justified through arguments that date back to the thinking about natural resource rents and costs of the 18th and 19th century economists Adam Smith and David Ricardo. At that time there was no knowledge of climate change and no comprehensive understanding of the full range of not only financial, but also social costs and benefits of different economic activities.

Reflecting the categories under the WTO definition of subsidies, this report focuses on a widely recognized subset of fossil fuel production subsidies—direct spending by government agencies and tax breaks to companies—and reviews where they directly benefit fossil fuel production. Fossil fuel production is also subsidized through investment by state-owned enterprise (SOEs) both domestically and internationally and through “public finance” including support from domestic, bilateral and multilateral international agencies through the provision of grants, loans, equity infusions and guarantees (Bast, et al., 2015). While both of these are very significant sources of public support for fossil fuel production—totalling hundreds of billions of dollars in gross flows annually—neither public finance nor SOE investment are included in this report’s analysis, since understanding the share of these that constitutes a subsidy (including comparisons with other market participants and market values) requires information that is not publicly available.

Both limited transparency and the difficulty in accessing comparable information creates significant barriers to a comprehensive estimate of fossil fuel production subsidies (see Section 3.3 and Box 3).

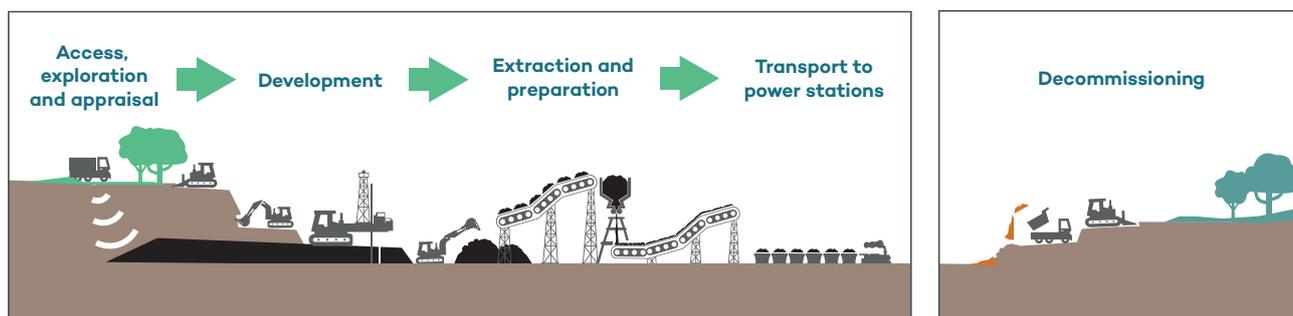
1.2 Defining Fossil Fuel Production

This report reviews fossil fuel production subsidies, as these have a significant climate impact through their role in “locking in” high-carbon energy systems and unlocking unburnable carbon (see Chapters 2 and 3). For the purpose of this report:

- Fossil fuels are defined as oil, natural gas, or solid fuels (peat, lignite, sub-bituminous or brown coal, bituminous or black coal or anthracite).
- Production of fossil fuels includes the following stages: gaining access to extraction sites, their exploration and appraisal, development, extraction and preparation of fossil fuels, transport (to utilities and refineries), construction and operation of refineries, distribution of fuel products as well as decommissioning and other post-operations costs (see Figure 1). Each stage of fossil fuel production involves a wide range of government support measures provided through direct spending and tax breaks (see Table 2 in Chapter 2).



Coal



Oil and gas

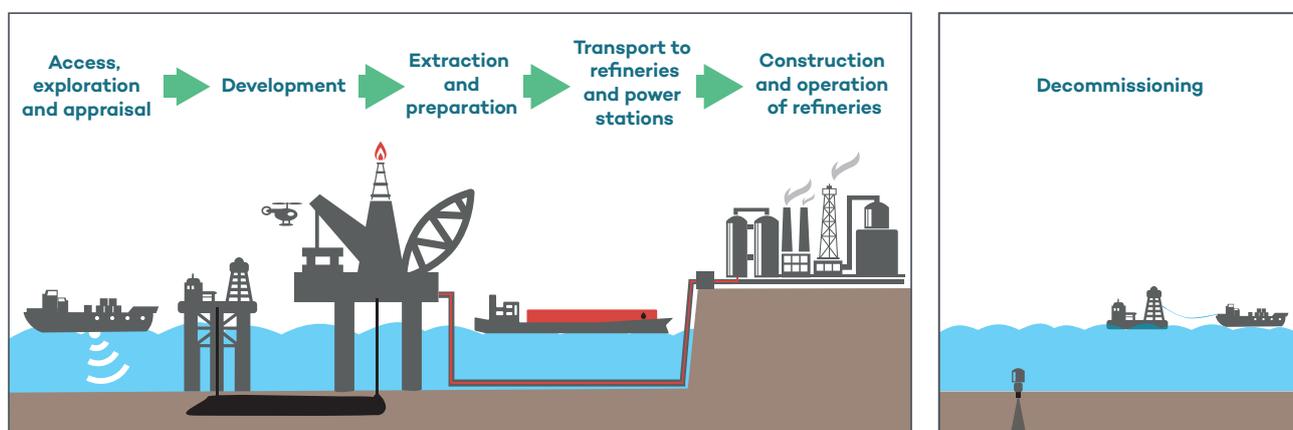


Figure 1. Stages of fossil fuel production

Source: Adapted from Bast, et al., 2015.

Although subsidies to generation of electricity based on fossil fuels and the consumption of oil, gas and coal also support their production both directly and indirectly (see Bast et al. for further discussion), this report is focused on production of oil, gas and coal, as there is a particular lack of transparency around supply-side subsidies. Therefore, this report specifically excludes support to consumption of fossil fuels as well as generation⁸ and consumption of fossil fuel-based electricity. For more information on subsidies to fossil fuel consumption, see the IEA price gap subsidy calculations (IEA, 2015b) and extensive research by the Global Subsidies Initiative as presented in Annex A, Part I.

⁸ Unlike refineries, which are often owned by the oil and gas companies, power plants belong to a different group of subsidy recipients: the government support that they receive is less likely to be reinvested into extraction.



1.3 How Subsidies to Fossil Fuel Production Contribute to Climate Change

To meet the aims of the Paris Agreement described above, the world will have to transition within the next few decades to energy systems that emit virtually no greenhouse gases (Schaeffer et al., 2015; Muttitt, 2016). This will require significant investment, yet governments are making these changes more difficult by providing support to existing greenhouse gas-intensive energy systems.

The imperative of aligning current energy decision making (including in the case of fossil fuel subsidies) with internationally agreed climate goals has given rise to the concept of the “climate test.” Simply put, a climate test is the idea that energy policy must align with climate science (Climate Test, 2016). A climate test, as proposed by several civil society organizations, would “use the latest climate science to evaluate all proposed energy supply and demand policies and projects in light of the globally agreed goal of limiting global warming to 1.5°C” (Climate Test, 2016). Such a test could potentially be used to assess whether a particular fossil fuel subsidy is compatible with a 1.5°C or 2°C emissions pathway. Fossil fuel production subsidies do not pass the climate test, since they seek to increase supply beyond the remaining carbon budget.

In recognition of the major shifts in investment required to meet international climate goals, one of the Paris Agreement’s three objectives is “[m]aking finance flows consistent with a pathway toward low greenhouse gas emissions and climate-resilient development”—yet governments continue to support fossil fuel production by the hundreds of billions of dollars per year. G20 governments alone support fossil fuel production with at least USD 444 billion annually, including direct subsidies from governments to fossil fuel companies, as well as through state-owned enterprise investment, and concessional public finance (Bast, et al., 2015). Government support flowing to fossil fuel production undermines climate action in three ways:

- Fossil fuel subsidies function as a negative price on carbon emissions, encouraging higher levels of fossil fuel production and consumption.
- Carbon lock-in—aided by subsidies—makes the transition to clean energy more difficult and costly.
- They subsidize unburnable carbon and enabling production of zombie energy.

1.3.1 Fossil Fuel Subsidies as a Negative Carbon Price

Subsidies to both production and consumption of fossil fuels effectively act as a negative price on carbon emissions (IEA, 2015b), encouraging inefficiently high levels of investment in fossil fuel production, and correspondingly, inefficiently high levels of their extraction. The increased level of oil, gas and coal production supported by subsidies undermines the competitiveness and attractiveness to investors of renewable energy and energy efficiency alternatives, inducing demand for fossil fuels through artificially low prices to end users.

The Global Carbon Pricing Leadership Coalition, made up of 74 countries and more than 1,000 companies, emerged at the UN climate negotiations in Paris in December 2015, advocating carbon pricing policies to “to redirect investment commensurate with the scale of the climate challenge” (Carbon Pricing Leadership Coalition, 2016). Yet many of the government and institutional members of this partnership still have a negative carbon price on the books, in the form of support to fossil fuel production and consumption, through subsidies and public finance, further tipping the scales in favour of the energy sources driving climate change. Many of these same institutions are also signatories to the Friends of Fossil Fuel Subsidy Reform Communique, which further highlights the disconnect between continued support for fossil fuel subsidies while advocating for stronger carbon price signals.



1.3.2 Carbon Lock-in

Another problem with government support for fossil fuel production is that it can make shifting away from a carbon-intensive energy system more difficult and much more expensive. If energy investments continue to favour emissions-intensive infrastructure to 2020, shifting to a low-carbon energy system will cost four times as much through 2035 as it otherwise would, making the political economy of a clean energy transition more difficult (Erickson, 2015; IEA, 2013). As investment flows into the capital-intensive and long-lived infrastructure that characterizes carbon-intensive energy systems, fossil fuel dependence and the carbon emissions that come with it becomes “locked in,” increasing the risk of exceeding climate limits (Erickson, 2015). Subsidies and other government support are often particularly important for the very large, long-lived projects that anchor the fossil fuel system and which increase the risk of lock-in the most.

Once capital-intensive investments are made, there is a strong incentive for producers to continue production to recoup investment costs, since once capital costs are sunk, a field or a plant is likely to continue operating as long as the income from production covers the ongoing operating costs. Policies that help to avoid these investments in the first place will be important to maintain a chance of transforming energy systems in a way that is consistent with internationally agreed climate goals.

1.3.3 Unburnable Carbon and Zombie Energy

According to the IPCC, as of 2014 at least three quarters of existing reserves of oil, gas and coal are unburnable—they must stay in the ground in order for there to be a two-in-three chance of remaining below the 2°C climate change threshold (IPCC, 2014). When considering a 1.5°C warming limit—a limit that world leaders agreed to strive to avoid in the Paris Agreement—even more fossil fuels will have to remain unburned.

Governments and companies continue to pour hundreds of billions of dollars into efforts to discover and develop new reserves and fossil fuel-producing infrastructure. Table 1 provides a comparison of budgets of emissions that can still be compatible with safe climate targets, on the one hand, and fossil fuel reserves already “with steel and cement” in the ground.

Table 1. The overshoot of fossil fuel reserves earmarked for extraction in comparison with global carbon budgets for a safe climate

CO ₂ equivalent of reserves in the existing and under-construction oil and gas fields, and coal mines in 2015	942 Gt
Global carbon budgets for likely (66%) chance of 2°C	800 Gt*
Global carbon budgets for medium (50%) chance of 1.5°C	350 Gt*

Sources: Based on Mutitt, 2016; IPCC 2014b, Le Quéré et al., 2015.

* IPCC estimated post-2011 budgets for 66 per cent chance of 2°C and 50 per cent chance of 1.5°C at 1,000 Gt and 550 Gt respectively. Post-2016 budgets are net of roughly 200 Gt emissions during 2012–2016 (roughly 40 Gt per year reported for 2012–2014 and projected for 2015–2016).



Against this background, government support for fossil fuel production also increases the risk of asset stranding. As defined by the Carbon Tracker Initiative, stranded assets in the context of fossil fuels are fuel energy and generation resources that, as a result of regulatory changes linked to the transition to a low-carbon economy, at some time prior to the end of their economic life are no longer able to earn an economic return (Carbon Tracker Initiative, 2016).

Moreover, this support has given an artificial life to fossil fuel production that would not be viable without subsidies. Using the financial community's terminology, these subsidy-driven extraction projects are zombies.

The ways in which production subsidies influence investment decisions and unlock zombie energy are explored in more detail in Chapters 2 and 3.



CHAPTER 2. Production Subsidies as a Key Driver of Investment in Fossil Fuel Supply

This chapter provides the basis for several assumptions in the modelling we describe in Chapter 3. In particular, it seeks to answer the questions asked by both experts and policy-makers: what is the impact of subsidies in terms of locking in carbon and unlocking fossil fuel supply? We further analyze if these are the same subsidies that should be removed first under the commitment of G20 and APEC leaders to “phase out inefficient fossil fuel subsidies that encourage wasteful consumption.” (G20, 2009; APEC, 2009).

In essence, it is the impact that subsidies to fossil fuel production have on a given company’s final investment decisions (FIDs) that unlock zombie energy and lock in high-carbon assets. Therefore, this chapter reviews the FID logic at the project, company and industry levels.

2.1 How Final Investment Decisions Are Made at the Project Level

There are many factors shaping investment decision making for exploration and production projects, including market prices, geological characteristics, political risks and fiscal treatment. Given the detailed information required to evaluate different investment options, fossil fuel companies usually rely on proprietary technical models that allow for numerous assumptions and types of analysis at a field or multi-field level—the type of models that academia or nongovernmental organizations (NGOs) rarely have access to and can reproduce.

At the same time, even with rigorous use of decision-support tools, companies’ evaluations often prove wrong. A recent study reviewing performance of 365 oil and gas megaprojects across the world found that 64 per cent of these face cost overruns, and 73 per cent report schedule delays (Ernst & Young, 2014). This example also illustrates how difficult it is to assess factors driving fossil fuel supply given the high degree of uncertainty in the industry.

Prior to making an investment decision, companies look at the expected cash flow, which changes throughout the project lifetime. A typical fossil fuel project incurs costs during the exploration, appraisal and development years. Expectations on cost recovery and profits are left to the production phase, where companies try to maximize the value of the extracted resource. A final cash outflow is required in the decommissioning stage, where costs are incurred to dismantle equipment and remediate the project site, including any environmental damage.

Figure 2 presents cash flow for a typical oil and gas extraction project. 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 fossil fuels (Chassin, 2014; Shafiee, Nehring, & Topal, 2009).⁹ It is assumed that it takes five years to develop the project, which then produces fuel for 20 years, and the final year is for the site abandonment process (decommissioning). In total, the project lifecycle in this case is 26 years, though in reality lifecycles for projects can be shorter or longer.

⁹ It is noteworthy that, on average, coal projects are less capital-intensive than oil and gas projects while they have higher operational costs, particularly for labour (though again a lot depends on each project in question).



In Figure 2, cash flow is presented first in undiscounted terms and then in discounted terms. Discounting of a nominal value of cash inflow or outflow in the future to its present value reflects the time value of money, in other words, 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 per cent and 12 per cent in real terms (Kasriel & Wood, 2013). One hurdle rate (i.e., the minimum rate of return on a project or investment required by a manager or investor) widely cited in the extractive industry analysis is 10 per cent¹⁰ (Lunden & Fjaertoft, 2014; Arora, 2012). In reality, discount rates also depend on the project and country in question and can be higher or lower accordingly. Sometimes a lower discount rate of 8 per cent can be used for de-risked or longer-term projects. Overall, discount rates of 10 per cent and 8 per cent seem to be the most conservative for analyzing fossil fuel projects and the impact of subsidies on their cash flow.

To analyze subsidy impacts on final investment decisions, it is most logical to follow the industry's own preferred approach and use the main tool in a project evaluation toolkit: discounted cash flow (DCF) analysis at the project level (see Box 1).

For example, using the DCF analysis, a study by the Global Subsidies Initiative assessed the economic viability of Yamal LNG and Prirazlomnoe, two large-scale extractive projects in the Russian Arctic,¹¹ with and without subsidies (Lunden & Fjaertoft, 2014). Production from Prirazlomnoe is economically viable even without subsidies. Yamal LNG, however, is not feasible without government support (for a list of other studies analyzing fossil fuel subsidy impact on fossil fuel supply see Annex A, part II). Focusing on the role of subsidies in DCF can help consolidate important arguments that can ultimately lead to shelving of certain projects aimed at new fossil fuel extraction (see Box 2).

¹⁰ Rystad, the widely used oil and gas industry database, applies a discount rate of 10 per cent in nominal terms, which translates in 8 per cent in real terms.

¹¹ Prirazlomnoe started producing oil in 2014. As of January 2017, Yamal LNG was at the construction stage.

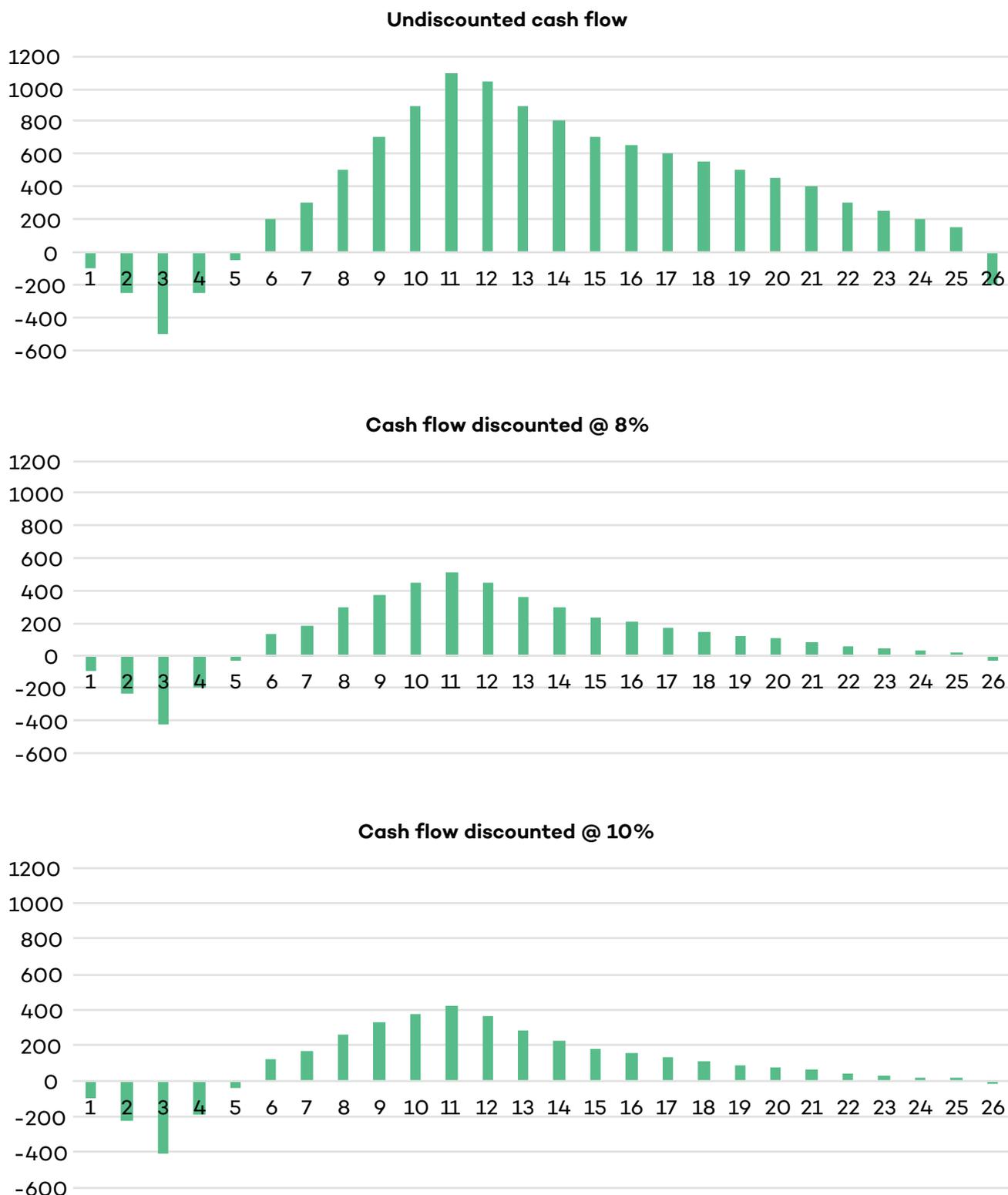


Figure 2. Undiscounted and discounted cash flow of the same hypothetical oil and gas project over its lifecycle (five years for project development, 20 years of production and one year for decommissioning)



BOX 1. INVESTOR TOOLS FOR DECISION MAKING AT A PROJECT LEVEL

Adding up Present Values of cash inflows and outflows¹² over an extractive project's lifecycle allows companies to calculate the entire project's net present value (NPV),¹³ which is one of the key tools in making final investment decisions. Another important tool is internal rate of return (IRR), which is the rate that makes the project's NPV equal to zero. IRR demonstrates how the project is expected to perform against such benchmarks as profitability of other projects and weighted average cost of capital (WACC) attracted to develop the projects.

If discounted cash flow (DCF) analysis produces a positive NPV and its IRR is higher than WACC on the market, there is a good case for investment. If NPV is negative, or if NPV is positive but IRR is lower than WACC, then investment does not make economic sense. However, often they are subsidies that tip NPV and IRR values over the decisive benchmark.

An extension of calculating NPV is calculating a project's breakeven price. Breakeven price of the project's product (oil, gas or coal) is the price that—considering all future cash flows (i.e., costs, revenues, government take)—is needed to deliver an NPV of zero assuming a given discount rate (Lewis, Robins, & Cleveland, 2015).

Alongside the DCF model, sensitivity and simulation analyses are often used to measure the impact of different scenarios on investment performance. For example, companies try to test whether an investment remains profitable if future fossil fuel prices or production volumes are lower than expected once extraction commences. Other assumptions to examine under this analysis include analysis of geological and political risks, as well as the risk of unexpected changes in such things as the fiscal regime, inflation and exchange rates.

Some investors may be interested in using not only profitability measures such as the NPV and IRR, but also to know how long it takes for the project to generate enough income to recover their initial investment. An adequate technique to address this question is the payback period (PP); a measure that ignores the time value of money. As a rule of thumb, the shorter the PP the better the investment opportunity. Historical evidence shows that the average payback period for projects in the oil and gas industry is usually five years or greater (Johnston, 2003).

¹² Cash flow refers to the total amount of cash given or received by a business at a particular point of time. If a cash flow is positive, it is called cash *inflow*; conversely, an amount transferred out of the business is called a cash *outflow*.

¹³ 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.



BOX 2. USING SUBSIDY ANALYSIS AT THE PROJECT LEVEL TO ADVOCATE THE SHELIVING OF NEW FOSSIL FUEL PRODUCTION

Because tax breaks and other subsidies for fossil fuel production drain government budgets, their analysis can be an important tool for advocates of leaving fossil fuels in the ground. Subsidies not introduced, and fossil fuel extraction projects not going ahead are important, though sometimes “invisible” wins for supply-side mitigation.

In recent years, several such wins were attained in the Arctic. One is the shelving of the giant Shtokman development in the Russian section of the Barents Sea. From mid-2000s, the Russian government, with Gazprom as the main investor, and several international oil and gas companies held active negotiations about the project’s implementation and certain tax breaks were introduced to make it more economically viable. Finally, the consortium of Gazprom, Statoil and Total asked for even more tax breaks, including the exemption from the 30 per cent export tax on natural gas. The Russian Ministry of Finance questioned the consortium’s arguments, including the calculations used to justify the subsidy request (“Shtokman Tax Break,” 2011; “No Tax Breaks,” 2012). As a result, the project was shelved indefinitely in 2012, even before world commodity prices started plummeting (Oliphant , 2012).

Another example is the Mackenzie Valley natural gas development in the Northwest Territories, Canada. Imperial Oil was demanding additional tax breaks to develop this CAD 7.5 billion project. Alternatives North, a civil society group, commissioned an independent report looking at the economics of the project that showed that the investment was viable without subsidies. Based on this report submitted to the Joint Review Panel and other evidence, the subsidy was not granted, which further delayed the development (Alternatives North, 2006; Park, 2007). As of October 2016, the project development plans were delayed until an uncertain date in view of low market prices for natural gas (“Deadline to Start Building,” 2016).

2.2 How Final Investment Decisions Are Made Beyond the Project Level

Both large fossil fuel companies and the industry as a whole make investment choices not just on a project-level basis, but also based on strategic considerations. The latter include risk diversification and opportunities to get a first-mover advantage with a new market, new technology, or new cluster of fields (Jahn et al., [Eds.], 2008). Strategic considerations also include optimization of costs across the entire value chain, from extraction to transportation and refining, from upstream to midstream and downstream, and also across jurisdictions (sometimes with the objective of benefiting from transfer pricing and tax havens). Further, companies often take certain investment decisions to build relationships with governments. In this respect, such relationships can be blurred when analysis extends to investment decisions by state-owned enterprises. In this case, the number of factors influencing companies’ investment decisions expands to include energy security, industry privatization or nationalization plans, social obligations and many more.

That is why some decisions that do not appear to make economic sense at a project level may still be taken at a corporate or industry level. One example is Shell spending USD 7 billion on exploration offshore of Alaska before taking the decision to withdraw from the region in 2015 in view of too little oil found (“Shell Abandons,” 2015).



In the fiscal dimension, at a corporate or industry level decision makers do not just think in terms of individual taxes or subsidies. Instead, they think in terms of “government take,” defined as the total amount of revenue that a host government receives from production, including taxes, royalties and government participation (Schlumberger Limited, n.d.). The corporate cash flow is thus determined by cash flows from all individual projects net of the government take.

Subsidies play a big role in such strategic decision making—and in bargaining between governments and companies (see Box 3). For example, a company can successfully lobby for reduced royalties (a form of subsidy) for one type of project and concede to a higher fee for a government-owned pipeline, using the latter as a bargaining chip. Or a government can require a company to invest in infrastructure or sell fossil fuels at a regulated price and compensate it with a large subsidized loan from government-owned banks (another form of subsidy) or a licence for a lucrative new development.

Further, most of the subsidies can be recycled within corporate finance, and subsidies received in one form or one jurisdiction, by increasing corporate profits and revenues, can be de facto reinvested to support other activities, ultimately unlocking more carbon. Subsidies to oil, gas and refining are particularly fungible along the entire value chain, since these production processes are often within the same companies.

It can be difficult to quantify subsidy impact on decision making at a corporate and industry level. But it should be noted that subsidies have ramifications for fossil fuel supply beyond the level of individual projects.

BOX 3. OIL AND GAS INDUSTRY’S REQUESTS FOR EVEN MORE SUBSIDIES: A RACE TO THE BOTTOM

As noted in Section 2.2, the relationship between governments and fossil fuel companies involves a lot of bargaining and negotiation. In the course of such bargaining, there is often a race to the bottom, where governments of one jurisdiction grant subsidies to fossil fuel companies in order to attract their investment and outcompete neighbouring jurisdictions that may also be negotiating government support for the same businesses.

Examples are numerous, especially in the 2014–2016 period of low oil prices. For instance, even before the decline in oil prices, in April 2013, the Alaskan government implemented a reform to the oil and gas tax regime to respond to both decreasing oil production and pressures from producers like ConocoPhillips, Exxon Mobil and BP. Fossil fuel companies went from having a 25 per cent base tax on profits increasing according to oil prices, to a 35 per cent flat rate that is deductible based on a series of incentives (Krauss, 2013). The reform prompted some new investments, including by ConocoPhillips at the Alpine Field in Alaska. As the biggest oil producer in the region, ConocoPhillips increased its capital expenditure budget more than 50 per cent for fiscal year 2014 to a total of USD 1.7 billion (Turcan, 2014). At the same time, Alaskan budget revenues from oil and gas have crashed, due to both the favourable tax regime and the low oil price. Given that the state is considering covering its persistent budget deficit by raising taxes on citizens, the rationale for tax breaks benefiting the oil and gas industry has become a heated political topic in Alaska (Doukas, 2015).

Another example is the United Kingdom, which in 2015 introduced a package of tax breaks for the oil and gas industry to stimulate declining production in the North Sea. Following that, according to the results of the 2015–16 fiscal year, U.K. oil and gas production not only did not bring any tax revenue, but generated a net cost of GBP 24 million to the government (“North Sea Receipts,” 2016). At the same time, in 2016 the U.K. oil and gas industry kept pushing the government for even more tax breaks (“North Sea Oil Industry,” 2016)



In addition to subsidy impacts at project and corporate level, there is a macroeconomic level as well, since subsidies to one industry represent an opportunity cost of not being used to support other industries or public goods such as education and health. The significant government support that fossil fuel production and consumption receive distorts the level playing field for renewable energy and energy efficiency measures.

2.3 Reading Signals of Production Subsidies

As noted in Section 2.1, many stakeholders do not have access to information on projects' NPVs and IRRs with or without subsidies, or even on the parameters necessary to calculate them independently, such as extraction costs. To help these stakeholders navigate the topic, this section takes an alternative approach. We review different types of subsidies and discuss their most likely impacts on unlocking fossil fuel supply based on the signals they are likely to give to investment decision makers.

At a project level, all subsidies can be divided into three categories as presented in Figure 3: a) those that give a long-term, strong signal to attract investment into supply, b) those that give a short-term, moderate signal and also lock in investment in high-carbon assets, and c) those that arguably have no impact at the project level, but can increase companies' revenues and profits and thus drive investment into fossil fuel supply elsewhere.

What determines the strength of the signal for an investment decision maker? One factor is obviously the amount of the subsidy. Another one is perceived stability of the subsidy regime over time, which sometimes depends on the subsidy-granting authority: legislative or executive branches of power, the expected office term of the relevant officials, and some other factors—this factor can be discussed qualitatively. A further factor (and one, which actually lends itself to quantification) is the time value of money, or more exactly, time value of reduced costs to companies due to various subsidies. This logic refers back to the discussion of Present Value and Discounted Cash Flow in Section 2.1 and Box 1.

For the pre-production stage of a project, the present value (PV) of subsidies is close to their undiscounted value, since they are not that far out in the future. By contrast, for subsidies related to the production and decommissioning stages, the present value is significantly lower, since they are much farther out in the future.

Using the PV formula, the typical project duration, and the discount rate of 8 per cent (see Box 1 and Footnote 13), the PV of any cost 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 6 to 26). If we use the discount rate of 10 per cent, the difference increases to three times higher (these multipliers are listed in Table 2). Figure 4 complements this explanation with visualizing discounted and undiscounted cash flow of the same hypothetical project with and without subsidies. In Figure 4, for illustrative purposes the subsidy amount is the same through the entire project cycle (in reality, subsidy amounts will differ over years), set at USD 100 million per year—and the difference that this subsidy makes to the discounted project cash flow is lower every year. At the same time, the applied discount rate matters too: the greater the discount rate, the lower the present value of a subsidy in the future.

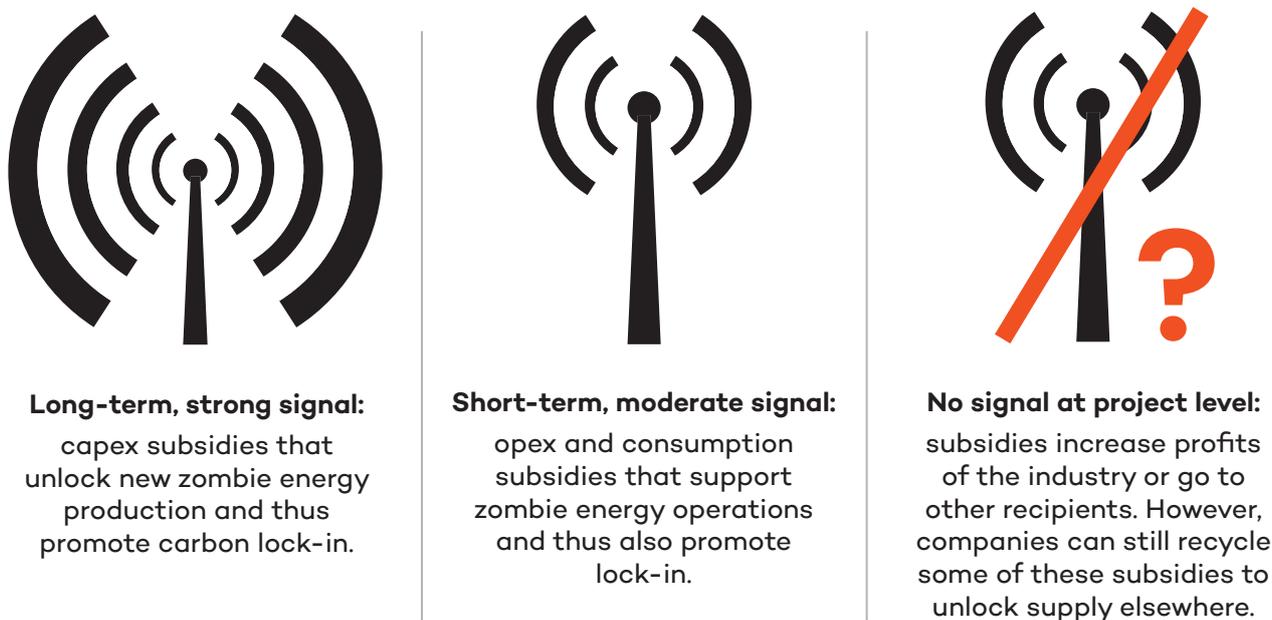


Figure 3. Signals that subsidies give to investment decision makers

Source: Authors' diagram.

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 6 to 26 of a project)
8%	1	2.5
10%		3

Source: Authors' calculations.

In other words, based solely on the time value of money perspective of final investment decisions, USD 1 of subsidies to a fossil fuel project during its pre-production stage locks in as much investment in fossil fuel extraction as USD 2.5 – USD 3 of subsidies during the production and post-production stages. It is further possible to generalize that these multipliers of 2.5 and 3 apply mostly to such types of subsidies as capital expenditure (or “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. Using it as a proxy for the strength of the subsidy signals to investors, we use the two indicative multipliers in the scenarios of the modelling exercise presented in Chapter 3.

The characteristics of capex, operating expenditure (or “opex”) and other subsidies are briefly discussed in the following section.

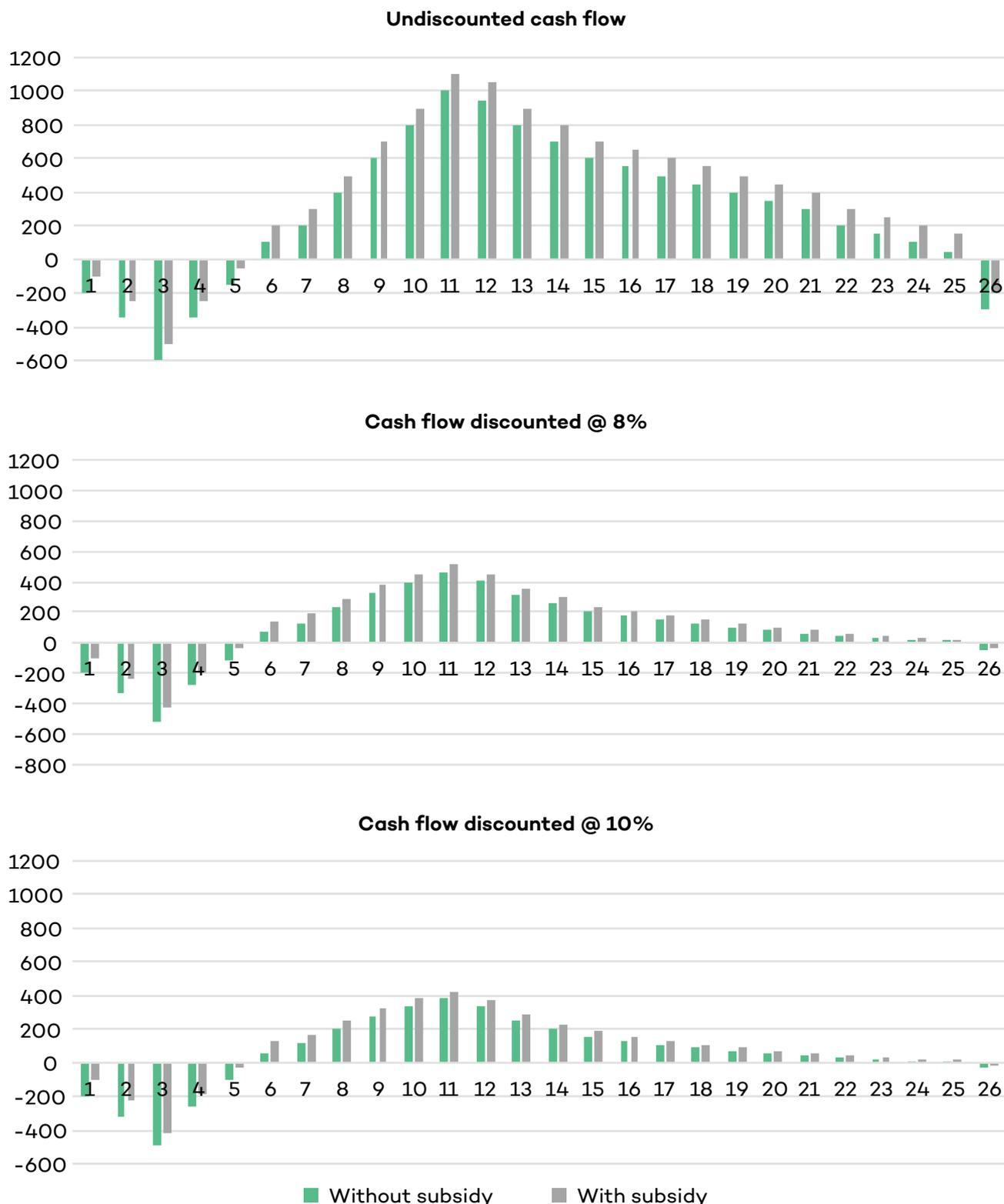


Figure 4. Undiscounted and discounted cash flow of the same hypothetical oil and gas project over its lifecycle, with and without subsidy* (five years for project development, 20 years of production and one year for decommissioning)

Source: Authors' diagram.

* For illustrative purposes the subsidy amount is the same through the entire project cycle (in reality subsidy amounts will differ over years), set at USD 100 million per year. The applied discount rate is also important—the greater the discount rate, the lower is the present value of a subsidy in the future.



2.4 Which Subsidies Have Which Impacts on Carbon Lock-In?

There are several typologies of subsidies depending on fuel (see FAQ #4), their beneficiaries, legal nature, economic mechanism and some other criteria. The discussion below draws on the existing typologies with respect to the implications specifically for carbon lock-in. Table 3 provides further examples.

2.4.1 Subsidies to Capital Expenditure

The fossil fuel industry is very capital-intensive and operates in a capital-scarce environment. The costs of developing new oil and gas fields are in the range of several billion US dollars. Coal is less capital-expensive globally, but some regions, such as Powder River Basin in the United States are also very costly in terms of fixed assets. The capital investments have to be made, normally, at early stages of extractive projects' lifecycle.

Therefore, every policy that reduces or enables a write-off of capital costs against taxable income of companies carries a lot of weight. In particular, these are capex subsidies that reduce companies' costs related to exploration,¹⁴ 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.

For instance, Snøhvit, a large natural gas site off the shore of Norway, has been granted specific tax benefits in the form of accelerated depreciation that assisted Statoil's final investment decision on its development and construction of a related LNG plant (EconPöyry, Aarsnes, & Lindgren, 2012). Another example is the Yamal LNG project in Russia, which has received support through about USD 6 billion of government funding of transport infrastructure around the site (seaport 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 affect project economics. In addition to the bulk capex expenditure at the development stage, some, though normally smaller, capital investments need to be made throughout the later part of the project cycle, for such things as 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 affecting long-term investment decisions.

2.4.2 Subsidies to Operating Expenditure

The second large group of subsidies is policies related to operational expenditures (opex) of fossil fuel producers. These subsidies reduce operational costs of fossil fuel extraction once the project has begun 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 directly influence either companies' final investment decisions about new projects, or the 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

¹⁴ Government support to exploration has been described as a subset of subsidies particularly inconsistent with climate goals (Bast et al., 2014).



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 United Kingdom and Germany (Steenblik & Coroyannakis, 1995), though they were later 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 widespread opex subsidies as royalty reduction on specific new or mature oil fields at national and subnational levels in the United States, Russia and many other countries have the same long-term effect of locking in high-carbon assets.

By 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,¹⁵ 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 recycle in coal mining business to improve profitability on a short-term basis.

2.4.3 Fossil Fuel Consumption Subsidies

In terms of impacts on final investment decisions, subsidies to consumption 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 consumption in the form of price caps, since these eat up their margins (Beaton, Gerasimchuk, Laan, Lang, Vis-Dunbar, & Wooders, 2013). On the other, consumption subsidies drive up demand for fossil fuels and often create a guaranteed market for them, making them more competitive compared to alternative energy choices (Clements, Coady, Fabrizio, Gupta, Alleyne, & Sdravovich, 2013; Merrill, et al., 2015b). In particular, the influence of subsidized fossil fuel prices can be traced to urban sprawl and wasteful energy consumption in transport and buildings in many countries (New Climate Economy, 2014).

2.4.4 Other Subsidies

There can be a case made that while the absolute majority of subsidies influence energy production and consumption choices, other government support measures pursue different objectives and therefore might have no intended impact on shifting production, carbon lock-in and emissions. For instance, it is challenging to quantify the direct climate impact of government support to extractive sites' rehabilitation and compensation of investors for the shutdown of coal plants. Other measures that can fall into this category are subsidies to assist social transitions in communities where many jobs depend—or once depended—on extraction of fossil fuels. In particular, this is true for such subsidies as aid packages for former coal-producing regions in Europe and government contributions for early retirement or retraining of coal miners in Mexico and Germany and (Bast, et al., 2015; Gass, Duan, & Gerasimchuk, 2016). However, these cases require more detailed analysis of both the direct and indirect impacts at both industry and macroeconomic level as suggested in Sections 2.1, 2.2 and 2.3. For instance, government support for early retirement of miners can make it easier and cheaper for coal companies to attract a younger labour force, which will ultimately reduce coal mining costs.

¹⁵ Whatever the stated policy objectives and the intended design of a subsidy, in almost every instance there are unintended beneficiaries and unexpected impacts of such policies (Beaton, et al., 2013).

Table 3. Classification of subsidies based on the signal they send for lock-in of 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.	<ul style="list-style-type: none"> • Direct funding of industry-specific R&D and tax breaks stimulating it. • Direct and indirect funding of fossil fuel companies at the project level, including preferential loans and loan guarantees. • Direct funding of exploration and exploration cost write-offs against payable taxes. • Funding of industry-specific infrastructure development (roads, ports, pipelines). • Accelerated depreciation of fixed assets. • Tax breaks beneficial for development and construction such as fuel tax reduction for heavy machinery or waivers for import duties and VAT on equipment. • Direct funding of site rehabilitation and rehabilitation cost write-offs against payable taxes.
Opex subsidies 	Start once the field or plant becomes operational.	<ul style="list-style-type: none"> • Direct and indirect funding of fossil fuel companies at a corporate level, including preferential loans and loan guarantees. • Bailout in case of operational losses. • Relief on royalties. • Tax holidays, tax credits and other tax breaks during project operation with respect to income tax, property tax, pollution and other taxes. • Prices and fees for input factors regulated at below-market level (e.g., for land, water, railroads, ports, pipelines). • Prices of output regulated or stimulated at above-market level, including through market protection. • 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.	<ul style="list-style-type: none"> • Conditional and unconditional cash transfers to fuel consumers. • Compensation to suppliers for selling fuels under regulated prices. • Fuel distribution and rationing on preferential terms. • Domestic market obligations for suppliers. • Consumer prices regulated at below-market level. • Cross-subsidies between different categories of consumers. • Tax relief on consumer side (exemptions from VAT, excise tax, etc.).
Other subsidies 	Various	<ul style="list-style-type: none"> • At project level only: subsidies to projects that are economically viable without them and thus increase company profits (though in reality companies can recycle these profits to invest in supply elsewhere). • Labour and pension debt subsidies. • Aid packages to regions that depend or formerly depended on fossil fuel extraction. • Compensation to investors for the shutdown of coal plants.

Source: Authors' diagram with the use of subsidy typologies developed and applied by the OECD (2010, 2015), World Bank (Kojima & Koplou, 2015) and other expert organizations (Lang, 2010; GSI, 2014; Bast, et al., 2015)



FAQ #4. DO PRODUCTION SUBSIDIES FOR COAL, OIL, AND GAS HAVE DIFFERENT IMPACTS ON CLIMATE?

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 subsidies to coal result in more carbon extraction than subsidies to oil, nor that subsidies to natural gas will have the least impact. In reality, everything depends on the percentage of extraction costs offset by subsidies, and physical and economic 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 USD 1 of subsidies will affect these curves in a different way. We model the subsidy-driven unlocking of reserves for different fossil fuels in Chapter 3 and discuss the findings in Chapter 4. In addition to the direct impact of subsidies on viability of extraction, it is also important to remember indirect impacts. For instance, oil and gas are often either co-produced from the same fields, or receive the same subsidies. Therefore, any subsidy to oil can be recycled in corporate finance to support extraction of natural gas, and the other way around.



CHAPTER 3. Modelling Removal of Fossil Fuel Production Subsidies

This chapter presents a first effort to model a global removal of subsidies to the production of coal, oil and gas that have been identified and quantified in the existing inventories. In particular, it draws on the database underlying the analysis of fossil fuel production subsidies in the G20 countries (Bast, et al., 2015) that in turn builds on OECD (2015) as well as other sources.

This exercise has been envisaged as a thought experiment and a proof of concept, as a first step and possible basis for other research and estimates. The goal was to create a simple and initial—yet—credible approach to analyze the global climate impact of production subsidy removal. As described in Chapters 1 and 2, a nuanced analysis of subsidy removal can be extremely demanding in terms of both effort and field- and project-level data required. By contrast, aggregate data are sometimes more readily available, and it is possible to create global simulations of energy demand and supply. To the extent possible, however, the chapter also builds on the discussion of investment decision making in Chapter 2.

As mentioned in the Introduction, the entire carbon accounting system is skewed toward managing demand. Countries can get credit for restricting emissions from consumption of fossil fuels (even if at the same time they export fossil fuels to other markets), but they do not get any credit for keeping fossil fuels in the ground. In the analysis below we therefore discuss both emission reductions and another metric that is important for supply-side mitigation: the amount of reserves that could become uneconomical to produce as a result of the global removal of production subsidies to coal, oil and gas.

The main research question answered in this chapter is:

- With the use of the existing dataset of G20 countries' national subsidies to fossil fuel production as proxy for the world, what emissions can be saved if subsidies to fossil fuel production are removed globally (that is, in both G20 and non-G20 countries), and what amount of oil, gas and coal would become uneconomical to produce?

The chapter is based on simulations with GSI-IF (p) model, the development and application of the which has also answered in the affirmative two methodological questions:

- Are the results of such top-down analysis similar to the results of bottom-up studies at project, basin and country levels?
- Can a single method be used to coherently assess the impact of subsidy removal across fuels, and their aggregated impacts on energy demand, emissions and the economy?

This chapter presents the data, the assumptions and the GSI-IF (p) model underlying the simulations. For a review of other studies estimating the climate benefits of the removal of subsidies to both fossil fuel consumption and production, see Annex A, Part II. Further technical details on the simulations underlying the results presented in this chapter can be found in Annex B.



3.1 Algorithm for Modelling a Global Removal of Fossil Fuel Production Subsidies

Cash flow and other simpler models (e.g., Lunden & Fjaertoft, 2014, Erickson et al., 2017) seek to show whether a removal of subsidies would make an individual project or cluster of projects at a national level uneconomical to run. More complex models are aimed at understanding not just such first-order impacts, but also second-order impacts, including:

- How the rest of the fossil fuel system would react, i.e., how demand would react to reduced supply.
- How the world price for one or more fossil fuels would affect GDP and how it would rebalance economic activity between sectors, including energy efficiency and development of non-fossil energy sources.

To the best of the authors' knowledge, this study pioneers the analysis of both first- and second-order impacts of a removal of subsidies to fossil fuel production at the global level with the use of the System Dynamics approach and GSI-IF (p) model (see Figures ES1 and ES2).

The impact of production subsidies on fossil fuel supply depends on three groups of factors: first, the amount and nature of subsidies or, using the language in Chapter 2, subsidy signals; second, the characteristics of reserves that receive these signals and subsidies; and third, all other factors that influence the business environment, including such decisive factors as the market price of coal, oil and gas. The three groups of factors interact directly and indirectly, forming a network of feedback loops (first- and second-order impacts) that need to be simplified and hypothesized about in a modelling effort.

Figure 5 serves two purposes. First, it summarizes the algorithm for modelling the impact of production subsidies and their removal on fossil fuel supply and emissions from fossil fuel combustion. Second, it is aimed at guiding the reader through the steps the authors have taken to arrive at the estimates of impacts of a global removal of fossil fuel production subsidies on both energy reserves and emissions. The numbers in each of the boxes of Figure 5 correspond to the relevant subsection of this chapter and Chapter 4. The following sections discuss the modelling algorithm step by step.

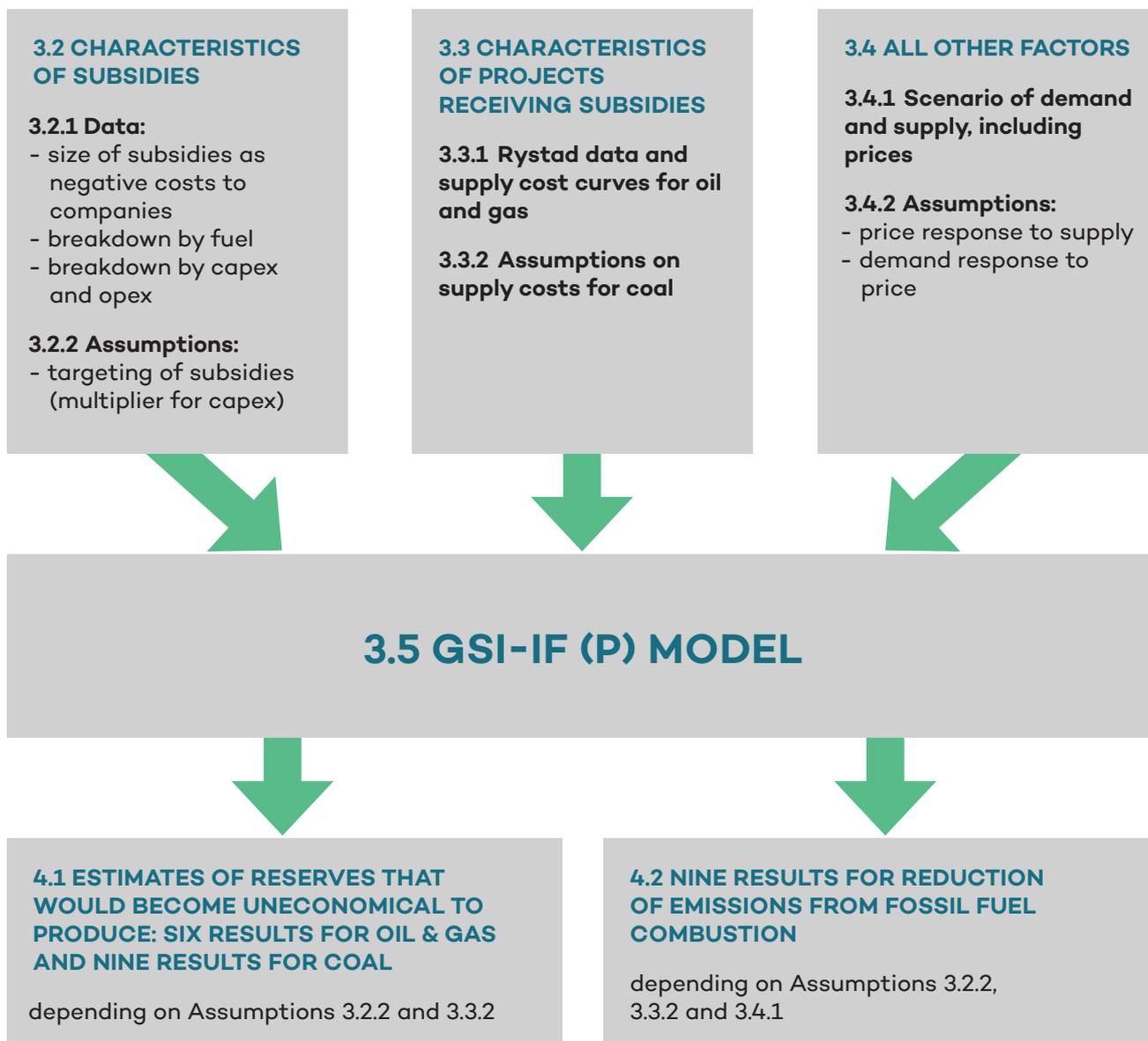


Figure 5. Algorithm for modelling a global removal of fossil fuel production subsidies (the numbers in each of the boxes correspond to the relevant subsection of Chapters 3 and 4.)

Source: Authors' diagram.



3.2 Model Input: Characteristics of subsidies

Unlike a more granular analysis of subsidy impacts based on the discounted cash flow at a project level (for instance, Erickson et al. [2017], for other examples see Annex A, Part II), GSI-IF (p) takes the same approach as several other macro-level studies of subsidy removal (Acar & Yeldan, 2016; Fulton, Buckley, Koplou, Sussams, & Grant, 2015) and simply treats all production subsidies as negative costs for companies that extract fossil fuel reserves.

3.2.1 Size of Subsidies and Breakdown by Fuel and Type

The modelling effort focuses only on subsidies to the production of coal, oil and gas (see definitions in Sections 1.1 and 1.2), including subsidies at such stages as appraisal, gaining access, field development, extraction, field decommissioning, refining, transportation and distribution while excluding subsidies to the generation and distribution of electricity based on fossil fuels. This line has been drawn based on the setup of the GSI-IF (p) model as well as by ownership considerations. Subsidies to refining, transportation and distribution often reduce the costs of the companies that extract coal, oil and gas. Moreover, these activities are often run by the same corporate structures that produce fossil fuel raw materials. This means that whatever business unit receives the subsidy, it can often be recycled to support other business units, especially if subsidies increase profits from operations. By contrast, we exclude subsidies to electricity based on fossil fuels, since in most cases they do not directly reduce costs of fossil fuel extraction and are received by companies that have ownership different from the extractive sector (though there are sometimes exceptions where power plants are owned by coal or natural gas producers).

The GSI-IF(p) modelling effort is based on the inventory of fossil fuel production subsidies in G20 countries co-published by OCI and ODI (Bast, et al., 2015), which in turn draws on the OECD fossil fuel subsidies database (OECD, 2015) as well as other sources. The inventory by Bast et al., (2015) has succeeded in quantifying some significant (though by far not all) G20 subsidies to fossil fuel production (through tax breaks and direct spending). Although it is unclear if this was due to an absence of subsidies or an absence of publicly available information (see Box 4), this inventory was only able to identify or quantify production subsidies in 15 of the total of 19¹⁶ member countries of the G20, failing to do so in three significant producer countries (Indonesia, Mexico and Saudi Arabia) and one insignificant producer (Italy). It is limited to the so-called “national subsidies” and excludes concessional elements of government support to fossil fuel extraction through public finance and state-owned enterprises.

For modelling of the production subsidy removal, we needed to disaggregate these country-level production subsidy data by fuel and by type. It should be noted—as it is in Bast et al. (2015)—that in practice, many subsidies are cross-cutting:

- through fuels
- through stages of project lifecycle
- through both capex and opex costs.

¹⁶ The 20th member of the G20 is the European Union.



BOX 4. BARRIERS TO IDENTIFYING AND QUANTIFYING FOSSIL FUEL SUBSIDIES

Research on fossil fuel production subsidies faces a number of challenges in collecting data and other necessary information. Some of the key barriers include:

- **Lack of transparency:** Support provided to the production of fossil fuels is often not reported in government budgets. Across different types of subsidies, tax expenditures are generally less well characterized than government budget support. This is likely to result in underestimations of production subsidies as these account for a large share of production subsidies. In addition, because subsidies are often provided directly to state-owned enterprise (SOEs) and private companies, details of resulting company income and tax payments may remain undisclosed, based on a stated need for commercial confidentiality. Finally, disagreement on the definition of a subsidy means that even when disclosure occurs, it may not be comprehensive.
- **Fragmented data:** Subsidies are often provided by different levels of government (national, subnational or local), and by various ministries (energy ministries are often a principal source of energy-related data, but data are sometimes also held by ministry of transport, health, taxes, or foreign affairs) (Koplow, et al., 2010). This means that even when governments do provide subsidy data, compiling information from various sources may be a significant challenge. In some countries, significant production subsidies are provided at the subnational level, and it is often particularly difficult to collect information on subsidies at this level.
- **Aggregation of information across industries, activities and fuels:** Again, when subsidy data are provided by governments, sometimes it is not sufficiently disaggregated to determine what specific industry, activity or fuel is receiving support. For example, support to coal mining is often aggregated with other all other types of mining, and data for subsidies to oil and gas production are almost always reported together.
- **Lack of resources and expertise:** Subsidy reporting within government budgets often involves highly technical terminology, fragmented national data and possible interaction between various taxes. This means that a collaboration is required between subsidy experts (with expertise in specific policy types such as credit support, insurance or tax systems) and country experts (who know the local language and are familiar with the governmental structure) to identify budgetary support and tax expenditures for fossil fuels (Koplow, et al., 2010).

For fossil fuel production subsidies, a lot of information (subject to consultations with governments) is provided in the OECD Inventory of Support Measures for Fossil Fuels 2015 and the Companion to the inventory (OECD, 2015) which survey consumption and production subsidies for the OECD countries and BRIICS countries (Brazil, Russia, India, Indonesia, China and South Africa). Building on the OECD inventory, in 2015 the Overseas Development Institute (ODI) and Oil Change International (OCI) (supported by the Global Subsidies Initiative [GSI]) developed a more detailed inventory of “national subsidies” for the G20 including direct spending and tax breaks (Bast, et al., 2015).

Some G20 governments have produced their own accounts.¹⁷ There has also been a call for governments to integrate tax expenditures with subsidies in their annual budgets, although Germany is the only country doing this effectively (Kojima & Koplow, 2015).

Ten countries in the G20 and APEC recently (in 2014) embarked on the first fossil fuel subsidy peer review process, which aims to provide a platform for countries to provide feedback on each other’s subsidy estimates and progress on phase-out.¹⁸ Although the peer review process may not produce a standardized method and format for fossil fuel subsidy tracking, making peer review results public could lead to wider transparency on fossil fuel subsidies and accountability for their phase-out. The first pair of G20 peer reviews, for China and the United States, were published in September 2016 and include production subsidies (G20 2016a, 2016b).

¹⁷ Canada, for example, has prepared a Study of Federal Support to the Fossil Fuel Sector (Office of the Auditor General of Canada, 2012); France has completed a review of the environmental impacts of energy-related tax concessions (Cours des Comptes, 2013); and an inventory of UK energy subsidies was compiled as part of a parliamentary enquiry (UK Parliament, 2014). The EU Directorate Generals (DGs) for Energy and Environment also commissioned fossil fuel and energy subsidy inventories for all EU member states in 2015, and DG Energy will update this information in 2016 (Oosterhuis, Ding, Franckx, Razzini, & Experts, 2014; Alberici, et al., 2014).

¹⁸ Within APEC, the first peer review of fossil fuel subsidies has been completed for Peru and New Zealand, parallel processes are under way or planned for the Philippines, Vietnam and Taiwan (Bridle, Toft & Merrill, 2016). Within G20, China and the United States published their reviews in September 2016, while peer review work has also started for Germany, Mexico and Indonesia (G20, 2016a, 2016b).



We attributed the value of cross-cutting subsidies to fuels based on each fuel's role in domestic primary energy production expressed in kilotonnes of oil equivalent according to energy balances from IEA Statistics (IEA, 2016). Figure 6 presents the results of this disaggregation at the G20 level, while Annex B lists the results of disaggregation by country. USD 32 billion was found to be subsidies for oil, USD 18 billion for gas and USD 8.5 billion for coal. USD 8.5 billion in subsidies went to the generation of fossil fuel-based electricity and hence was excluded from further analysis. In addition, there was USD 3 billion more in subsidies to the fossil fuel sector, but not directly attributable to companies in the sense of carbon lock-in, given the challenges treating these subsidies as directly reducing industry costs (see Section 2.4.4); hence, these were also excluded from the analysis.

Per unit of total production, this disaggregation has yielded the following G20 averages weighted on production in each country:¹⁹ oil is subsidized at USD 2.6 per barrel, gas at USD 0.3 per thousand cubic feet,²⁰ and coal at USD 1.2 per metric tonne.

These weighted averages have been assumed to be not just G20 values, but global values for the input into the GSI-IF(p) model. This is an assumption we needed to make given the lack of global data, including the lack of information on production subsidies in major fossil fuel-producing countries outside G20, in particular, the Gulf countries, Nigeria and Venezuela. Meanwhile, this assumption is very conservative and thus likely to err at the low end, since the G20 inventory by Bast et al. (2015) has not quantified many of the identified production subsidies.

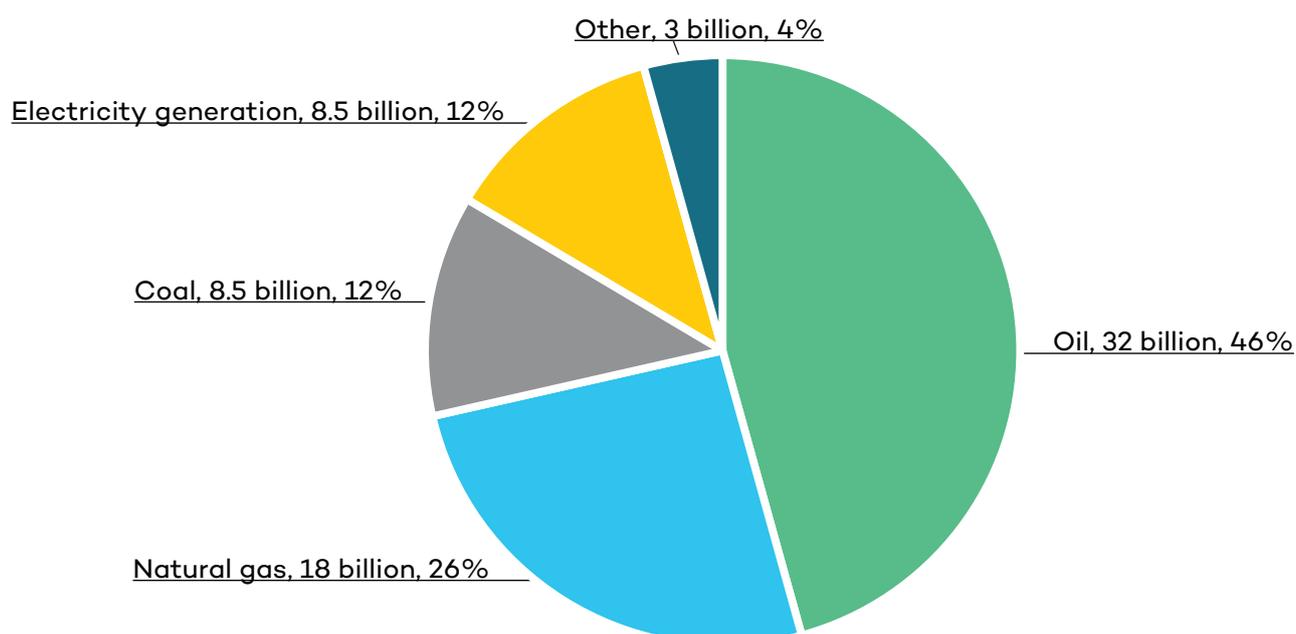


Figure 6. Disaggregation of the USD 70 billion worth of G20 fossil fuel production subsidies by fuel, shares on annual average basis in 2013–2014

Source: Authors' diagram based on Bast, et al. (2015).

¹⁹ The data on production of each fuel by country has been sourced from the BP Statistical Review of World Energy (BP, 2016) for most cases and converted from IEA kilotonne of oil equivalent data to relevant units in cases where production was not significant and therefore not reported separately in BP's Statistical Review.

²⁰ A thousand cubic feet of natural gas equals a million of British Thermal Units (BTU).



We further attempted to disaggregate production subsidies by those that reduce capex, sending a strong, long-term signal to investors, and those that reduce opex, sending a moderate, short-term signal to attract investment (see discussion in Section 2.3).

The nature of many subsidies makes it easy to classify them as either opex or capex subsidies²¹ (see Table 3). However, there are also many subsidies that are cross-cutting through several stages of a project's lifecycle and can be viewed as a mixture of opex and capex subsidies.²² Any hypotheses about disaggregating such subsidies can be subject to criticism, but for the proof of concept we assumed the simplest approach, and attributed half of any cross-cutting subsidy value to capex and half to opex. Results are presented in country tables in Annex B.

3.2.2 Assumptions About the Targeting of Subsidies and Multiplier for Capex

One of the critical questions for modelling is whether subsidies are benefiting all of fossil fuel extraction (untargeted), or just marginal projects (targeted). Both assumptions have their proponents,²³ but we had to find a midway between them.

The way the GSI-IF (p) model is set up applies per-unit subsidies only to yet-undeveloped marginal fields and operates within USD 5 bands on the cost curves (see Section 3.3 and Annex B for more detail). A field's marginality depends on the price, which is an endogenous variable in the model and changes over time and depending on different scenarios (see Section 3.3.2). This is explained in detail in Box B1 of Annex B with respect to modelling of future developments.

However, the targeting question also has implications for inputs into the model based on past developments. The empirical data that we had—the G20 inventory by Bast et al. (2015)—did not have the information on how each subsidy was targeted at particular types of reserves with USD 5 dollar bands or any other tiers on the cost curves. We had the total value of subsidies, but no data on whether all of the production or only marginal fields were benefitting from these subsidies.

In particular, the per-unit subsidy values provided in Section 3.2.1 attribute the G20 subsidy data to all of the production by fuel in each country and then derive the weighted average. By contrast, if subsidies in G20 inventory are targeted at higher-cost production, their value should be divided only by the eligible portion of production, not all of it. In other words, the values from Section 3.2.1 would require some kind of a multiplier to allow for subsidy targeting.

In the meantime, another type of such multiplier was discussed in Section 2.5 and can be linked to the empirical data by Bast et al. (2015). This G20 inventory has the information on whether subsidies are capex or opex, and in Section 3.2.1 we split the subsidy numbers for each fuel between capex and opex subsidies. As discussed in Sections 2.4 and 2.6, many capex subsidies apply to fossil fuel projects at early stages of their lifecycles, and thus are more likely to benefit new and marginal projects. The signals that capex subsidies send to investment decision makers at pre-production stages of a project are 2.5 to 3 times stronger than signals sent by opex and other subsidies at later stages of the project, depending on the discount rate (see Section 2.5).

²¹ Accelerated depreciation is always a capex subsidy, as are subsidies to exploration. Subsidies to infrastructure development and R&D are also classified as capex subsidies. Royalty relief is always an opex subsidy, since royalties are paid only when fields start producing (although there are cases where royalty relief is only granted for new projects in which case this policy can be aimed at promoting new project development and assist in recovery of capex costs too).

²² An earlier inventory by Bast, et al. (2014) tried to single out exploration subsidies as a capex subsidy category with particularly harmful implications for the climate, but found out that many subsidies cross-cut through both exploration and production stages of an extractive project's life-cycle.

²³ On the one hand, the assumption that subsidies benefit only high-cost projects reflects the frequent policy objective of subsidies that are designed to attract investment in new supply. On the other, some anecdotal evidence and previous research (Metcalf, 2016) indicates that many subsidies are mis-targeted and benefit not just high-cost but all of companies' production, also increasing companies' profits from existing operations. For a review of previous research findings, see Annex A, Part II.



As a thought experiment, we therefore ran simulations with and without multipliers for capex subsidies that have been disaggregated from opex subsidies as explained in Section 3.2.1 and presented in country tables in Annex B. This is a proxy approach to estimating subsidy targeting. In Section 3.2.1 we calculated the subsidy for each fuel's production without capex subsidy multiplier, and within G20 the weighted averages are the following: oil is subsidized at USD 2.6 per barrel, gas at USD 0.3 per thousand cubic feet and coal at USD 1.2 per metric tonne. If a 2.5 and 3 multiplier is applied to capex subsidies, oil is subsidized at USD 3.5–3.8 per barrel, natural gas at USD 0.4–0.5 per thousand cubic feet and coal at USD 1.6–1.7 per metric tonne.

The capex multipliers therefore make a difference for the input data based on the inventory for 2013 and 2014 by Bast et al. (2015), but a very conservative one. Its impact is much less than if we assumed, for instance, that subsidies had been targeted at half of the producing reserves (see Table 4). This is a very conservative compromise between the opposing views that in reality subsidies are either highly targeted or mis-targeted. We further discuss what differences the multiplier use makes in terms of the modelling results, clearly singling out these scenarios.

Table 4. Multipliers for capex subsidies and their equivalents of targeting subsidy at a portion of producing reserves if applied as model inputs: 2013–2014 data from the inventory by Bast et al. (2015)

	Oil		Natural gas		Coal	
	Subsidy per barrel	Equivalent of production benefiting from subsidy*	Subsidy per thousand cubic feet	Equivalent of production benefiting from subsidy*	Subsidy per metric tonne	Equivalent of production benefiting from subsidy*
No multiplier for capex	USD 2.6	100%	USD 0.3	100%	USD 1.2	100%
Multiplier for capex @ 2.5	USD 3.5	74%	USD 0.4	75%	USD 1.6	75%
Multiplier for capex @ 3	USD 3.8	68%	USD 0.5	60%	USD 1.7	70%

Source: Authors' calculations.

* Eq. of production benefiting from subsidy = $\frac{100\%}{\$ \text{ value with multiplier divided by } \$ \text{ value without multiplier}}$



3.3 Model Input: Characteristics of projects receiving subsidies

The key characteristic of the reserves that benefit from subsidies is the breakeven price at which their exploitation becomes economically viable. This parameter is described by what is commonly referred to as “supply cost curves,” or simply “cost curves”—the series of reserve categories, each of which has different development costs, from lower to higher. We reviewed cost curves for each fuel: oil (McGlade, Rystad, IIASA GEA as outlined in Rogner [2012]); natural gas (McGlade & Ekins, 2015; Rystad Energy, 2016; IIASA GEA as outlined in Rogner, [2012]), coal (McGlade & Ekins, 2015; IIASA GEA as outlined in Rogner [2012]; and WoodMac as outlined in [Aldina, 2013]).

Annex B provides a detailed description of the cost curves review. The review provided the basis for selecting the most appropriate cost curves for running the simulations.

3.3.1 Rystad Data and Supply Cost Curves for Oil and Gas

For simulating production subsidy removal for oil and gas, we use global cost curves from the Rystad Energy UCube Upstream database. Oil is a globally tradable commodity and, while the natural gas market can be segmented by key regions, the use of a global cost curve can be justified given the long-term nature of simulations. To ensure consistency across data sources and improve comparability, in the case of oil and gas we converted Rystad data (annual production and breakeven price) into “cumulative production and breakeven price” (starting from 2015 to compute cumulative production). We then used the estimated annual average production breakeven price (estimated across price brackets) and the cumulative production from Rystad to determine the curve.

3.3.2 Assumptions on Supply Costs for Coal

Unlike the oil and gas markets, the coal market is highly segmented. We therefore use both a global cost and two regional cost curves. The global cost curve for coal is used mainly for consistency—the results of these simulations should be treated with caution. The global coal cost curve is based on the one for hard coal from Rogner (2012). The two additional cost curves are for the U.S. Powder River Basin (PRB) and Australia Export (AUS), both based on Carbon Tracker Initiative (2015a).



3.4 Model Input: All other factors

These sectors of GSI-IF(p) that most relevant to the estimation of the impact of fossil fuel production subsidy removal include (a) energy demand, (b) fossil fuel production, (c) fossil fuel prices and (d) emissions.

The purpose of the Energy Demand module is to estimate energy demand for the residential, commercial, industrial, transportation, agriculture, fishery and forestry sectors. Sectoral energy demand is disaggregated into five energy sources (i.e., renewables, coal, petroleum, natural gas and electricity), following the IEA classification. The drivers of energy demand are population, GDP, energy prices and technology (energy efficiency). Energy conservation and fuel switching are also included in the model. Elasticities are used to forecast energy demand in relation to economic growth and energy prices (the change in the price of a specific energy source relative to others is considered, rather than an absolute change in price).

Fossil fuel production is estimated for oil, natural gas and coal. The structure of Production and Price modules for oil, gas and coal are similar. In order to avoid repetition in model description, we use the modules related to oil as an example. The Oil Production module estimates world oil production by considering production capacity from investments and reserves and resource availability. The purpose of this module is to calculate oil production and to keep track of both world fossil fuel resources and reserves (which are affected by the ultimately recoverable resources and technology). The purpose of the Oil Price module, again taken as an example for oil, natural gas and coal prices, is to calculate the international oil price (prioritizing the medium- and long-term trends). The main factors affecting fossil fuel prices are the availability of reserves and resources (affecting the long-term trend), and the demand-supply balance (affecting the medium-term trend).

The Emissions module calculates fossil fuel emissions for all types of GHG including carbon dioxide (CO₂), nitrous oxide (N₂O), sulphur oxides (SOX) and methane (CH₄). This is a broader scope since some of the models, indicators and policy discussions focus on CO₂ only. The calculation of emissions is based on fossil fuel consumption and conversion factors from energy to emissions. The GSI-IF(p) model does not take into account changes in emissions resulting from the impacts of subsidy removal on the fossil fuel extraction process (for instance, methane leakage, gas flaring or higher emissions from extraction from high-cost fields).

Several additional modules are included in GSI-IF(p). These include electricity generation (which takes into account production capacity, measured in megawatts (MW), load factors for each technology, as well as efficiency for thermal generation). The model includes also economic activity (GDP as well as households and government accounts), which are affected by energy productivity (consumption and prices).

3.4.1 Scenario of Demand and Supply, Including Prices

GSI-IF (p) can run different scenarios, but for the purposes of this report we rely on the widely known IEA Current Policies scenarios. The Current Policies projection incorporates existing policies that have been formally approved—and which would result in warming significantly beyond the limits enshrined in the Paris Agreement, namely at least 5°C of warming in the longer term. This makes the Current Policies scenarios an extreme climate pathway (Muttitt, 2016).

The Current Policies scenario assumes a recovery of energy demand, which will result in higher energy prices, up to USD 145 per barrel for oil in 2050, according to the baseline.



Market prices for coal, oil and gas are endogenous variables with the GSI-IF(p) model; that is, they are simulated by the model itself in response to the main drivers such as the parameters shaping both demand and supply, from economic growth to subsidy removal. Figure 7 illustrates oil price dynamics over 2017–2050 under the Current Policies baseline.

In addition, we also discuss a hypothetical scenario assuming that market prices for fossil fuels do not change over 2017–2050 and remain at the low level of 2015–2016, including roughly USD 50 per barrel of oil.

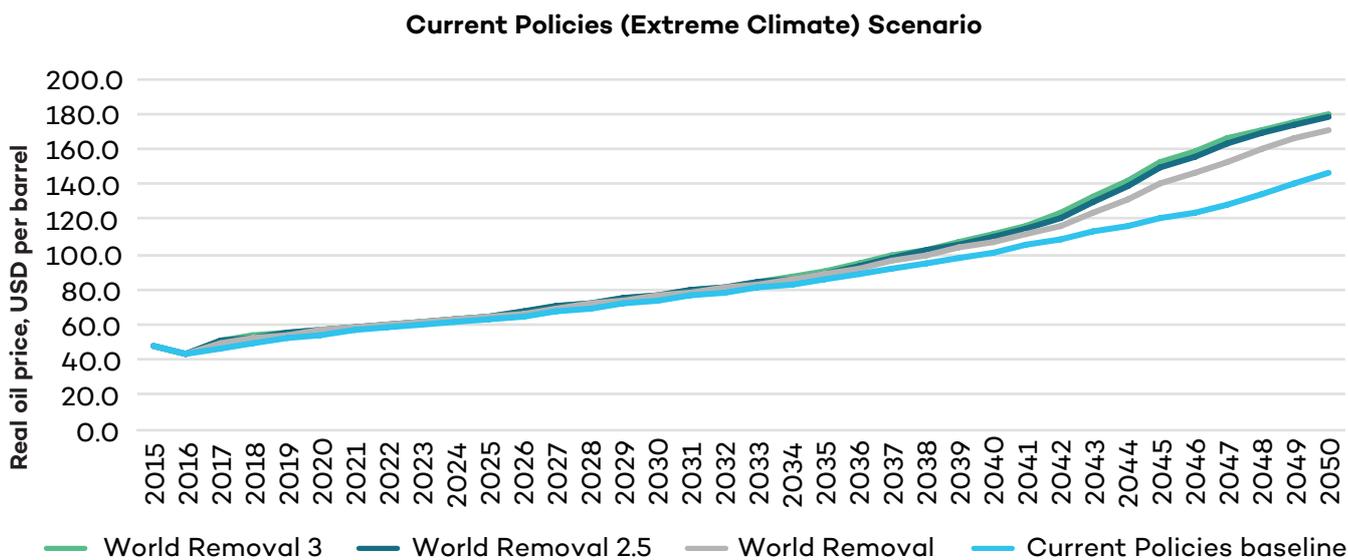


Figure 7. Oil price in real terms under Current Policies scenario: Production subsidy removal and baseline

Source: Authors’ diagram based on IEA Current Policies scenario (IEA, 2015a) and GSI-IF(p) simulations.

3.4.2 Price Response to Supply and Demand Response to Price

As a thought experiment, the GSI-IF (p) global model simulates a simultaneous removal of fossil fuel production subsidies in all countries (both G20 and non-G20), which therefore captures leakage effects.²⁴

As a first step, the removal of subsidies is expected to increase fossil fuel production costs, representing an upward shift of the cost curve (Figure 8). An increase in production costs reduces the economic attractiveness of fossil fuel production, at least for certain fields and for the projects that currently receive subsidies, or would have received subsidies under the baseline scenario. At the same time, the market price of fossil fuels would not change immediately due to the fact that supply comes from the already developed sites (see Figure 8).

²⁴ Leakage describes the migration of emission-intensive activities from jurisdictions that implement mitigation policies to “pollution havens,” which in a global system results in lower emission reductions than might be expected from the mitigation policy in question. 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 (ETS), 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 it is possible to model it.

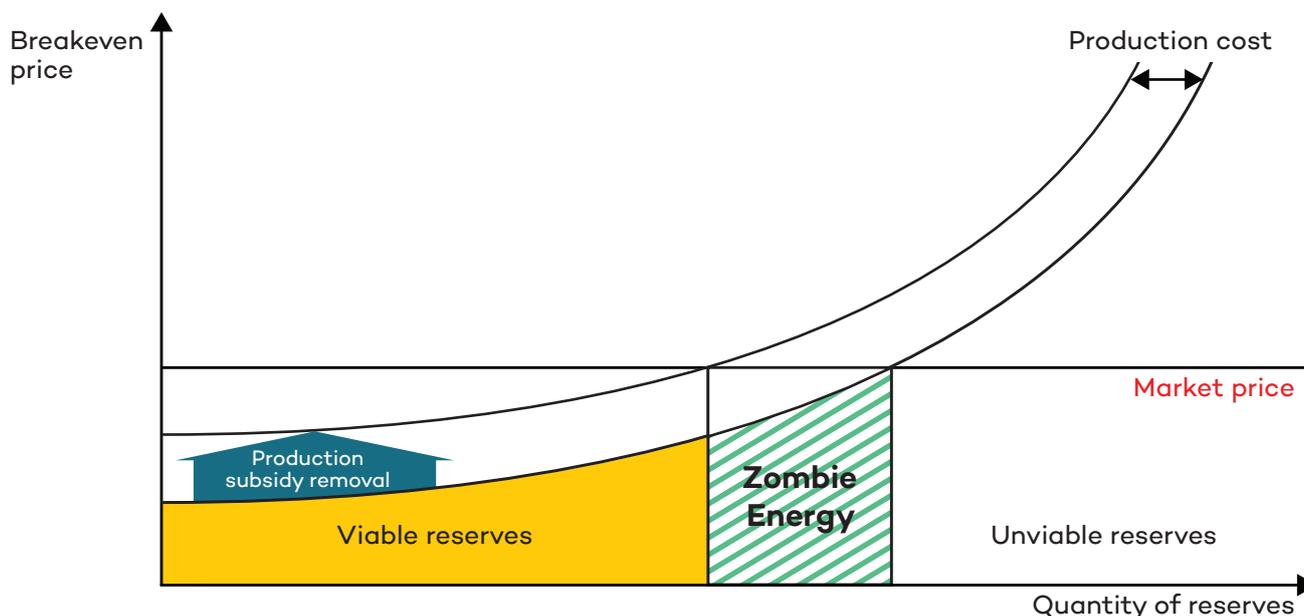


Figure 8. Schematic representation of the cost curve, indicating the impact of production subsidy removal

Source: Authors' diagram.

A change in market prices will emerge if, due to the increased cost of production, the extraction of fossil fuels would decline (not necessarily in absolute terms—a decline relative to the baseline scenario would be sufficient to stimulate an increase in market prices). This is because supply would be constrained (or lower than previously expected) while demand would continue to grow with no modifications relative to the baseline scenario. In this case, the market price would increase, making some fossil fuel extraction projects profitable again, and hence offsetting some of the impacts of production subsidy removal (see Figure E2).

Meanwhile, if the market price of fossil fuels increases, demand is likely to decline below expectations (or grow less than what is projected under the baseline scenario) due to energy conservation, and possibly energy efficiency and fuel switching. This reduces fuel expenditure for consumers, which may be able to offset the increase in market price (due to the constraint on supply) with efficiency improvement or other interventions.

Further, if demand declines, which normally happens over the medium and long terms (unless major price shocks take place), the demand-supply ratio will also decline, bringing market prices back to their original level, and possibly to the baseline trend. This development indicates that fuel expenditure may not well be below the baseline case, with prices possibly being at a similar level but with energy consumption being lower. The repercussion on production is again reduced profitability (as observed in the case of subsidy removal), with some oil and gas fields, or coal sites, becoming less economically attractive.

These developments have two main impacts on reserves and emissions. On the one hand, an increase in the production costs of fossil fuels is likely to reduce extraction from some fields and increase it from others if reserves from low-cost fields are available (e.g., production from more-economical fields could increase, for example, due to technology improvements in recovery of oil, gas and coal extraction). On the other hand, changes in demand (due to higher market prices and conservation, efficiency improvements or fuel switching) will have lasting impacts. This translates into reduced extraction (and hence to a higher level of reserves) as well



as in lower emissions. In addition, fossil fuel extraction and its costs are affected by the availability of reserves. To sum up, production subsidies directly influence the economic viability of production and—indirectly—demand and emissions.

While these dynamics may seem complicated, the above is a highly simplified description of the many feedback loops that influence the energy sector. For instance, capital in this sector has a long lifetime. Therefore, if high costs have already been incurred, production from these fields will continue even during years in which the market price is below the breakeven price of the field. Further, subsidy policies also go through cycles that are influenced by global commodity prices, because in the periods of low prices for oil, gas and coal, extractive companies demand and often receive more subsidies from governments. In GSI-IF(p) simulations it was assumed that the level of subsidization is exactly the same for all fuels over 2017–2050, which is a simplification. However, many factors level out on a longer-term basis, and the GSI-IF (p) model's span accommodates such feedback loops.

3.5 GSI-IF (p) Model

The GSI-IF(p) model uses System Dynamics as its methodological foundation (Sterman, 2000). It integrates sectoral knowledge in a single framework of analysis, incorporating the energy sector with social, economic and environmental sectors and indicators. The model runs differential equations in semi-continuous time and creates “what if” scenarios. It differs from Computable General Equilibrium (CGE) models in that it does not optimize the system (it uses simulation rather than optimization), and also has a much broader cross-sectoral coverage. This is achieved by using stocks and flows of biophysical and economic variables, and by explicitly accounting for feedback loops, delays and nonlinearity.

The model includes several direct, indirect and induced impacts of production subsidy removal, some of which form important feedback loops as described below. It runs multiple scenarios that enable estimates within the most reasonable range rather than a single data point output. For a more detailed model description, see Annex B.

The GSI-IF(p) model draws its name from GSI-IF—a model previously used by GSI to estimate emission reductions from the removal of fossil fuel consumption subsidies (Merrill, et al., 2015a). The GSI-IF and GSI-IF (p) models share the same Energy Demand modules.



CHAPTER 4. Climate Benefits of Ending Fossil Fuel Production Subsidies: Findings from modelling

This chapter presents the findings of the modelling described in Chapter 3. We first discuss the findings in terms of fossil fuel reserves that would become uneconomical to produce. We then present the estimates of emission reductions as a result of global removal of subsidies to fossil fuel production.

4.1 Results of GSI-IF(p) Simulations: Reserves that would become uneconomical to produce

Simulations with the GSI-IF(p) model find that the removal of fossil fuel production subsidies in 2017 would lead to significant levels of reserves of oil, gas and coal becoming uneconomical to produce through 2050. The most relevant are the results obtained with the use of multiplier 3 for capex subsidies, which is equivalent to a very conservative assumption of subsidies being targeted at about 70 per cent of fossil reserves (see Section 3.2.2 and Table 4). In reality, subsidies can be much more targeted at the fields balancing around the margin of economic viability, and thus have even more unlocking power.

Hence the high-level results summarized in Table 5 are all with the use of the multiplier 3 for capex subsidies, while Tables 6 through 8 also show the sensitivity analysis for using a different multiplier or no multiplier at all (thus equivalent to no subsidy targeting).

The reserves of energy that would be uneconomical to produce as a result of production subsidy removal amount to 120–138 Gt of CO₂ over 2017–2050. This is equivalent to 13–15 per cent of all reserves in the existing and under-construction oil and gas fields, and coal mines in 2015 (942 Gt of CO₂; see Table 1 and Muttitt, 2016). The amount of reserves that may not be produced is only estimated for reserves at the margin of profitability: these fields are the most sensitive to subsidy removal, and hence prime candidates for halting production.

We note that these quantities are not necessarily permanently left in the ground. How much would be permanently left in the ground depends solely on demand response and would equal emission reductions from avoided consumption. In their turn, demand response and emission reductions from avoided consumption are sensitive to price assumptions as described above. Other things equal, the lower the price of fossil fuels, the greater the impact of production subsidy removal in terms of carbon permanently left in the ground, and vice versa. In particular, in our modelling, the reserves that would become uneconomical to produce as a result of ending fossil fuel production subsidies could be potentially produced and consumed before 2050 if the prices go above the levels assumed in the IEA Current Policies scenario (USD 145 in 2050). Depending on the price scenario, these reserves could also still be available, and could be exploited after 2050.

In this sense, the effect of production subsidy removal can be compared with a temporary moratorium on marginal fossil fuels. Meanwhile, we could reasonably expect that the quantity of fossil fuels being produced would be much lower than today if the world has been successful in meeting the Paris Agreement limits. For example, the fossil fuels temporarily rendered uneconomical to produce as a result of production subsidy



removal might never become economical if coupled with the removal of consumption subsidies and other demand-side policies.

Table 5. Carbon equivalent of energy reserves that would be uneconomical to produce as a result of ending subsidies to fossil fuel production

Fossil fuel	CO ₂ equivalent if burned*	Current Policies, multiplier of 3 for capex	
		Energy reserves	Carbon equivalent if burned
Oil	0.43 t per barrel	150 billion barrels	65 Gt of CO ₂
Natural Gas	54.7 t per million cubic feet	550 trillion cubic feet	30 Gt of CO ₂
Coal, Australia export cost curve	2.066 t per t of coal	12 billion t	25 Gt of CO ₂
Coal, PRB cost curve	2.066 t per t of coal	21 billion t	43 Gt of CO ₂
Total			120-138 Gt of CO ₂

Source: Authors' calculations based on the outputs of GSI-IF (p) modelling.

* Emission factors as provided by US EPA (n.d.) based on IPCC (2006).

Oil reserves that would become uneconomical to produce without production subsidies are in the range between 105 billion barrels (double U.S. proved reserves in 2015) and 150 billion barrels (30 years of production by the former Soviet Union at the 2015 level). Affected reserves of natural gas are estimated between 325 trillion cubic feet (five times Norway proved reserves in 2015) and 550 trillion cubic feet (4.4 years of global production at 2015 level).

Table 6. Oil and natural gas that would become uneconomical to produce as a result of production subsidy removal over 2017–2050

	No multiplier for capex subsidies	Multiplier of 2.5 for capex subsidies	Multiplier of 3 for capex subsidies
Oil	105 billion barrels of oil = double proved reserves of United States in 2015	140 billion barrels of oil = 10 years of Organization of Petroleum Exporting Countries (OPEC) production at 2015 level	150 billion barrels of oil = 30 years of production by the former Soviet Union at the 2015 level
Natural gas	325 trillion cubic feet of natural gas = 5 times Norway proved reserves in 2015	495 trillion cubic feet of natural gas = 1.3 times proved reserves of United States at 2015 level	550 trillion cubic feet of natural gas = 4.4 years of global production at the 2015 level

Source: Authors' calculations. All comparisons based on data on oil reserves and production from BP, 2016.



Unlike more globalized markets for natural gas and particularly oil, the coal market is more fragmented, and thus the impacts of subsidy removal on coal will be differentiated by region. Therefore, the results for a global cost curve for coal in Table 7 are for background only—simulations with a global cost curve are not very plausible.

If the modelling is based on cost curves for Australia’s export coal, or Powder River Basin coal in the United States, the coal reserves uneconomical to produce without subsidies would be between 11 trillion metric tonnes (three years of China production at 2015 level) and 21 trillion metric tonnes (2.7 years of global production at 2015 level) (see Table 7).

For all fuels, these top-down results are consistent with findings of bottom-up studies discussed in Annex A, Part II (also see Box B4 in Annex B for a comparison with findings by (Fulton, et al., 2015)).

Table 7. Coal that would become uneconomical to produce as a result of production subsidy removal over 2017–2050

	No multiplier for capex subsidies	Multiplier of 2.5 for capex subsidies	Multiplier of 3 for capex subsidies
Global cost curve for coal (no geographical market segmentation)	1 billion metric tonnes = reserves of Czech Republic in 2015	1 billion metric tonnes = 5 years of coal production in Germany at 2015 level	1 billion metric tonnes = 1.2 years of coal production in United States at 2015 level
Cost curve for coal approximated based on Australian export coal	9 billion metric tonnes = reserves of Turkey in 2015	11 billion metric tonnes = 3 years of production in China at 2015 level	12 billion metric tonnes = 25 years of production in Australia at 2015 level
Cost curve for coal approximated based on Powder River Basin coal	21 billion metric tonnes = half of Germany’s coal reserves in 2015	21 billion metric tonnes = 2.7 years of global production at 2015 level	21 billion metric tonnes = 31 years of production in India at 2015 level

Source: Authors’ calculations. All comparisons based on data on coal reserves and production from BP, 2016.

In this analysis, the CO₂ equivalent of reserves that would stay in the ground is higher from the removal of subsidies to oil than for gas and coal. Oil production is most impacted as a result of subsidy removal for two main reasons: the amount of subsidies given to oil is larger (on a unit basis and as a share of market price); the cost curve for oil is steeper than that for other fuels, especially coal, because oil has a relatively lower amount of “cheap” reserves than natural gas or coal. These two effects drive a stronger increase in prices, which lowers demand and consumption, and hence emissions.

The GSI-IF(p) can also simulate subsidy removal by fuel, but it shows that the maximum mitigation effect can be achieved if subsidies are removed for all fossil fuels, because otherwise fuels can partially substitute for each other and production and consumption will shift toward fuels that are subsidized most, limiting the intended GHG emissions savings. This suggests that it is preferable not to overstress the importance of subsidy removal for a particular fuel, be it oil or coal.

This is echoed by the only study that looks, retrospectively, at the climate benefits of removing both producer and consumer subsidies (Stefanski, 2016). This study looked at the impacts of both producer and consumer



subsidies globally, thus also taking into account leakage effects. It finds that carbon emissions would have been 20.7 per cent lower between 1980 and 2010 had fossil fuels not been supported by governments through both consumption and production subsidies.

Because of possible substitution of fossil fuels within the energy mix, the sum of savings from the removal of subsidies to just one fuel type (coal, oil or gas) can be smaller than the savings if they are all phased out together. This is an important reason why it is important to promote the removal of subsidies to all fuel types, on both supply- and demand-side.

4.2 Results of GSI-IF(p) Simulations: Emission reductions

A lot of studies consider emission reduction (or growth) resulting from a given policy against business-as-usual scenarios that would lead to levels of climate warming far beyond what has been agreed in international forums. By contrast, it is also possible to measure climate benefits of policies using a different point of departure: carbon budgets for 1.5°C and 2°C targets, which is the volume of GHGs that can still be released while staying within the globally agreed climate limits. We use both approaches discussing the climate benefits of subsidy removal against both business-as-usual baselines and carbon budgets outlined in Table 1 in Section 1.3.

The impact of production subsidy removal on GHG emissions from fuel combustion is highly sensitive to market prices for fossil fuels. Against the Current Policies scenario—a scenario that assumes up to a price of USD 145 per barrel of oil by 2050 and takes the climate change to above 5°C—the emission reduction from combustion is estimated up to 37 gigatonnes (Gt) of CO₂. This is equivalent to 6 per cent of the reduction²⁵ that we need to reach the 2°C target with a 66 per cent chance of success, or 4 per cent of the reduction that we need to reach the 1.5°C target with a 50 per cent chance (see Table 8 for aggregate estimates of avoided emissions over 2017–2050).

This cumulative reduction of up to 37 Gt of CO₂ over 2017–2050 averages at approximately 1.1 Gt of CO₂ per year, or 2 per cent relative to the Current Policies baseline in the period 2017–2050. This would be roughly equivalent to eliminating all emissions from the aviation sector: according to business-as-usual projections, between 2016 and 2050 global aviation would generate an estimated 43 Gt of CO₂ emissions (Pardee, 2015).

If, by contrast, fossil fuel prices remain at the level of 2015–2016 (approximately USD 50 per barrel for oil), 138 Gt of CO₂ in energy reserves affected by production subsidy removal would never be extracted.²⁶ This is because while these reserves remain uneconomical to produce due to both low prices and production subsidy removal, the role of these fossil fuels in providing energy services would be taken by other energy sources, including renewables. These energy reserves would thus not be burned, bringing the aggregate CO₂ emissions reduction up to 175 (37+138) Gt of CO₂ over 2017–2050. This is equivalent to 29 per cent of the reduction²⁷ that we need to reach the 2°C target with a 66 per cent chance of success, or 17 per cent of the reduction that we need to reach the 1.5°C target with a 50 per cent chance.

²⁵ Under the Current Policies scenario, the projected emissions over 2017–2050 will amount to 1,395 Gt. Compared with the carbon budgets presented in Table 1, this means an overshoot of 1,045 Gt over the target compatible with 50 per cent of 1.5°C, and an overshoot of 595 Gt over the target compatible with 66 per cent chance of 2°C.

²⁶ This is a simplified hypothetical interpretation for CO₂ emissions only, while the simulation for the Current Policies scenario is for all GHG emissions, not just CO₂. In this interpretation, we also assume that only fossil fuel prices change due to exogenous factors, and all other factors remain the same as in the Current Policies scenario.

²⁷ Under the Current Policies scenario, the projected emissions over 2017–2050 will amount to 1,395 Gt. Compared with the carbon budgets presented in Table 1, this means an overshoot of 1,045 Gt over the target compatible with 50 per cent chance of 1.5°C, and an overshoot of 595 Gt over the target compatible with 66 per cent chance of 2°C.

Thus, depending on fossil fuel prices, the GHG emission reductions from a removal of production subsidies could be anywhere between 37 and 175 Gt of CO₂, and, provided that demand for fossil fuels follows the baseline, the lower market prices for fossil fuels will be, the greater the climate benefits of a production subsidy removal (see Table 8 for aggregate estimates of avoided emissions over 2017–2050).

Overall, the climate benefits are likely to be underestimated in the GSI-IF(p) simulations for several reasons. First, underlying estimates of subsidies to fossil fuel production rely on incomplete data, whereas many of the already-identified subsidies in G20 countries have yet to be quantified. Second, for the input data it assumes that most subsidies are targeted at all production and not just marginal fields. Third, the modelling itself focuses on the emissions reductions and energy reserves rendered uneconomical to produce as a result of demand response to changes in production, which, in turn, is triggered by subsidy removal. It does not capture several other important factors discussed below with view to future research, such as a possible domino effect of subsidy removal on private sector divestment.

At the same time, these conservative estimates place the phase-out of subsidies to fossil fuel production on the policy-makers' table as a solid option among other climate change mitigation policies. This is particularly true for the countries that are significant producers of fossil fuels, since the GHG savings for them will be greater.

Table 8. Emissions* from energy combustion avoided as a result of fossil fuel production subsidy removal over 2017–2050

Price scenario	No multiplier for capex subsidies	Multiplier of 2.5 for capex subsidies	Multiplier of 3 for capex subsidies
Prices to up to USD 145 per barrel of oil by 2050 and also increase for natural gas and coal	22 Gt of CO ₂ equivalent for all avoided GHG emissions = 3.6 times CO ₂ emission allowances and offsets traded globally in 2015**	33 Gt of CO ₂ equivalent for all avoided GHG emissions = global CO ₂ emissions from fuel combustion in 2015	37 Gt of CO ₂ equivalent for all avoided GHG emissions = nearly all estimated global CO ₂ emissions in 2015
Prices remain constant during 2017–2050 at the same level as in 2015–2016, cost curve for Australia export coal	Up to 157 Gt of CO ₂ only (120 Gt + 37 Gt) = estimated global CO ₂ emissions for four recent years, 2012–2015		
Prices remain constant during 2017–2050 at the same level as in 2015–2016, cost curve for PRB coal	Up to 175 Gt of CO ₂ only (138 Gt + 37 Gt) = 29% of the reduction that we need to reach the 2°C target with a 66% chance of success		

Source: Authors' calculations.

* Based on BP (2016). Global CO₂ emissions from fuel combustion are smaller than all global CO₂ emissions since the latter also include emissions from industrial processes and the cement sector. In 2015 global CO₂ emissions from all sectors were projected to be 39.2 Gt CO₂ (Le Quéré et al., 2015).

** CO₂ emission allowances and offsets traded globally in 2015 equaled 6.2 Gt (Allcot Group, 2016).



FAQ # 5. WHY CAN THE IMPACT OF SUBSIDY REMOVAL ON RESERVES (IN GT) BE GREATER THAN THE PARALLEL IMPACT ON ANNUAL GHG EMISSION REDUCTIONS?

The removal of fossil fuel production subsidies is projected to have large impacts on reserves (and on the corresponding CO₂ content) and more contained impacts on the annual amount of emissions resulting from the burning of fossil fuels, for any given year. Let's look at this step by step.

The removal of fossil fuel production subsidies is expected to increase production costs. An increase of costs, in the absence of changes in the market price, will lead to some reserves becoming uneconomical to produce. Out of all the reserves that become uneconomical to produce, only a small portion will be produced in a given year. This will lead to a relatively small increase in production costs and market price when subsidies are removed, which will then affect demand and consumption.

If the market price increases over time, some of the reserves that were uneconomical to produce due to the removal of subsidies will be produced (e.g., those uneconomical to produce at USD 55/barrel in 2016 will be economical in 2020 if the price rises to USD 70/barrel), while others could become uneconomical if the subsidy is not reintroduced (e.g., the reserves with a breakeven price of USD 75/barrel are uneconomical to produce if a subsidy of USD 5/barrel is not introduced when the market price is at USD 70/barrel).

In this sense, 120–138 Gt of CO₂ equivalent of reserves can still be unlocked post-2050 if fossil fuel prices go up either as a result of market factors or subsidies. By contrast, if the market price of fossil fuels does not change over time, then the full amount of uneconomical reserves will stay in the ground.



KEY CONCLUSIONS AND RECOMMENDATIONS

While this report is just one of the early steps in improving the understanding of the impacts of fossil fuel production subsidies on the climate, its findings conform to the recommendations from the previous body of research on the topic (e.g., Bast, et al. [2015]; GSI [2016]; Fulton, et al. [2015]; Erickson et al. [2017]).

It is increasingly clear that we can only use a small percentage of proven fossil fuel reserves if global warming is to be limited to well below 2°C. In this context, government support flowing to fossil fuel production undermines climate action in three ways. First, fossil fuel subsidies are a negative price on carbon emissions, encouraging higher levels of fossil fuel production and consumption and thus greater emissions. Second, carbon lock-in—aided by subsidies—makes the transition to clean energy more difficult and costly. Third, subsidies unlock unburnable carbon and enable production of “zombie energy”—coal, oil and gas that would not be viable to produce without government support.

While the urgent need to phase out fossil fuel subsidies to consumers has received growing global attention and support, subsidies to fossil fuel production are discussed much less and are often hidden by both governments, and the companies who receive them (Bast et. al., 2015; Whitley & van der Burg, 2015). This is particularly problematic in the context of the recent declines in oil, coal and gas prices that facilitate consumption subsidy removal, but lead fossil fuel producers to demand even greater levels of government support.

As a first step, in their voluntary peer reviews released with the G20 process in September 2016, the United States and China, the world’s two largest emitters, listed several significant subsidies to fossil fuel production (G20, 2016a, 2016b). This is one of the first cases where governments officially put the removal of subsidies to fossil fuel supply on the table of required policy changes.

Summary of Findings

Recognizing this lack of transparent information and attention to the issue, this report is an attempt at estimating the climate benefits of a global removal of subsidies to fossil fuel production.

Subsidies as Signals to Fossil Fuel Producers

Government support to fossil fuel production gives strong signals to investment decision makers. In this context, we find that the most dangerous subsidies for the climate are those that lock in investment into the extraction of fossil fuels on a long-term basis. This includes subsidies to exploration and field development, such as write-offs of these expenses against taxable income. Based solely on the time value of money, a dollar of subsidies that reduce capital costs (for example, accelerated depreciation) has triple the value to investment decision makers compared with a dollar of subsidies that have short-term impacts (for instance, royalty relief for extraction or subsidies to fossil fuel consumption).



Impacts of Removing Fossil Fuel Production Subsidies on GHG Emissions

Our modelling finds that, against the IEA Current Policies scenario,²⁸ a global removal of fossil fuel production subsidies results in estimated GHG emissions reductions of up to 37 Gt of CO₂ equivalent. This translates into up to 6 per cent of the reduction²⁹ needed to reach the 2°C target with a 66 per cent chance of success, or 4 per cent of the reduction that we need to reach the 1.5°C target with a 50 per cent chance.

This cumulative reduction of up to 37 Gt of CO₂ over 2017–2050 averages at approximately 1.1 Gt of CO₂ per year, or 2 per cent relative to the Current Policies baseline in the period 2017–2050. This would be roughly equivalent to eliminating all emissions from the aviation sector.³⁰

Importantly, the GHG emissions reductions relative to the baseline are highly sensitive to the price assumptions. In particular, if we only change one factor in the IEA Current Policies scenario,³¹ namely fix the fossil fuel prices at the level of 2015–2016 (approximately USD 50 per barrel for oil), the aggregate CO₂ emissions reduction would be as high as 175 Gt over 2017–2050. This is equivalent to 29 per cent of the reduction needed to reach the 2°C target with a 66 per cent chance of success, or 17 per cent of the reduction that we need to reach the 1.5°C target with a 50 per cent chance.

Thus, depending on fossil fuel prices, the GHG emission reductions from a removal of production subsidies can be anywhere between 37 and 175 Gt of CO₂, and—provided that demand for fossil fuels follows the baseline—the lower market prices for fossil fuels will be, the greater the climate benefits of a production subsidy removal.

Impact of Removing Fossil Fuel Production Subsidies on Economic Viability of Fossil Fuel Reserves

The reserves of fossil fuels that would be uneconomical to produce as a result of subsidy removal amount to 120–138 Gt of CO₂ over 2017–2050. This is equivalent to 13–15 per cent of all reserves in the existing and under-construction oil and gas fields, and coal mines in 2015 (942 Gt of CO₂—see Muttitt, 2016).

We note that these quantities are not necessarily permanently left in the ground. How much would be permanently left in the ground depends solely on demand response and would equal emission reductions from avoided consumption. In their turn, demand response and emission reductions from avoided consumption are sensitive to price assumptions as described above. Other things equal, the lower the price of fossil fuels, the greater the impact of production subsidy removal in terms of carbon permanently left in the ground, and vice versa. In particular, in our modelling the reserves that would become uneconomical to produce as a result of ending fossil fuel production subsidies could be potentially produced and consumed before 2050 if the prices go above the levels assumed in the IEA Current Policies scenario (USD 145 in 2050). Depending on the price scenario, these reserves could also still be available, and could be exploited after 2050.

²⁸ Our modelling uses the IEA Current Policies scenario as a baseline, a scenario that assumes a price of up to USD 145 per barrel of oil by 2050 and takes climate change to above 5°C in the longer term.

²⁹ Under the Current Policies scenario, the projected emissions over 2017–2050 will amount to 1,395 Gt. Compared with the carbon budgets presented in Table 1, this means an overshoot of 1,045 Gt over the target compatible with a 50 per cent chance of 1.5°C, and an overshoot of 595 Gt over the target compatible with a 66 per cent chance of 2°C.

³⁰ According to business-as-usual projections, between 2016 and 2050 global aviation would generate an estimated 43 Gt of carbon dioxide emissions (Pardee, 2015).

³¹ See Footnote 28. This is a hypothetical scenario where we fix fossil fuel prices at only the 2015–2016 level, while demand for fossil fuels continue to grow and all other parameters and assumptions remain the same as in the IEA Current Policies scenario.



In this sense, the effect of production subsidy removal can be compared with a temporary moratorium on marginal fossil fuels. Meanwhile, we could reasonably expect that the quantity of fossil fuels being produced would be much lower than today if the world has been successful in meeting the Paris Agreement limits. For example, the fossil fuels temporarily rendered uneconomical to produce as a result of production subsidy removal might never become economical if coupled with the removal of fossil fuel consumption subsidies and other demand-side policies.

Next Steps: Further analysis into the impact of removing fossil fuel production subsidies

Our findings are conservative estimates of the potential climate benefits as the underlying modelling is based only on evaluating impacts of the removal of the subset of subsidies (direct spending and tax breaks) for oil, gas and coal production that have already been quantified, and does not include the removal of fossil fuel production subsidies linked to fossil fuel electricity generation.

A lack of transparency in government reporting—and even more hidden subsidies channelled through public loans, guarantees and state-owned enterprises—obscures the full extent of government support to fossil fuels; in addition, due to a lack of data our analysis does not include subsidies to power generation. Governments should work together to establish a reporting system for all fossil fuel subsidies, starting by expanding the current OECD inventory to include all countries. This can also be expanded by peer reviews building on the examples of the China and U.S. voluntary peer review of fossil fuel subsidies published under G20 in 2016.

The climate benefits are likely to be much higher if governments remove all their existing support to the production of fossil fuels, including those subsidies that remain unquantified, and support provided through public finance and state-owned enterprise investments. Capital in the sector is very mobile and highly concentrated within a few multinational companies, which can reinvest profits increased because of subsidies to some of their operations into the development of new supply projects elsewhere. Some subsidies can appear less pernicious than 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.

Moreover, emission reductions, and reserves of oil, gas and coal that could stay in the ground would be even higher if the elimination of upstream production subsidies is coupled with the removal of subsidies to fossil fuel consumption. A backward-looking analysis (Stefanski, 2016) found that global carbon emissions would have been 21 per cent lower between 1980 and 2010 if countries had not subsidized fossil fuels.

In addition to direct impacts, subsidy removal on specific activities may also increase the wider risk perception in the sector, thereby triggering a certain amount of private divestment from fossil fuels.

Furthermore, regulation to address the rising impacts of air pollution, to achieve improvements in energy efficiency, and to increase the competitiveness of renewables and electric vehicles are all making fossil fuel production projects increasingly risky investments. An increasing share of fossil fuel investments are likely to lose money in rapidly transforming energy markets, creating the risk that government support is diverting finite resources to the development of “zombie energy.”



More research is necessary to fill in the gaps as well as to take the modelling to a new level, including through:

- Assessing climate benefits using baseline scenarios consistent with globally agreed climate action (instead of using the IEA Current Policies scenario) to illustrate the full potential of a given mitigation action such as fossil fuel subsidy removal.
- Developing and consolidating better data sets on national subsidies to fossil fuel producers, ideally based on more comprehensive bottom-up inventories in key producing countries, including those outside of G20, particularly for large producers including Iran, Iraq, Venezuela, Columbia and Norway.
- Developing and consolidating better data sets and understanding of the subsidy component (concessional elements) of public finance and state-owned enterprise investment that promote current and future production of fossil fuels.
- Improving understanding of the wider effects of government support to fossil fuel production on investment decisions. Subsidies leverage private capital both directly (in projects that receive subsidies) and more broadly in terms of risk perception, a global subsidy phase-out might trigger a certain amount of wider private divestment from fossil fuels.
- Expanding the scope of modelling to include production subsidies through support to generation of electricity based on fossil fuels—in G20 alone, at least USD 8.5 billion in annual subsidies went to fossil fuel-based power production in 2013–2014. These were only excluded from this analysis due to methodological limitations.
- Expanding the scope of modelling to include the removal of both consumption and production subsidies to fossil fuels and explore the potential of their partial reallocation to support renewable energy and energy efficiency.
- Continued assessments of subsidy removal on project-, policy- and country- specific basis such as Erickson et al. (2017).

Similarly to “shared, but differentiated” climate change responsibility, discussions around “unburnable carbon” and ending production subsidies must take into account equity considerations (Kartha, 2016). This is because governments may use production subsidies to attract investment into fossil fuels, often with the objective of using royalties and other revenues for development. In addition, assessments of supply-side climate policy options including through ending subsidies, must learn lessons from broader conversations in the field of natural resource policies and management such as on the “green paradox,”³² “resource curse,” “Dutch disease” and many more.

It would also be important for policy-makers to see the modelling results for impacts beyond climate benefits, in particular, impacts on public budgets, employment and the wider economy. Fossil fuel subsidy phase-out both upstream and downstream is an important enabling condition for the transition to a green economy, but it is important to understand how it relates to other enabling conditions and green economic policies on the demand-side (for instance, carbon pricing, removal of consumption subsidies, or fuel and energy efficiency standards) and supply-side (for example, phase-out of coal-fired electricity generation or moratoriums on new production)(Harris et al., 2015; Lazarus et al., 2015). The scope of analysis for selection of the most sustainable policies can become very 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.

³² The “green paradox” is the observation that policies aimed at curbing fossil fuel supply and demand can act like an announced expropriation for the owners of fossil fuel resources, encouraging them to accelerate resource extraction and hence to accelerate global warming (Sinn, 2008).



The urgency to reduce emissions in order to comply with the Paris Agreement is huge. The removal of production subsidies would have a significant impact, but it is only one of a number of policies that need to be implemented, e.g. fossil fuel consumption subsidy reform, the phase-out of coal-fired power plants and support for technology innovation. Production subsidy removal is not in competition with these—it is an essential part of the necessary policy package.



References

- Acar, S. & Yeldan, E. (2016, March). Environmental impacts of coal subsidies in Turkey: A general equilibrium analysis. *Energy Policy*, 90, March 2016, 1–15.
- Aldina, J. (2013). *Canada's role as a global coal supplier*. Vancouver: Coal Association of Canada 2013 Conference.
- Aldy, J. (2013). Eliminating fossil fuel subsidies. In: M. Greenstone, Harris, M., Li., K. Looney, A., & Patashnik, J. (Eds.). *15 Ways to rethink the federal budget*. Washington, D.C.: Brookings Institution Press. Retrieved from http://www.hamiltonproject.org/assets/legacy/files/downloads_and_links/THP_15WaysRethinkFedDeficit_Feb13_rev_1.pdf
- Allcot Group. (2016). *Review of carbon markets in 2015 and outlook for 2016–2018*. Retrieved from <http://allcot.umcgroup.fr/blog/review-of-carbon-markets-in-2015-and-outlook-for-2016-2018-107.html>
- Alternatives North. (2006). *Independent report finds Mackenzie Gas Project will be highly profitable and that governments are forgoing billions in potential tax revenue* [Media release]. Retrieved from <https://anotheralt.files.wordpress.com/2016/02/2006-10-18-mgp-economic-analysis-media-release.pdf>
- Anderson, K. & McKibbin, W. J. (2000). Reducing coal subsidies and trade barriers: Their contribution to greenhouse gas abatement. *Environment and Development Economics*, 5(4), 457–81.
- Arora, S. (2012, January). Investment decision making in the upstream oil industry: An analysis. SSRN *Electric Journal*, 13. Retrieved from https://papers.ssrn.com/sol3/papers.cfm?abstract_id=1983123
- Asian Development Bank. (2015). *Fossil fuel subsidies in Asia: Trends, impacts, and reforms integrative report*. Retrieved from <http://www.adb.org/sites/default/files/publication/182255/fossil-fuel-subsidies-asia.pdf>
- Asia-Pacific Economic Cooperation. (2009). *APEC Summit. Leaders' Declaration— Sustaining growth, connecting the region*. Singapore: APEC. Retrieved from http://www.apec.org/Meeting-Papers/Leaders-Declarations/2009/2009_aelm.aspx
- Backus, G., Greene, J., & Masevice, A. (1979). *FOSSIL 79: Documentation* (Three vols.). Hanover NH: Resource Policy Center, Dartmouth College.
- Baker Institute & California Energy. (2012). *Rice World Gas Trade Model* (2012 Natural Gas Market Trends, In Support of the 2012 Integrated Energy Policy Report Update).
- Bassi, A. & Davidsen, P. (2013). *Modeling peak oil: The dynamics of world petroleum resource estimates* (Working Paper 6). Retrieved from http://www.ke-srl.com/KnowlEdge_Srl/Research_files/Modeling%20Peak%20Oil_6.pdf
- Bast, E., Doukas, A. Pickard, S., van der Burg, L., & Whitley, S. (2015). *Empty promises: G20 subsidies to oil, gas and coal production*. London/Washington D.C.: Overseas Development Institute /Oil Change International. Retrieved from: <https://www.odi.org/publications/10058-empty-promises-g20-subsidies-oil-gas-and-coal-production>
- Bast, E., Makhijani, S., Pickard, S. & Whitley, S. (2014). *Fossil fuel bailout: G20 subsidies to oil, gas and coal exploration*. London/Washington D.C.: Overseas Development Institute/Oil Change International. Retrieved from <http://priceofoil.org/content/uploads/2014/11/G20-Fossil-Fuel-Bailout-Full.pdf>



- Baunsgaard, T. (2001). *A primer on mineral taxation*. Washington, D.C.: IMF. Retrieved from <http://www.imf.org/external/pubs/ft/wp/2001/wp01139.pdf>
- Beaton, C., Gerasimchuk, I., Laan, T., Lang, K., Vis-Dunbar, D., & Wooders, P. (2013). *A guidebook to fossil-fuel subsidy reform for policy-makers in Southeast Asia*. Geneva/Winnipeg: IISD-GSI. Retrieved from http://www.iisd.org/gsi/sites/default/files/ffs_guidebook.pdf
- BGR. (2009). *Energierohstoffe 2009—Reserven, Ressourcen, Verfügbarkeit*. Federal Institute for Geoscience.
- BGR. (2010). *Reserves, resources and availability of energy resources*. Federal Institute for Geoscience and Natural Resources.
- BGR. (2012). *Reserves, resources and availability of energy resources*. Federal Institute for Geoscience and Natural Resources.
- Bridle, R., Toft, L. & Merrill, L. (2016). *Building on momentum: Recommendations from the GSI for fossil fuel subsidy reform at the G20*. Geneva/Winnipeg: GSI/IISD. Retrieved from <https://www.iisd.org/library/building-momentum-recommendations-gsi-fossil-fuel-subsidy-reform-g20>
- BP. (2016). *BP Statistical Review of World Energy 2016*. Data workbook. BP. Retrieved from <http://www.bp.com/en/global/corporate/energy-economics/statistical-review-of-world-energy.html>
- Burniaux, J. & Chateau, J. (2014). Greenhouse gases mitigation potential and economic efficiency of phasing-out fossil fuel subsidies. *International Economics*, 140, 71–88. Retrieved from <http://dx.doi.org/10.1016/j.inteco.2014.05.002>
- Carbon Disclosure Project. (2014). *Investor CDP 2014 Information Request Royal Dutch Shell*. London: Carbon Disclosure Project.
- Carbon Pricing Leadership Coalition. (2016). *Carbon Pricing Leadership Coalition*. Retrieved from <http://www.carbonpricingleadership.org/leadership-coalition>
- Carbon Tracker Initiative. (2015a). *Assessing thermal coal production subsidies*. Retrieved from <http://www.carbontracker.org/wp-content/uploads/2015/09/Thermal-Coal-Prod-Subsidies-final-12-9.pdf>
- Carbon Tracker Initiative. (2015b). *Fossil fuel supply in a carbon constrained world*. Retrieved from <https://www.carbontracker.org/wp-content/uploads/2015/11/Fossil-fuel-demand-in-a-carbon-constrained-world-Final.pdf>
- Carbon Tracker Initiative. (2016). *Resources: Key terms*. Retrieved from www.carbontracker.org/resources/
- Chassin, Y. (2014). *Is the Canadian oil industry subsidized?* Retrieved from <http://www.iedm.org/48731-is-the-canadian-oil-industry-subsidized>
- ChinaDialogue. (2016, June 6). *Subsidies blamed for overcapacity in China's coal sector* [Interview with Dr. Liu Qiang]. Retrieved from <https://www.chinadialogue.net/article/show/single/en/8991-Subsidies-blamed-for-overcapacity-in-China-s-coal-sector>
- Choucri, N. (1981). *International energy futures: Petroleum prices, power, and payments*. Cambridge: MIT Press.



Clements, B., Coady, D., Fabrizio, S. Gupta, S., Alleyne, T. & Sdravovich, C. (2013). *Energy Subsidy Reform: Lessons and implications*. International Monetary Fund. Retrieved from <http://www.imf.org/external/np/pp/eng/2013/012813a.pdf>

Climate Test. (2016). *Climate Test*. Retrieved from www.climate-test.org

Coady, D., Parry, I., Sears, L., & Shang, B. (2015). *How large are global energy subsidies?* (IMF Working Paper WP/15/105). Retrieved from <https://www.imf.org/external/pubs/ft/wp/2015/wp15105.pdf>

Cour des Comptes (2013). *Les dépenses fiscales rattachées à la mission écologie, aménagement et développement durables relatives à l'énergie*. Retrieved from <https://www.ccomptes.fr/Publications/Publications/Les-depenses-fiscales-rattachees-a-la-mission-ecologie-amenagement-et-developpement-durables-relatives-a-l-energie>

Deadline to start building Mackenzie Gas Project extended to 2022. (2016). CBC. Retrieved from <http://www.cbc.ca/news/canada/north/mackenzie-gas-project-construction-deadline-extension-1.3613412>

Doukas, A. (2015). *Alaska's oil and gas production tax is now a corporate handout*. Retrieved from <http://priceofoil.org/2015/08/28/alaska-oil-and-gas-production-tax-is-now-a-corporate-handout/>

Durand-Lasserve, O. et al. (2015). *Modelling of distributional impacts of energy subsidy reforms: an illustration with Indonesia* (OECD Environment Working Papers No. 86). OECD Publishing. Retrieved from <http://dx.doi.org/10.1787/5js4k0scrqq5-enc>

EconPöry Management Consulting, Aarsnes, F. & Lindgren, P. (2012). *Fossil fuels – At what cost? Government support to upstream oil and gas in Norway*. Geneva/Winnipeg: GSI/IISD. Retrieved from https://www.iisd.org/gsi/sites/default/files/ffs_awc_norway.pdf

Erickson, P. (2015). *Carbon lock-in from fossil fuel supply infrastructure*, Seattle: Stockholm Environment Institute. Retrieved from <https://www.sei-international.org/mediamanager/documents/Publications/Climate/SEI-DB-2015-Carbon-lock-in-supply-side.pdf>

Erickson, P., Down, A., Lazarus, M., & Koplow, D. (2017). *Effect of government subsidies for upstream oil infrastructure on US oil production and global CO₂ emissions*. Stockholm Environment Institute & EarthTrack. Retrieved from <https://www.sei-international.org/publications?pid=3036>

Erickson, P., & Lazarus, M. (2013). *Accounting for greenhouse gas emissions associated with the supply of fossil fuels* (Discussion brief). Seattle: Stockholm Environment Institute. Retrieved from <https://www.sei-international.org/mediamanager/documents/Publications/Climate/SEI-DB-2013-New-fossil-fuel-economy-2.pdf>

Ernst & Young (2014). *Spotlight on oil and gas megaprojects*. Retrieved from <http://www.ey.com/gl/en/industries/oil--gas/ey-spotlight-on-oil-and-gas-megaprojects#.WAUCTO-7rIU>

Fæhn, T., Hagem, C., Lindholt, L., Mæland, S., & Rosendahl, K.E. (2013, June). *Climate policies in a fossil fuel producing country: Demand versus supply side policies* (Statistics Norway Research department Discussion Paper 747). Oslo: Statistics Norway. Retrieved from https://www.ssb.no/en/forskning/discussion-papers/_attachment/123895?_ts=13f51e5e7c8

Farrell, A. E. (2008). *Energy notes*. News from the University of California Energy, Vol. 6.

Fiddaman, T. S. (1997). *Feedback complexity in integrated climate-economy models*. Cambridge, MA: Sloan School of Management, MIT.



- Forrester, J. W. (1961). *Industrial dynamics*. Cambridge, MA: MIT Press.
- Fulton, M., Buckley, T., Koplow, D., Sussams, L., & Grant, A. (2015). *A framework for assessing thermal coal production subsidies*. London: Energy Transition Advisors, IEEFA, Earth Track, Carbon Tracker Initiative. Retrieved from <https://earthtrack.net/documents/framework-assessing-thermal-coal-production-subsidies>
- G20. (2009). *G20 Leaders Statement: The Pittsburgh Summit*. Retrieved from <http://www.g20.utoronto.ca/2009/2009communique0925.html>
- G20. (2016a). *China's efforts to phase out and rationalise its inefficient fossil-fuel subsidies*. Retrieved from <http://www.oecd.org/site/tadffss/publication/>
- G20. (2016b). *The United States' efforts to phase out and rationalise its inefficient fossil fuel subsidies*. Retrieved from <http://www.oecd.org/site/tadffss/publication/>
- Gas Research Institute. (1990). *GRI baseline projection of the US energy supply and demand to 2010*. Washington DC: Gas Research Institute, Strategy Plan Analysis Division.
- Gass, P., Duan, X. & Gerasimchuk, I. (2016). *Stories of coal phase-out: Lessons learned for China*. Geneva: IISD.
- Global Subsidies Initiative. (n.d.). *Fossil fuels - At what cost?*, Geneva: GSI (Global Subsidies Initiative). Retrieved from <https://www.iisd.org/gsi/fossil-fuel-subsidies/fossil-fuels-what-cost>
- Global Subsidies Initiative. (2006). *A subsidies primer*. Geneva: IISD. <https://www.iisd.org/gsi/subsidy-primer>
- Global Subsidies Initiative. (2014). *Comparison of fossil-fuel subsidy and support estimates*. Retrieved from http://www.iisd.org/gsi/sites/default/files/ffs_methods_estimationcomparison.pdf
- Global Subsidies Initiative. (2016). *Building on momentum: Recommendation from the GSI for fossil fuel subsidy reform at the G20*. Winnipeg/Geneva: IISD/GSI. Retrieved from <http://www.iisd.org/sites/default/files/publications/building-on-momentum-recommendations-ffsr-g20.pdf>
- Harris, M., Beck, M., & Gerasimchuk, I. (2015). *The end of coal: Ontario's coal phase-out*. Winnipeg: IISD. Retrieved from <http://www.iisd.org/library/end-coal-ontarios-coal-phase-out>
- Ibarrarán, M. E., Bassi, A.M, & Boyd, R. (2015). Integrating SD + CGE models to assess green economy policies: Methods and application to Mexico.
- Insurers call on G20 to phase out fossil fuel subsidies by 2020. (2016, August 29). *Reuters*, Retrieved from <http://www.reuters.com/article/us-g20-climatechange-idUSKCN1142GN>
- Intergovernmental Panel on Climate Change. (2006). *2006 IPCC Guidelines for National Greenhouse Gas Inventories. Vol. 2*. Geneva: IPCC. Retrieved from http://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/2_Volume2/V2_1_Ch1_Introduction.pdf
- Intergovernmental Panel on Climate Change. (2007). *Climate Change 2007: Impacts, adaptation and vulnerability*. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Retrieved from https://www.ipcc.ch/pdf/assessment-report/ar4/wg2/ar4_wg2_full_report.pdf
- Intergovernmental Panel on Climate Change. (2014a). *Climate change 2014: Mitigation of climate change*, Geneva: IPCC. Retrieved from https://www.ipcc.ch/pdf/assessment-report/ar5/wg3/ipcc_wg3_ar5_full.pdf



Intergovernmental Panel on Climate Change. (2014b). Climate Change 2014, Synthesis Report, table 2.2, p.68, http://ipcc.ch/pdf/assessment-report/ar5/syr/AR5_SYR_FINAL_All_Topics.pdf

International Energy Agency. (2013). Redrawing the energy-climate map. Paris: IEA. Retrieved from http://www.iea.org/publications/freepublications/publication/weo_special_report_2013_redrawing_the_energy_climate_map.pdf

International Energy Agency. (2015a). *Energy and climate change. World Energy Outlook special report*. Paris: IEA. Retrieved from <https://www.iea.org/publications/freepublications/publication/WEO2015SpecialReportonEnergyandClimateChange.pdf>

International Energy Agency. (2015b). *Energy subsidies*. Retrieved from www.worldenergyoutlook.org/resources/energysubsidies

International Energy Agency. (2015c). *World Energy Outlook 2015*. Paris: IEA. Retrieved from <http://www.worldenergyoutlook.org/weo2015/>

International Energy Agency. (2016). *IEA statistics: Energy balance flows*. Retrieved from <http://www.iea.org/statistics/>

International Monetary Fund. (2015). *How large are global energy subsidies?* Washington, D.C.: IMF. Retrieved from <https://www.imf.org/external/pubs/ft/wp/2015/wp15105.pdf>

Jahn F., Cook M., & Graham M. (Eds.). (2008). Chapter 1. The field life cycle. In: *Hydrocarbon Exploration and Production* (2nd edition). Elsevier.

Johnston, D. (2003). *International exploration, economics, risks and contract analysis*. Tulsa: PennWell Books.

Kartha, S. (2016). *Fossil fuel production in a 2°C world: The equity implications of a diminishing carbon budget*. Discussion Brief. Stockholm: Stockholm Environment Institute. Available from <https://www.sei-international.org/mediamanager/documents/Publications/Climate/SEI-DB-2016-Equity-fossil-fuel-production-rents.pdf>

Kasriel, K. & Wood, D. (2013). *Upstream petroleum fiscal and valuation modeling in Excel: A worked examples approach*. New York: Wiley.

Kojima, M. & Koplów, D. (2015). *Fossil fuel subsidies: Approaches and valuation*. Washington, D.C.: World Bank. Retrieved from <http://documents.worldbank.org/curated/en/961661467990086330/Fossil-fuel-subsidies-approaches-and-valuation>

Koplów, D., Lin, C., Jung, A. & Thone, M. (2010). *Mapping the characteristics of producer subsidies: A review of pilot country studies*, Geneva: Global Subsidies Initiative. Retrieved from https://www.iisd.org/gsi/sites/default/files/mapping_ffs.pdf

Krauss, C. (2013). To reinvigorate production, Alaska grants a tax break to oil companies. *The New York Times*. Retrieved from http://www.nytimes.com/2013/04/16/business/energy-environment/alaska-grants-a-tax-break-to-oil-companies.html?_r=0

Kretzmann, S. (2015). *A convenient lie: Why fossil fuel supply matters for the climate*. Washington, D.C.: Oil Change International.

Lang, K. (2010). *Defining fossil-fuel subsidies for the G-20: Which approach is best?* Geneva/Winnipeg: GSI/IISD. Retrieved from <https://www.iisd.org/gsi/march-2010-defining-fossil-fuel-subsidies-g-20-which-approach-best>



- Larson, B. (1994), *World fossil fuel subsidies and global carbon emissions in a model with interfuel substitution* (Background paper). Washington, DC: World Bank. Retrieved from <http://documents.worldbank.org/curated/en/1994/02/442269/world-fossil-fuel-subsidies-global-carbon-emissions-model-interfuel-substitution>
- Larson, B., & Shaw, A. (1992). *World fossil fuel subsidies and global carbon emissions* (Background Paper No 25 for the World Development Report). Washington, DC.: World Bank. Retrieved from <http://documents.worldbank.org/curated/en/1992/10/699563/world-fossil-fuel-subsidies-global-carbon-emissions>
- Lazarus, M., Erickson, P. & Tempest, K. (2015). *Supply-side climate policy: The road less taken*, Seattle: Stockholm Environment Institute. Retrieved from http://sei-us.org/Publications_PDF/SEI-WP-2015-13-Supply-side-climate-policy.pdf
- Leidos Inc. (2014). *Global natural gas markets overview*. EIA. Retrieved from https://www.eia.gov/workingpapers/pdf/global_gas.pdf
- Lewis, B. (2016). Pressure mounts on G20 for fossil fuel subsidies deadline. *Reuters*. Retrieved from <http://www.reuters.com/article/us-g20-finance-energy-subsidies-idUSKCN0ZE1XI>
- Lewis, M., Robins, N., & Cleveland, S. (2015). *Carbon supply cost curves: Evaluating financial risk to gas capital expenditures*. Carbon Tracker. Retrieved from <http://www.carbontracker.org/wp-content/uploads/2015/06/CTI-gas-report-Final-WEB.pdf>
- Lin, B. & Ouyang, X. (2014). A revisit of fossil-fuel subsidies in China: Challenges and opportunities for energy price reform. *Energy Conversion and Management*, 82, 124–134.
- Lunden, L. & Fjaertoft, D. (2014). *Government support to upstream oil & gas in Russia: How subsidies influence the Yamal LNG and Prirazlomnoe projects.*, Geneva, Moscow, Oslo: IISD-GSI, WWF Russia, Sigra Group. Retrieved from https://www.iisd.org/gsi/sites/default/files/ffs_awc_russia_yamalpirazlomnoe_en.pdf
- McCullum, D. Bauer, N. Calvin, K., Kitous, A. & Riahi, K. (2014). Fossil resource and energy security dynamics in conventional and carbon-constrained worlds. *Climatic change* 123(3–4), 413–426. Retrieved from <https://www.pik-potsdam.de/members/nicolasb/mccollum-authors-copy-10-1007-s10584-013-0939-5.pdf>
- McGlade, C. & Ekins, P. (2015). The geographical distribution of fossil fuels unused when limiting global warming to 2 °C. *Nature Climate Change*, 187–190.
- Mendelevitch, R. (2015). *Leaving coal unburned: Options for demand-side and supply-side policies*. Berlin: DIW Roundup. Retrieved from https://www.diw.de/de/diw_01.c.522192.de/presse/diw_roundup/leaving_coal_unburned_options_for_demand_side_and_supply_side_policies.html
- Merrill, L., Bassi, A., Bridle, R. & Christensen, L. (2015a). *Tackling fossil fuel subsidies and climate change: Levelling the energy playing field.*, Copenhagen: Nordic Council of Ministers. Retrieved from <http://www.iisd.org/library/tackling-fossil-fuel-subsidies-and-climate-change>
- Merrill, L., Harris, M., Casier, L. & Bassi, A. (2015b). *Fossil-fuel subsidies and climate change: Options for policy-makers within their Intended Nationally Determined Contributions*. Copenhagen: Nordic Council of Ministers. Retrieved from <https://www.iisd.org/gsi/fossil-fuel-subsidies-and-climate-change>
- Metcalf, G. (2016, August). *The impact of removing tax preferences for U.S. oil and gas production*. New York City and Washington, D.C.: Council on Foreign Relations. Retrieved from <http://www.cfr.org/energy-policy/impact-removing-tax-preferences-us-oil-gas-production/p38150>



- Muttitt, G. (2016). *The sky's limit. Why The Paris Climate Goals require a managed decline of fossil fuel production*. Oil Change International: Washington, D.C. Retrieved from <http://priceofoil.org/2016/09/22/the-skys-limit-report/>
- Naill, R. F. (1977). *Managing the energy transition*. Cambridge, MA: Ballinger.
- New Climate Economy. (2014). *Economy, N.C., 2014. Better growth, better climate: The new climate economy report*. New Climate Economy. Retrieved from <http://newclimateeconomy.report/2014/>
- No tax breaks yet for Shtokman-Russia dep finmin. (2012). *Reuters*. Retrieved from <http://www.reuters.com/article/russia-gas-shtokman-idUSL6E8EN4PF20120323>
- North Sea oil industry calls for rescue package of tax breaks in budget. (2016, March 8). *The Guardian*. Retrieved from <https://www.theguardian.com/business/2016/mar/08/north-sea-oil-industry-calls-for-rescue-package-of-tax-breaks-in-budget>
- North Sea receipts hit record low. (2016, May 26). *BBC News*. Retrieved from <http://www.bbc.com/news/uk-scotland-scotland-business-36388621>
- Office of the Auditor General of Canada (2012). *Fall Report of the Commissioner of the Environment and Sustainable Development*. Ottawa, ON: Office of the Auditor General of Canada. Retrieved from www.oag-bvg.gc.ca/internet/English/parl_cesd_201212_04_e_37713.html
- Ogarenko, I., & Hubacek, K. (2013). Eliminating indirect energy subsidies in Ukraine: Estimation of environmental and socioeconomic effects using input-output modeling. *Journal of Economic Structures*, 2(7). Retrieved from <http://journalofeconomicstructures.springeropen.com/articles/10.1186/2193-2409-2-7>
- Oliphant, R. (2012). Gazprom puts Shtokman and partners on the shelf. *The Moscow Times*. Retrieved from <https://themoscowtimes.com/articles/gazprom-puts-shtokman-and-partners-on-the-shelf-17389>
- Oosterhuis, F., Ding, H., Franckx, L., Razzini, P., and Member State Experts. (2014). *Enhancing Comparability of Data on Estimated Budgetary Support and Tax Expenditures for Fossil Fuels: Final Report*. Retrieved from http://ec.europa.eu/environment/enveco/taxation/pdf/201412ffs_final_report.pdf
- Organisation for Economic Co-operation and Development. (2010). *Measuring support to energy, Version 1.0*. Paris: OECD. Retrieved from <http://www.oecd.org/env/45339216.pdf>
- Organisation for Economic Co-operation and Development. (2013). *Effective carbon prices*. Paris: OECD. doi 10.1787/9789264196964-en
- Organisation for Economic Co-operation and Development. (2015). *Inventory of support measures for fossil fuels*. Paris: OECD. Retrieved from <http://www.oecd.org/trade/oecd-companion-to-the-inventory-of-support-measures-for-fossil-fuels-2015-9789264239616-en.htm>
- Organisation for Economic Co-operation and Development. (2016). Description of the ENV-Linkages model. *In The Economic Consequences of Outdoor Air Pollution*. Paris: OECD. Retrieved from http://www.oecd-ilibrary.org/environment/the-economic-consequences-of-outdoor-air-pollution_9789264257474-en
- Pardee, V. (2015) *Up in the air: How airplane carbon pollution jeopardizes global climate goals*. Center for Biological Diversity. Retrieved from http://www.biologicaldiversity.org/programs/climate_law_institute/transportation_and_global_warming/airplane_emissions/pdfs/Airplane_Pollution_Report_December2015.pdf



- Park, G. (2007). Mackenzie gas line wanted — alive, but not at any price. *Petroleum News*. Retrieved from <http://www.petroleumnews.com/pntruncate/938607505.shtml>
- Le Quéré et al. (2015). Global Carbon Budget 2015. *Earth System Science Data*, 7, 371–374. Retrieved from <http://www.earth-syst-sci-data.net/7/349/2015/essd-7-349-2015.pdf>
- Ricardo, D. (1821). *On the principles of political economy and taxation*. London.
- Richardson, G. P., & Pugh, A. L. (1981). *Introduction to system dynamics modeling With DYNAMO*. Cambridge: MIT Press.
- Rogner, H.-H. (1997). An assessment of world hydrocarbon resources. *Annual review of energy and the environment* 22, 217–262. Retrieved from <http://nilsrotgans.nl/work/portfolio/academy/carbon%20footprint/sketch/sketch/les%203/annurev.energy.22.1.217.pdf>
- Rogner, H.-H. (2012). *Global energy assessment – Toward a sustainable future, Chapter 7*. Cambridge UK/New York, NY/Laxenburg, Austria: Cambridge University Press/International Institute for Applied Systems Analysis.
- Rystad Energy (2016). *Rystad Energy UCube Upstream Database*. Retrieved from <http://www.rystadenergy.com/Databases/UCube>
- Sawyer, D. & Stiebert, S. (2010). *Fossil Fuels: At what cost? Government support for upstream oil activities in three Canadian provinces: Alberta, Saskatchewan, and Newfoundland and Labrador*, Winnipeg & Geneva: International Institute for Sustainable Development. Retrieved from https://www.iisd.org/gsi/sites/default/files/ffs_awc_3canprovinces.pdf
- Schaeffer, M., Rogelj, J., Roming, N., Sferra, F., Hare, B., & Serdeczny, O. (2015). *Feasibility of limiting warming to 1.5 and 2 C*, Berlin: Climate Analytics. Clymate Analytics: Berlin. Retrieved from http://climateanalytics.org/files/feasibility_1o5c_2c.pdf
- Schlumberger Limited. (n.d.). *Oilfield glossary*. Retrieved from http://www.glossary.oilfield.slb.com/Terms/government_take.aspx
- Schwanitz, V.J., Piontek, F., Bertram, C., & Luderer, G. (2014). Long-term climate policy implications of phasing out fossil fuel subsidies. *Energy Policy*, 67, 882–894.
- Shafiee, S., Nehring, M. & Topal, E. (2009). Estimating average total cost of open pit coal mines in Australia. *Proceedings Australian Mining Technology Conference*, 134–145. Retrieved from <http://www.infomine.com/library/publications/docs/Shafiee2009a.pdf>
- Sinn, H. W. (2008). Public policies against global warming: A supply side approach. *International Tax and Public Finance*, 15(4), 360–394. doi:10.1007/s10797-008-9082-z
- Steenblik, R. & Coroyannakis, P. (1995). Reform of coal policies in Western and Central Europe: Implications for the environment. *Energy Policy*, 23(6), 537–553.
- Stefanski, R. (2016). Into the mire: A closer look at fossil fuel subsidies. *School of Public Policy SPP Research Papers*, 9(10). Retrieved from <https://www.policyschool.ca/wp-content/uploads/2016/05/fossil-fuels-stefanski.pdf>
- Sterman, J. D. (1983). Economic vulnerability and the energy transition. *Energy Systems and Policy* 7(4), 259–301.



- Sterman, J. D. (2000). *Business dynamics: Systems thinking and modeling for a complex world*. Boston: Irwin/McGraw-Hill.
- Sterman, J. D., & Richardson, G. P. (1985). An experiment to evaluate methods for estimating fossil fuel resources. *Journal of Forecasting*, 197–226.
- Shell abandons Alaska Arctic drilling. (2015, September 28). *The Guardian*. Retrieved from <https://www.theguardian.com/business/2015/sep/28/shell-ceases-alaska-arctic-drilling-exploratory-well-oil-gas-disappoints>
- Shtokman tax break expected soon*. (2011). *The Moscow Times*. Retrieved from <https://themoscowtimes.com/articles/shtokman-tax-break-expected-soon-10240>
- Turcan, C. (2014). *After tax cut, ConocoPhillips expands Alpine Field In Alaska*. Retrieved from <http://seekingalpha.com/article/2779835-after-tax-cut-conocophillips-expands-alpine-field-in-alaska>
- UK Department of Energy and Climate Change. (2015, August 17). Response to Freedom of Information Request. Retrieved from https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/455512/FOI_2015_15038_PUB.pdf
- UK Parliament. (2013). *Energy subsidies in the UK*. Commons Select Committee. Retrieved from www.parliament.uk/business/committees/committees-a-z/commonsselect/environmental-audit-committee/inquiries/parliament-2010/energysubsidies-in-the-uk/
- United Nations (2015). *Addis Ababa Action Agenda*. Retrieved from http://www.un.org/esa/ffd/wp-content/uploads/2015/08/AAAA_Outcome.pdf
- United Nations Framework Convention on Climate Change. (2015). *Paris Agreement*. Retrieved from <https://unfccc.int/resource/docs/2015/cop21/eng/109r01.pdf>
- United Nations Environment Programme. (2015). *The emissions gap 2015 – Executive summary*. UNEP. Retrieved from http://uneplive.unep.org/media/docs/theme/13/EGR_2015_ES_English_Embargoed.pdf
- US Environmental Protection Agency. (n.d.). *GHG equivalencies calculator - Calculations and references*. US EPA: Washington, D.C. Retrieved from <https://www.epa.gov/energy/ghg-equivalencies-calculator-calculations-and-references>
- United States Geological Survey. (1976). *Principles of the Mineral Resource Classification System of the U.S. Bureau of Mines and U.S. Geological Survey (USGS Bulletin 1450-A)*. Washington, D.C. Retrieved from <https://pubs.usgs.gov/bul/1450a/report.pdf>
- United States Geological Survey. (2000). *World petroleum assessment*. Retrieved from <https://pubs.usgs.gov/fs/fs-062-03/FS-062-03.pdf>
- Van den Bergh, K., & Delarue, E. (2015). Quantifying CO₂ abatement costs in the power sector. *Energy Policy*, 80, 88–97.
- Victor, D. (2009). *The politics of fossil-fuel subsidies*. Geneva/Winnipeg: GSI/IISD. Retrieved from http://www.iisd.org/gsi/sites/default/files/politics_ffs.pdf
- What is a zombie bank? Definition and meaning. (n.d.). *Market Business News*. Retrieved from <http://marketbusinessnews.com/financial-glossary/zombie-bank/>



Whitley, S. & van der Burg, L. (2015). *Fossil fuel subsidy reform: From rhetoric to reality*, London: New Climate Economy. Retrieved from http://www.greenfiscalspolicy.org/wp-content/uploads/2015/11/Fossil-fuel-subsidy-reform_from-rhetoric-to-reality.pdf

Wildau, G. (2016, February 29). China's: The state-owned zombie economy. *The Financial Times*. Retrieved from <https://www.ft.com/content/253d7eb0-ca6c-11e5-84df-70594b99fc47>

WoodMackenzie. (2013). *Impacts of delaying IDC deductibility (2014–2025)*. Prepared for the American Petroleum Institute. Washington, D.C. Retrieved from <http://www.api.org/~media/Files/Policy/Taxes/13-July/API-US-IDC-Delay-Impacts-Release-7-11-13.pdf>

World Bank. (2016). *World Development Indicators*. Retrieved from <http://databank.worldbank.org/data/reports.aspx?source=world-development-indicators>

World Energy Council. (2007). *Survey of energy resources*. World Energy Council. Retrieved from <https://www.worldenergy.org/publications/2007/2007-global-energy-survey/>

World Trade Organization. (1994). *Uruguay Round Agreement: Agreement on subsidies and countervailing measures, Article 1-9*. Geneva, World Trade Organization. Retrieved from https://www.wto.org/english/docs_e/legal_e/24-scm.pdf

Zhao, H., Dahl, C., & Luo, D. (2015, May). *How OECD countries subsidize oil and natural gas producers and modeling the consequences: A review with recommendations*. Golden, CO: Colorado School of Mines. Retrieved from <http://econbus.mines.edu/working-papers/wp201503>.



ANNEX A. Existing Research on the Climate Impact of Removing Fossil Fuel Subsidies

This Annex provides a brief overview of existing studies on the impact of removing fossil fuel subsidies to consumer subsidies (Part I) and producer subsidies (Part II).

There is only one study—Stefanski (2016)—that looks at the climate benefits of removing subsidies to all fossil fuels and at a global level (including both subsidies to production and consumption). Stefanski looked at past differences in country energy profiles that could not be explained by other factors, and made an assumption the residual differences are explained by government support (through fossil fuel subsidies). Stefanski's work estimated that carbon emissions would have been 20.7 per cent lower between 1980 and 2010 had fossil fuels not been supported by governments through both consumption and production subsidies.

All other previous studies only look at partial removal of subsidies—only subsidies to consumption (globally, or at a country level, for all fuels or only for some), or only subsidies to production (in a particular country or at project level, or for a particular type of fuel).

PART I. What Do We Know About the Climate Impact of Fossil Fuel Consumption Subsidies and Their Reform?

There is growing research on and interest in the climate benefits of removing fossil fuels subsidies, which thus far has focused on consumption subsidies at both the global and national levels. A number of studies have modelled the climate benefits of subsidy removal globally and for individual countries. An updated overview of this research, first presented in 2015 (Merrill, et al., 2015b) is given in Table A1 below. The range of emissions reductions from the phase-out of consumption fossil fuel subsidies is very broad depending on the scenarios utilized, the countries included in the modelling, the scale of the subsidies, the definition used and the time frame for phase-out.

Research on the relationship between the phase-out of consumption fossil fuel subsidies and emissions reductions also stresses that although the removal of subsidies to consumption does lead to domestic and international reductions in GHG emissions, it is no substitute for a global climate agreement with a clear cap on emissions and clear climate policies (IEA, 2015; Merrill, et al., 2015a; Burniaux & Chateau, 2014; Schwanitz et al., 2014). For example, research has found that fossil fuel subsidy reform in the presence of an emissions cap, leads to greater emissions reductions of around 8 per cent to 10 per cent and locks in the reductions from reforms over the long term (Burniaux & Chateau, 2014).

Much discussion in the studies outlined below is given over to: 1) the problem of leakage (Schwanitz et al, 2014; Burniaux & Chateau, 2014); 2) the size of the subsidies; 3) the price of oil; 4) modelling of savings from FFSR being redirected into coal (Schwanitz et al., 2014); 5) price elasticities (Merrill et. al., 2015a); and 6) impacts on the electricity merit order and fuel switching (Van den Bergh & Delarue, 2015). For a full review of these influences and outcomes see Merrill et al. (2015b).



Table A1. Emissions reductions scenarios from removal of fossil fuel consumption subsidies, existing research

Emissions Reduction Range (from removing consumption subsidies)	Study and its main findings
Global assessments for all fuels	
5–9% and 7%	9% reduction globally assuming no change in the oil price and a 5% reduction globally assuming a change in the oil price from removal of USD 230 billion of subsidies. An equivalent reduction in carbon emissions could be achieved by an OECD carbon tax of in the order of USD 50–90 per tonne (Larson & Shaw, 1992). A 7% reduction in emissions from removal of USD 210 billion subsidies, accounting for inter-fuel substitution. Reduction of national carbon emissions by more than 20% relative to the baseline emissions in some countries (Larson, 1994).
18.1–22.9%	An 18.1–22.9% decrease in carbon dioxide emissions based on global removal of consumer pre- and post-tax fossil fuel subsidies (Coady, Parry, Sears, & Shang, 2015).
10% by 2030 (energy sector emissions only)	A 10% reduction in energy sector emissions by 2030, from accelerating the (partial) phase-out of subsidies to fossil fuel consumption (part of the IEA's Bridge Scenario, which also includes improvements in energy efficiency [49%], limiting construction and use of least-efficient coal-fired plants [9%], minimizing methane emissions from upstream oil and gas production [15%] and renewables investment [17%]) (IEA, 2015). FFSR moderating the growth in demand as well as supporting energy efficiency, and the only end user price considered in this scenario of energy sector measures (IEA, 2014).
8.2% by 2050, 2.5% by 2020	An 8% reduction in global GHG emissions of 6.1 gigatonnes of carbon dioxide (by 2050) from a staggered removal of consumer fossil fuel subsidies based on 2008 subsidy figures. An emissions cap on OECD countries and Brazil increases the reduction to 10% (Burniaux & Chateau, 2014, Table 2, p. 16).
3% by 2020	A multilateral phase-out of energy consumption subsidies leads to 3% global GHG emission reductions at horizon 2020 relative to the baseline (Durand-Lasserre, et al., 2015, p. 53.) For a description of the OECD Environmental-Linkages Model see OECD (2016) pp. 101–105.
0.6%–2.7% by 2100 depending on the scenario	The report confirms “the short-term benefits of phasing out fossil fuel subsidies as found in prior studies. However, these benefits are only sustainable to a small extent in the long term if dedicated climate policies are weak or non-existent” (Schwanitz et al, 2014, p.882). “Over the whole time frame, until 2100 the cumulative savings range from 50.6Gt (0.6%) in the G20 phase-out scenario to 220.8 Gt (2.7%) in the scenario Zero2020” (p.886).
Country-level assessments	
Various, depending on the country	Country-specific reductions: China, a 3.72% carbon dioxide reduction between 2006 and 2010 (Lin & Ouyang, 2014); India: 1.3–1.8%, Indonesia: 5.1–9.3%, Thailand: 2.8% by 2030 (ADB, 2015); Indonesia 7.9–8.3% 2020 (Durand-Lasserre et al., 2015); Ukraine, 3.6% reduction or 15 million tonnes of CO ₂ e (Ogarenko & Hubacek, 2013); Mexico, 34 million tonnes of CO ₂ e saved every year between 2014–2035 from a mix of Green Growth transport measures including FFSR giving a NPV of USD 193,300 million between that period (Ibarrarán, Bassi, & Boyd, 2015).
Average of 11% in 2020 from 20 countries, total of 2.82 Gt of CO ₂ equivalent	Average of 11% in 2020 from across 20 countries (country (as a % of national emissions reductions): Algeria (22%), Bangladesh (9%), China (1%), Egypt (15%), Ghana (3%), India (3%), Indonesia (7%), Iran (18%), Iraq (41%), Morocco (2%), Nigeria (2%), Pakistan (3%), Russia (6%), Saudi Arabia (30%), Sri Lanka (2%), Tunisia (6%), UAE (14%), US (0.2%), Venezuela (34%), and Vietnam (2%)). This average across 20 countries rises to 18% by 2020 with modest recycling of saved revenues toward renewables (10%) and energy efficiency (20%). Average annual government savings of USD 93 per tonne of CO ₂ abated. (Merrill et al. 2015a).

Source: Authors' summary based on Merrill et al. (2015a) and Merrill et al. (2015b) updated and corrected.



PART II. What Do We Know About the Impact of Fossil Fuel Production Subsidies and Their Reform on Climate Change?

The body of work on fossil fuel production subsidies is limited to the inventories by OECD (OECD, 2015), several NGOs such as GSI, OCI, OCI and EarthTrack (GSI, n.d.; Bast, et al., 2014; Bast, et al., 2015), though interest in the topic is growing in the environmental NGO community and with individual scholars, such as Acar & Yeldan (2016), Anderson & McKibbin (2000) and Stefanski (2016). Historically, work on preferential treatment of fossil fuel production belongs to a wider body of literature on taxation of natural resources, though this literature does not frame tax and royalty relief as subsidy (i.e., Ricardo, 1821; Baunsgaard, 2001; Johnston, 2003). More recently, fossil fuel production subsidy reform became an issue for research on supply-side mitigation measures (Faehn, et al., 2013; Lazarus, et al., 2015; Fulton, et al., 2015; Mendelevitch, 2015).

The emerging research on climate impacts of fossil production subsidy reform is still in the early stages in the policy community.

An overview of the existing country-level assessments of climate impacts of producer subsidies is presented in Table A2. Most studies stick to demand-side metrics—that is, emission reductions from demand response to producer subsidy reform through relevant feedback loops. Some studies also present findings using an additional metric—reserves left in the ground as a result of subsidy removal.

Predictably, estimates vary a lot across countries, basins and projects depending on fuels produced, subsidies provided, time horizon and whether or not leakage is taken into account. Percentages of emission reductions relative to the baseline scenario are lower at the global level because only a subset of the world's countries are significant producers of fossil fuels. Emissions savings for these producing countries are higher, as demonstrated by the examples of the United States, Norway, Australia and Turkey.



Table A2. Emissions reductions scenarios from removal of fossil fuel production subsidies, existing research

Emissions Reduction Range (from removing production subsidies)	Study and its main findings
Country-level assessments	
2% (10% in oil sands) by 2020 in Canada	According to the analysis commissioned by the Global Subsidies Initiative, the removal of CAD 2.84 billion in subsidies to upstream oil and gas in Canada would reduce oil production in three Canadian provinces by 5% between 2011 and 2020, and would decrease Canada's emissions by 2% (10% in oil sands). The reform would have almost no impacts on the economy (Sawyer & Stiebert, 2010). The study uses a computable general equilibrium (CGE) model of the Canadian economy.
Around 4% cumulatively for the removal of three subsidies in Norway	Another study prepared for the Global Subsidies Initiative assesses impacts of the removal of three of the largest fiscal subsidies to oil and gas production in Norway: the exploration reimbursements, the investment deductions and the Snohvit field (EconPöyryManagementConsulting, et al., 2012). Removing the investment deductions, which are estimated to be NOK 20.812 billion (USD 3.3 billion) in 2009, would likely reduce government revenue from petroleum taxes by about 5.3%, employment in the oil and gas sector by 0.3% and national CO ₂ emissions by 1%. Removing the exploration reimbursements, estimated at NOK 4.024 billion in 2009, would likely reduce government revenue from petroleum taxes by 2.9%, employment in the oil and gas sector by 0.2% and national CO ₂ emissions by 0.5%. In the case of the Snohvit field, if it had not been subsidized through tailor-made tax breaks, the overall impact would include a reduction in government revenue from petroleum taxes by 13.2%, employment in the oil and gas industry by 0.7% and national CO ₂ emissions by 2.4%. The study relies on bottom-up assessment methods.
10%, or 7 Mt of CO ₂ by 2020 in Norway via introduction of an oil production tax up to USD 50 per barrel	The state-of-the-art assessment by Statistics Norway is one of the very few studies that compares leakage from demand-side and supply-side mitigation measures (Faehn et al., 2013). The study suggests that leakage from supply-side mitigation measures is smaller and for an oil-producing country such as Norway, supply-side mitigation measures can be more effective for emissions reductions. The study discusses a scenario whereby 2020 Norway can reduce its emissions by 10 Mt of CO ₂ , or 15% by 2020 relative to the baseline scenario, including 3 Mt (roughly 5%) by demand-side measures and 7 Mt (roughly by 10%) supply-side measures aimed at reducing oil production. To this end, Norway's oil production should be reduced by 3.4% relative to 2012, which could be achieved, for instance by introducing an additional oil production tax of up to USD50 per barrel. The study does not discuss production subsidies per se, but it is clear that before introduction of an additional oil production tax, their elimination would be a first step. The study uses a combination of models, including a computable general equilibrium (CGE) model of the Norwegian economy, a multi-field model of Norwegian oil production and models estimating global demand and supply of energy.
5% by 2030 in Turkey	An academic study looks at the impacts of eliminating two groups of subsidies in Turkey: subsidies to coal production and regional investment subsidies benefiting the coal mining and coal-fired electricity generation. The value of these subsidies was estimated at USD 730 million in 2013, or USD 11 per MWh of generation. Eliminating coal production subsidies would lead to a 2.5% decline in total CO ₂ (eq) by 2030. Additionally, removal of regional investment subsidies would reduce emission by 5.4%. The impacts on the economy are estimated to be insignificant (Acar & Yeldan, 2016). As a methodological tool for their analysis, the authors developed a regionally differentiated applied general equilibrium model spanning over 2015–2030.



Emissions Reduction Range (from removing production subsidies)	Study and its main findings
Country-level assessments (continued)	
Conflicting results for the proposed repealing of intangible drilling credit in the United States	Deductions against Intangible Drilling and Development costs are an important tax incentive for independent oil companies in the United States, introduced in 1913. In 2009 there was a proposal to curb this support measure. One study commissioned by the oil industry concluded that the subsidy removal would cut USA oil and gas production by 15%, or 3.8 million barrels of oil equivalent daily—thus leaving these fuels in the ground (WoodMackenzie, 2013). In contrast, independent research has concluded that the removal of the subsidy would affect industry profits, but have little impact on production (Aldy, 2013).
Insignificant impact on emissions of removing 3 oil and gas production subsidies in the United States through 2030	A study models firm behaviour in response to the potential loss of each of the three major tax preferences for oil and gas producers in the United States, including the intangible drilling credit (see the preceding example). It finds that removing these three tax preferences in the United States would increase the global price of oil by 1% by 2030. U.S. oil production could drop 5% and global consumption could fall by less than 1% in that timeframe. Meanwhile, domestic natural gas prices could rise between 7% and 10%, and both domestic gas production and consumption could fall between 3% and 4%, with insignificant impacts on emissions (Metcalfe, 2016).
8 Gt of CO ₂ abated through the removal of subsidies to oil production in the United States	Erickson et al. (2017) show that billions of dollars in federal and state subsidies could enable large amounts of oil and gas production in the U.S. that would not otherwise be economic. At USD 50 per barrel, roughly the January 2017 oil price, 45% of discovered (but not yet producing) U.S. oil would depend on subsidies to reach minimum returns acceptable to investors. The additional oil produced due to subsidies would emit 8 billion tonnes of CO ₂ abated once combusted.
Basin-level assessments	
0.7–2.5 Gt of CO ₂ abated through a 8%–29% decline in demand for US PRB coal	A Carbon Tracker Initiative assessment looks at thermal coal subsidies in two major producing regions: US Powder River Basin (PRB), estimated at USD 8 per tonne and Australia, estimated at USD 4 per tonne. According to this analysis, the removal of the US PRB subsidies would result in a 8%–29% reduction in demand for US PRB coal, with associated cumulative reductions of 0.7 to 2.5 Gt CO ₂ to 2035. Further, over the same time period, the removal of Australia's coal subsidies would lead to a 3%–7% reduction in demand for Australian Seaborne coal, though with smaller carbon reductions due to substitution of coal from other (often also subsidized) producers. The study relies on a supply-demand partial equilibrium framework.
Project-level assessments	
Of the two assessed fields, one would not be developed (leaving 481 billion cubic metres of natural gas and 13.4 million tonnes of liquid hydrocarbons in the ground)	A study for the Global Subsidies Initiative assesses the economic viability of Yamal-LNG and Prirazlomnoe, two large-scale extractive projects in the Russian Arctic with and without subsidies (Lunden & Fjaertoft, 2014). Prirazlomnoe is found to be viable even without subsidies, which are thus just foregone government revenue. Yamal-LNG, however, is found to be unfeasible without government support. Had it not been provided, the field would not be developed, and all its reserves would stay in the ground. These reserves amount to 481 billion cubic metres of natural gas and 13.4 million tonnes of liquid hydrocarbons—this is equivalent to 60% of annual natural gas extraction in the United States in 2015. The study uses cash flow analysis based on the RusTax-model developed by Sigra Group. The model is tailored to assess the economic impacts of government support in the form of tax breaks and investment subsidies on petroleum projects.

Source: Authors' summary.



ANNEX B. Approach and Findings From Modelling a Global Removal of Fossil fuel Production Subsidies

B1.0 Introduction

This analysis aims to create an initial, empirically grounded approach to examine the global impact of fossil fuel producer subsidy removal on: i) fossil fuel reserves that will become uneconomical to produce; and ii) on GHG emissions. The existing literature (or lack thereof) seems to indicate that detailed national and field data are required, both to estimate the impact of producer subsidy removal on local economies and energy demand, and the resulting global energy supply and trade implications (Zhao, Dahl, & Luo, 2015).

The approach proposed in this study is different. It starts by using aggregate data (e.g., from country databases on production subsidies, and national or global cost curves derived from field-related data). These data are utilized to create global simulations of energy demand and supply, which allow for assessment of the relationships between production subsidies and changes in supply (recoverable reserves) and price of fossil fuels, changes in demand and subsequent change in emissions.

This approach was developed because of the need to test whether the results of a macro analysis would be similar to those of a bottom-up one (e.g., when using a global curve as opposed to detailed field data). If this is the case, it will provide new information to decision makers to inform subsidy removal strategies worldwide, as well as in the context of commitments to phase out inefficient fossil fuel subsidies under G20 and APEC, as well as Nationally Determined Contributions (NDCs) under the UNFCCC process.

This annex presents the methodology utilized as well as the results of the analysis. It also touches upon the strengths and weaknesses of this work—as well as its complementarity with other ongoing research on the removal of fossil fuel subsidies, including subsidies to consumers.



BOX B1. DEFINING AND IDENTIFYING THE IMPACT OF PRODUCER FOSSIL FUELS SUBSIDY REMOVAL ON RESERVES AND EMISSIONS

Defining fossil fuel reserves that would not be produced as a result of subsidy removal in the context of a modelling exercise is complicated. The following elements need to be considered:

- An increase in production costs caused by the removal of production subsidies makes some reserves shift from being economical to being uneconomical.
- This development depends on how subsidies are allocated (targeted or untargeted) across projects. At a project level, three scenarios can be identified:
 - Subsidy is given to reserves that are uneconomical without it, and become economical with it. This subsidy unlocks reserves and leads to new production. The removal of this subsidy has the opposite effect.
 - Subsidy is given to reserves that are uneconomical without it, and still remain uneconomical even with subsidy. This subsidy and its removal have potentially no impact on production.
 - Subsidy is given to reserves that are already economical even without it. The subsidy and its removal do not have direct impacts on production. In the meantime, the extra profitability of companies may indirectly lead to the development of other fields at the threshold of profitability.
- In our modelling, we assume the perfect targeting of subsidies only at reserves that would otherwise be uneconomical, mainly because this is the stated policy objective of such government support measures.
- However, data on the reserves (and production) that are subsidized are not available at the global level. As a result, our assumption of the perfect targeting of subsidies requires two things: (1) an estimation of all the reserves that are in the breakeven price bracket that would become uneconomical with subsidy removal, and (2) an estimation of the portion of the reserves in this breakeven price bracket that could be produced in a given year.
- In fact, especially at the global level, production is spread across several breakeven price (and cost) brackets. This means that only a small portion of the reserves in, for instance, the USD 45 to USD 50/bbl breakeven price bracket is produced in a given year (e.g., in the year 2000 only 1.9 per cent of the reserves in the breakeven price range of USD 40 to USD 45 per barrel were actually produced) due to production capacity, readiness of the field, etc.
- As a result, of all the reserves that would become uneconomical in a given year when considering production costs and price, only a portion will ultimately not be produced in that same year relative to a scenario in which subsidies are maintained.
- In addition, because the oil price is dynamic, and its future trends are largely unforeseeable (due to the simultaneous effect of demand and supply, which are in turn affected by a multitude of other factors), it is very difficult for governments to design a subsidy with the intended policy effect.
- When considering future years, if we assume that the market price increases every year, the threshold of profitability will also increase (e.g., moving from USD 50 in 2016 to USD 60/bbl in 2017). In this case, some reserves that were uneconomical in 2016 will become economical in 2017. Similarly, some reserves that would have been economical in 2017 with the subsidy will not be economical if the subsidy is removed. As a result, the amount of reserves that are uneconomical due to the removal of production subsidies would change every year if the market price changes, both because some reserves have become economical (due to market forces) while others (at a higher price point) have become uneconomical with the removal of subsidies.
- Again, the amount of affected energy reserves, at any given point in time, will result to be larger than the amount of reserves that are not produced in a given year. Similarly, emission reductions will be smaller than the carbon contained in the reserves that become uneconomical due to subsidy removal.

Not all the items described above would necessarily apply to a regional or national context, where production may be more concentrated around a specific (and similar) production cost and breakeven price. In this case, the impact of subsidy removal will be felt more markedly in the short term, due to the fact that a larger portion of the reserves that become uneconomical will ultimately not be produced, especially if it is possible to import fossil fuels at lower costs.



B2.0 Methodological Approach

B2.1 Scope of the Analysis

The analysis is carried out with the GSI-IF(p) model, a System Dynamics model that performs simulations of economic developments under different scenarios. The model treats subsidies as negative costs for fossil fuel companies, similarly to several other studies that investigated impacts of fossil fuel production subsidies and their removal (Fulton, Buckley, Koplou, Sussams, & Grant, 2015; Acar & Yeldan, 2016). The model includes several direct, indirect and induced impacts of producer subsidy removal, some of which form important feedback loops as described below.

As a first step, the removal of subsidies is expected to increase fossil fuel production costs, representing an upward shift of the cost curve (Figure B1).

This assumes that the increased cost (originating from the removal of subsidies) would not be passed through to consumers. Alternative assumptions could be tested on cost pass-through (e.g., none, partial or full) of these increased costs onto consumers in order to measure the potential effect of subsidy removal on production (direct, indirect and induced), also depending on different regional contexts.

An increase in production costs reduces the economic attractiveness of fossil fuel production (at least for certain fields) and for the projects that currently receive subsidies, or would have received subsidies under a baseline scenario. As a result, some of the reserves that were economical to produce without subsidies become unviable.

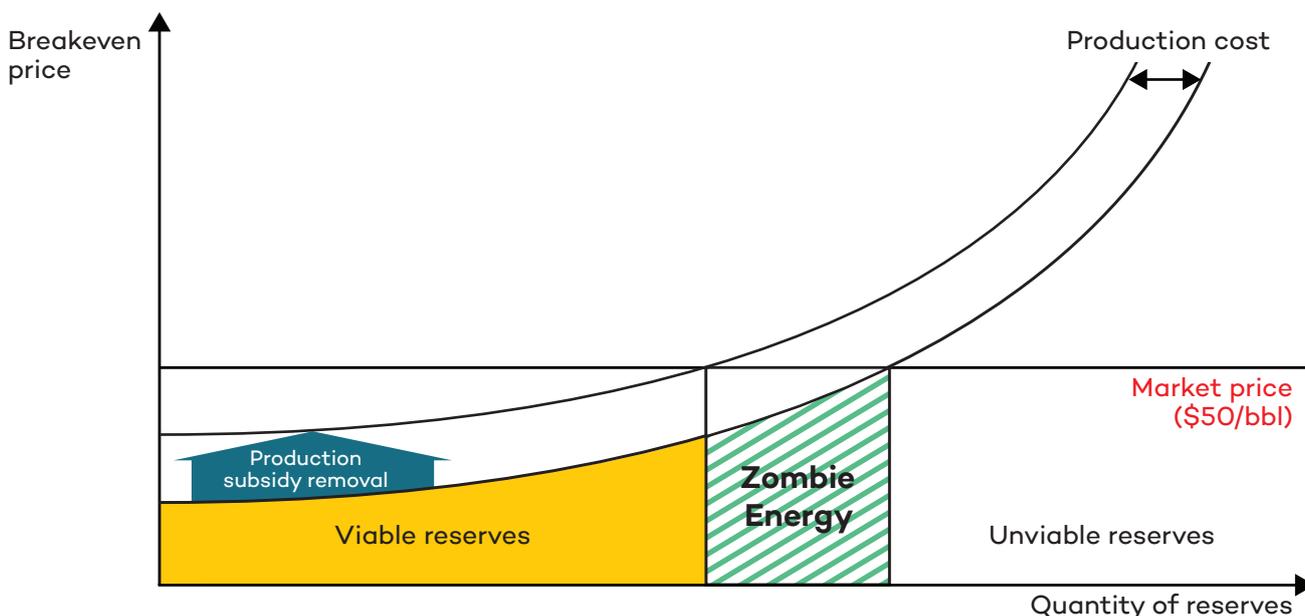


Figure B1. Schematic representation of the cost curve, with an indication the impact of production subsidy removal.

Source: Authors' diagram.

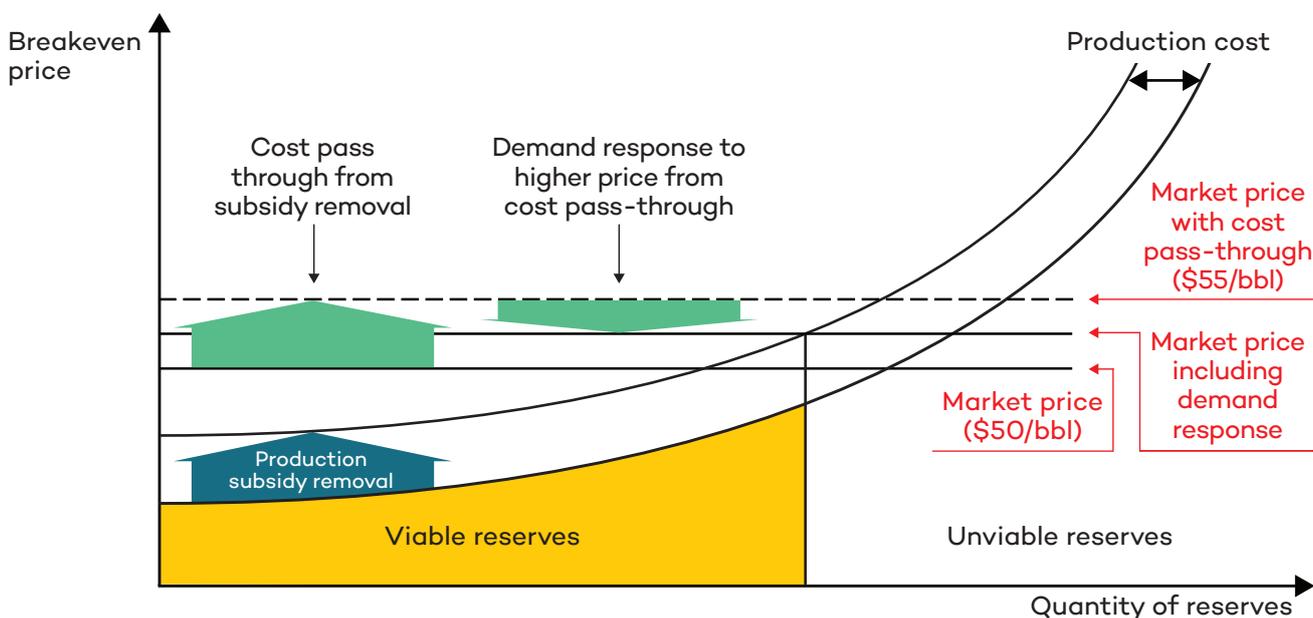


Figure B2. Medium-term impact of subsidy removal on viable and unviable reserves, including demand effects.

Source: Authors' diagram.



A change in market prices will emerge if, due to the increased cost of production, the extraction of fossil fuels declines (not necessarily in absolute terms—a decline relative to the baseline scenario would be sufficient to stimulate an increase in market prices). This is because supply would be constrained (or lower than previously expected) while demand would continue to grow with no modifications relative to the baseline scenario. In this case, the market price would increase, making some fossil fuel extraction projects profitable again, and hence offsetting some of the impacts of producer subsidy removal (see Figure B2).

Meanwhile, if the market price of fossil fuels increases, demand is likely to decline below expectations (or grow less than what projected under the baseline scenario) due to energy conservation, and possibly energy efficiency and fuel switching. This leads to emission reductions and lowers fuel spending for consumers, which may be able to offset the increase in market price (due to the constraint on supply) with efficiency improvement or other interventions.

Further, if demand declines, which normally happens over the medium and long terms (unless major price shocks take place), the demand-supply ratio will also decline, bringing market prices closer to their original level, and possibly to the baseline trend. This development indicates that fuel expenditure may well not be below baseline, with prices possibly being at a similar level but with energy consumption being lower. The repercussion on production is again reduced profitability (as observed in the case of subsidy removal), with some oil and gas fields, or coal locations, becoming less economically attractive.

BOX B2. UNDERSTANDING THE UNDERLYING DYNAMICS OF FOSSIL FUEL SUBSIDY REMOVAL

A simple example is provided to better understand the dynamics mentioned above (see Figure B2). Assuming a market oil price of USD 50/bbl and average subsidy allocated of USD 5/bbl, the marginal breakeven price would be USD 55/bbl. The removal of the subsidy would cancel projects with a marginal breakeven between USD 50/bbl and USD 55/bbl, if prices remained roughly the same in the short term. However, in the medium term, this decrease in supply from the projects that would not go ahead due to the removal of the subsidy would likely cause an increase in the market price. This is due to the relationship between demand and supply. If demand remains at the level of pre-subsidy removal, the price is likely to increase, for example to USD 53 or possibly even up to USD 55/bbl. If this is the case, the price movement will stimulate a reduction in demand and emissions, and make economical some of the supply that the removal in subsidies took out of the market. It is unlikely that all of the removed supply would be reinstated, but precisely how much depends on the impact that demand and supply have on the market price.

There are two main impacts on reserves and emissions of the mechanisms mentioned above. On the one hand, an increase in the production costs of fossil fuels is likely to reduce extraction from some fields and increase it from others, if reserves from low-cost fields are available (e.g., production could be increased from more economical fields, for example, due to technology improvements in recovery of oil, gas and coal extraction). On the other hand, changes in demand (due to higher market prices and conservation, efficiency improvements, or fuel switching) will have lasting impacts. This translates to reduced extraction (and hence to a higher level of reserves) as well as in lower emissions.¹

¹ One aspect that this modelling exercise does not take into account due to lack of data is the propensity of marginal fossil fuel reserves to have higher emissions per unit of production during the extraction process (an example would be oil sands).



Considering the above, it can be said that the energy sector is dominated by balancing feedback loops (or those loops that seek equilibrium, forming goal-seeking trends, rather than exponential growth or decay). In fact, supply responds to demand, which is directly affected by prices and indirectly influenced by the amount of reserves that are economically viable. In addition, production (and its cost) is affected by the availability of reserves (depicting another balancing loop). As we can see from Figure B4, while at present most production is from reserves within lower breakeven price brackets, these are expected to become depleted and in the future more production will come from higher cost fields. To sum up, production subsidies influence the economic viability of production directly, and demand and emissions indirectly.

While these dynamics may seem complicated, what is presented above is a highly simplified description of the many feedbacks that influence the energy sector. For instance, capital costs often represent the majority of expenditures during the exploration and development of fields, whereas operational costs are normally low once the field has been brought onstream. Further, capital in this sector has a long lifetime. Therefore, if high costs have already been incurred, production from these fields will continue even during years in which the market price is below the project’s long-term breakeven price (which includes full recovery of capex and rate of return). As a result, some of the consequences of producer subsidy removal could be delayed, or become more visible only during the medium and longer term. Besides, since many fields produce both oil and gas (Figure B3), the reduction in subsidies to oil production may result not only in reduced production of oil, but also reduced production of gas, and vice versa. This outcome may well amplify the impacts of fossil fuel subsidy removal, again in the short term.

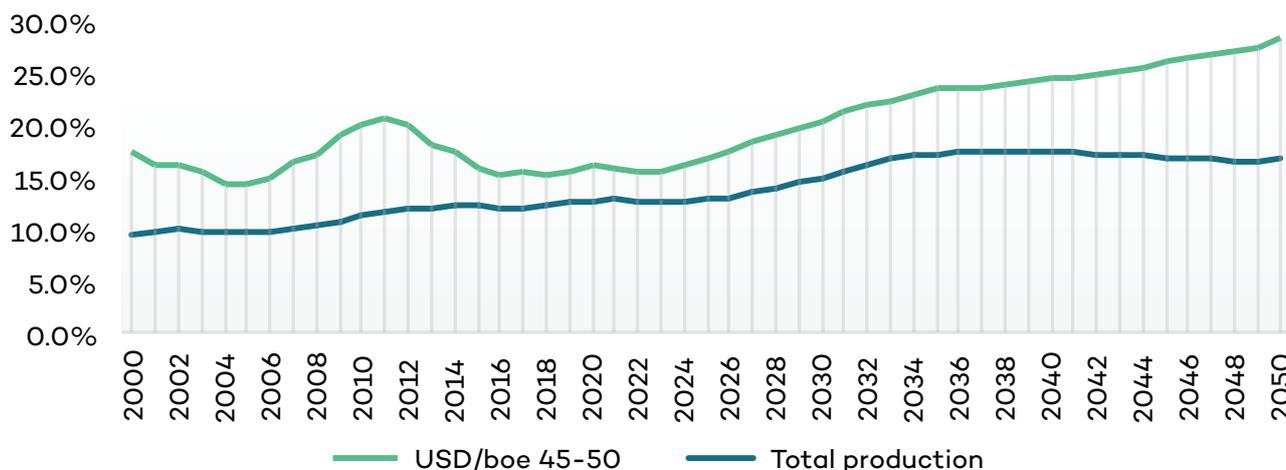


Figure B3. Share of oil production that is obtained from natural gas and gas-condensate fields, breakeven price range USD/boe 45-50 and total production.

Source: Authors’ diagram based on Rystad Energy, 2016.

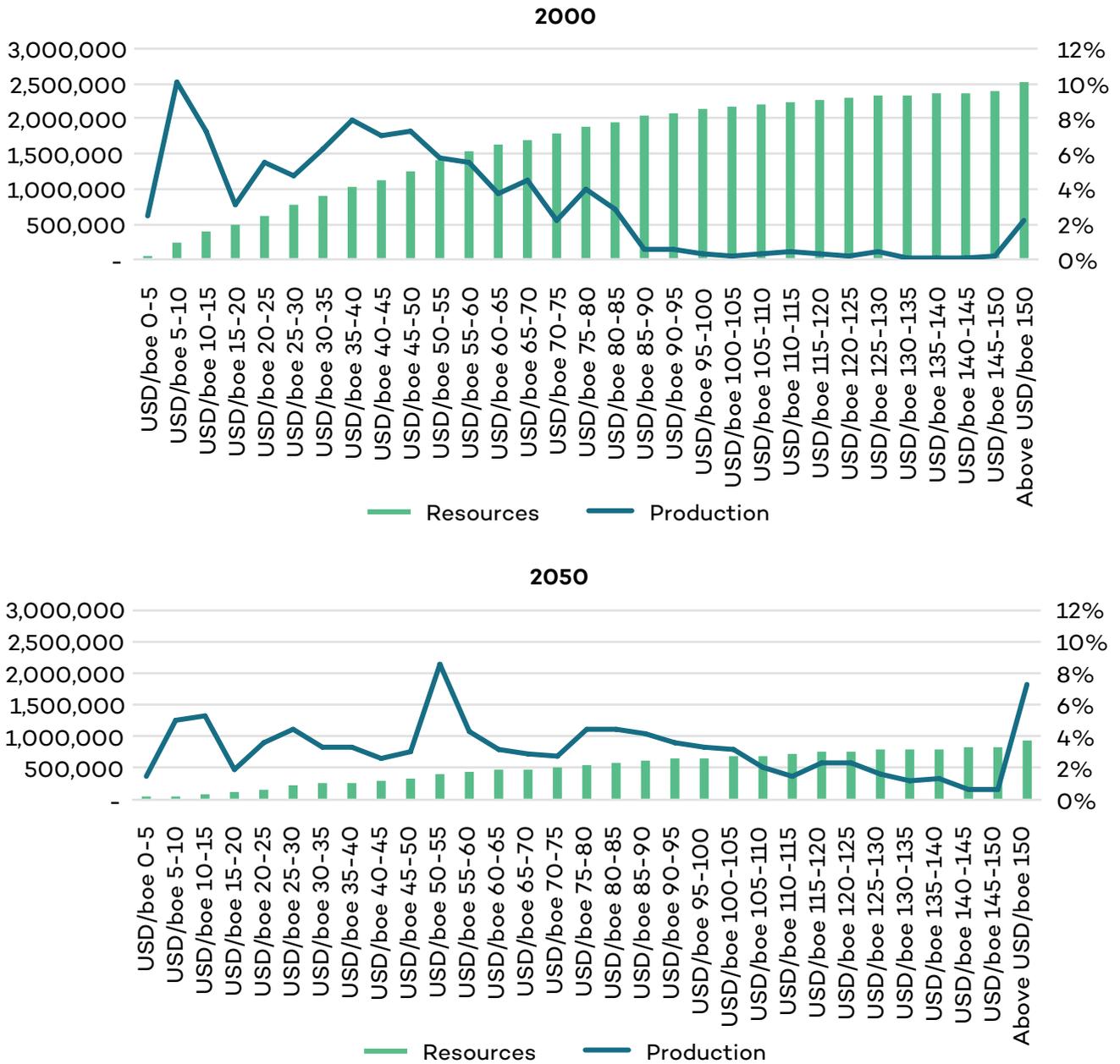


Figure B4. Cumulative resources and share of annual production, by breakeven price bracket (years 2000 and 2050).

Source: Authors' diagram based on Rystad Energy, 2016.



B2.2 Production Subsidy Data and Assumptions

The modelling with GSI-IF (p) relies on the latest available subsidy estimates for the G20 countries (Bast, Doukas, Pickard, van der Burg, & Whitley, 2015), treating them as a proxy for the world. The modelling assumed removal of all policies that meet the WTO definition of a subsidy and are specific to extraction of oil, gas and coal starting from 2017. For a qualitative account of the subsidy estimates and their analysis please refer to Section 3.2 of the main report.

Given the data limitations, the disaggregation has been carried out for 15 of the G20 countries: Argentina, Australia, Brazil, Canada, China, France, Germany, India, Japan, South Korea, Russia, South Africa, Turkey, the United Kingdom and the United States.

First, this subsidy dataset has been disaggregated by fuel. For subsidies cross-cutting through several fuels we split the value based on each fuel's role in primary energy supply of the relevant country.² The disaggregation has been applied only to upstream subsidies related to the extracting cycle for oil, natural gas and coal. Out of the total of USD 70 billion reported as national subsidies in the G20 inventory (Bast, et al., 2015), USD 11.5 billion were excluded from disaggregation and modelling. Excluded are USD 8.5 billion in subsidies to electricity generation and USD 3 billion in other subsidies that represent industry-specific social aid policies and are unlikely to affect extraction. Out of the remaining USD 58.5 billion in upstream subsidies USD 32 billion were for oil, USD 18 billion for gas and USD 8.5 billion for coal.

On this basis, we calculated the per-unit value of production subsidy for each fuel based on empirical data for 2013–2014: barrel for oil, thousand cubic feet for gas, and metric tonne for coal. Further, the value of each fuel's per-unit subsidy was considered without any multiplier (Removal scenario) as well as with multipliers 2.5 (Removal 2.5 scenario) and 3 (Removal 3 scenario). See Section 3.2.2 of the main report for discussion of multipliers. The obtained values are presented Tables A3, A4 and A5.

For simplicity, these per-unit subsidy values were assumed to be the same for each year over 2017–2050, though in reality subsidy values depend on many factors and can also change over time (e.g., following the trend of energy prices). Overall, these subsidy values appear to be underestimates, since an important portion of the identified subsidies to fossil fuel production have not been quantified and since fossil fuel prices are generally expected to increase in the years to come. In particular, the G20 dataset has no monetary estimates of subsidies to the production of oil, gas and coal in such major extracting economies as Indonesia, Mexico and Saudi Arabia.

As explained in the sections on cost curves, for the GSI-IF (p) modelling it was assumed that over 2017–2050 all subsidies are allocated equally along the cost curve. The result is that only the production at the margin will be affected by the removal of subsidies. In fact, those fields that are already economical or uneconomical without subsidies are not directly impacted.

² The data on fuel production by each country has been sourced from the BP Statistical Review of World Energy (BP, 2016) for most cases and converted from IEA kilotonne of oil equivalent data to relevant units in cases where production was not significant and therefore not reported separately in BP Statistical Review.

**Table B3. Subsidies to oil in select G20 countries, annual averages for 2013–2014***

	National subsidies, million USD	Production in 2013, million barrels	Subsidies, USD per barrel of crude oil	Capex subsidies, % of all subsidies	Opex subsidies, % of all subsidies	Capex* multiplier of 3 + opex, USD per barrel	Capex* multiplier of 2.5 + opex, USD per barrel
Argentina	Not quantified	235	Not quantified	Not quantified	Not quantified	Not quantified	Not quantified
Australia	587	149	3.95	100%	0%	11.85	9.88
Brazil	2,475	772	3.21	51%	49%	6.48	5.66
Canada	1,743	1,460	1.19	76%	24%	3.01	2.55
China	576	1,539	0.37	0%	100%	0.37	0.37
France	24	7	3.43	100%	0%	10.29	8.57
Germany	3	24	0.12	100%	0%	0.37	0.31
India	2	331	0.01	100%	0%	0.02	0.02
Japan	264	4	65.75	97%	3%	193.32	161.42
South Korea	Not quantified	4	Not quantified	Not quantified	Not quantified	Not quantified	Not quantified
Russia	18,214	3,934	4.63	2%	98%	4.81	4.77
South Africa	2	1	1.37	100%	0%	4.11	3.42
Turkey	228	17	13.29	100%	0%	39.87	33.23
United Kingdom	664	316	2.10	8%	92%	2.43	2.35
United States	7,518	3,672	2.05	44%	56%	3.85	3.40
Average subsidy for these countries, weighted based on production			2.59			3.78	3.45

Source: Authors' disaggregation and calculations based on IEA, 2016; Bast E., Doukas, Pickard, van der Burg, & Whitley, 2015; BP, 2016.

* Per-unit subsidy values are not comparable across countries since each country has its own taxation benchmarks.

**Table B4. Subsidies to natural gas in select G20 countries, annual averages for 2013-2014***

	National subsidies, million USD	Production in 2013, billion cubic feet	Subsidies, USD per thous. cubic feet of natural gas (kcf)**	Capex subsidies, % of all subsidies	Opex subsidies, % of all subsidies	Capex* multiplier of 3 + opex, USD per thous. cubic feet (kcf)*	Capex* multiplier of 2.5 + opex, USD per thous. cubic feet (kcf)*
Argentina	1,555	1,241	1.25	22%	78%	1.80	1.67
Australia	1,528	2,044	0.75	100%	0%	2.24	1.87
Brazil	4,11	767	0.54	50%	50%	1.07	0.94
Canada	872	5,512	0.16	42%	58%	0.29	0.26
China	93	4,307	0.02	0%	100%	0.02	0.02
France	7	12	0.58	64%	36%	1.33	1.14
Germany	7	292	0.02	100%	0%	0.07	0.06
India	2	1,132	0.00	100%	0%	0.01	0.00
Japan	86	117	0.74	100%	0%	2.21	1.84
South Korea	2	18	0.11	100%	0%	0.33	0.27
Russia	4,462	21,353	0.21	5%	95%	0.23	0.22
South Africa	18	44	0.41	100%	0%	1.23	1.03
Turkey	52	18	2.85	100%	0%	8.55	7.12
United Kingdom	398	1,278	0.31	11%	89%	0.38	0.36
United States	8,244	24,200	0.34	43%	57%	0.63	0.56
Average subsidy for these countries, weighted based on production			0.28			0.49	0.44

Source: Authors' disaggregation and calculations based on Bas, Doukas, Pickard, van der Burg, & Whitley, 2015; IEA, 2016; BP, 2016.

* Per-unit subsidy values are not comparable across countries since each country has its own taxation benchmarks.

** A thousand cubic feet of gas equals a million of British Thermal Units

**Table B5. Subsidies to coal in select G20 countries, annual averages for 2013-2014***

	National subsidies, million USD	Production in 2013, million metric tonnes	National subsidies, USD per tonne of coal	Capex subsidies, % of all subsidies	Opex subsidies, % of all subsidies	Capex* multiplier of 3 + opex, USD per tonne	Capex* multiplier of 2.5 + opex, USD per tonne
Argentina	475	Negligible	6,012.66**	0%	100%	Excluded**	Excluded**
Australia	1,498	471	3.18	83%	17%	8.46	7.14
Brazil	71	9	8.26	50%	50%	16.51	14.45
Canada	73	69	1.06	100%	0%	3.19	2.66
China	2,706	3,974	0.68	0%	100%	0.68	0.68
France	5	0.3	16.03	100%	0%	48.08	40.06
Germany	790	191	4.14	4%	96%	4.48	4.39
India	75	609	0.12	64%	36%	0.28	0.24
Japan	Not quantified	1	Not quantified	Not quantified	Not quantified	Not quantified	Not quantified
South Korea	213	2	118.33	0%	100%	118.33	118.33
Russia	65	355	0.18	14%	86%	0.23	0.22
South Africa	Not quantified	257	Not quantified	Not quantified	Not quantified	Not quantified	Not quantified
Turkey	330	60	5.46	10%	90%	6.56	6.28
United Kingdom	83	13	6.48	48%	52%	12.71	11.15
United States	2,045	893	2.29	10%	90%	2.75	2.63
Average subsidy for these countries, weighted based on production			1.22			1.65	1.53

Source: Authors' disaggregation and calculations based on Bast E. , Doukas, Pickard, van der Burg, & Whitley, 2015; BP, 2016; IEA, 2016.

* Per-unit subsidy values are not comparable across countries since each country has its own taxation benchmarks

** Per-unit subsidy to coal in Argentina is a clear outlier and hence was excluded from the analysis.

B2.3 Utilization of Subsidy Data in the Model

Subsidy data are used in the model to estimate fossil fuel production costs. The baseline scenario assumes that subsidies will remain in place going forward, while alternative scenarios assume that the removal of production subsidies will increase the cost of production.

Specifically, the production cost of fossil fuels is estimated using existing cost curves and projected production. In other words, functions are utilized that assign a specific breakeven price value based on projected cumulative production (for simplicity, cumulative production is calculated from 2015). The amount of subsidy that would be removed (e.g., USD/bbl) is then added to the cost, with different trajectories depending on the scenario simulated (e.g., immediate, linear over five years).



BOX B3.

Initially, we collected cost curves for each fuel: oil (McGlade, Rystad, IIASA GEA as outlined in [Rogner, 2012]), natural gas (McGlade & Ekins, 2015; Rystad Energy, 2016; IIASA GEA as outlined in [Rogner, 2012]), coal (McGlade & Ekins, 2015; IIASA GEA as outlined in [Rogner, 2012] and WoodMac as outlined in [Aldina, 2013]). To ensure consistency across data sources and improve comparability, in the case of oil and gas, we converted Rystad data (annual production and breakeven price) into “cumulative production and breakeven price” (starting from 2015 to compute cumulative production). We then used the estimated annual average production breakeven price (estimated across price brackets) and the cumulative production from Rystad to determine the curve. The implementation in the model is dynamic by (1) using cumulative production projected by the model (which, for instance, could be affected by changes in demand, e.g., the implementation of aggressive energy efficiency interventions) and (2) using the breakeven price estimated with Rystad data.

With a change in production cost (and in the breakeven price required to ensure profitability), the production of a portion of fossil fuel production and reserves would become uneconomical. For instance, with production cost at USD 50/bbl and a desired internal rate of return (IRR) of 10 per cent,³ oil production would be economical with a market price of USD 55/bbl. With a subsidy of USD 5/bbl the same fields could be produced economically with a market price of USD 50/bbl. In other words, the removal of subsidies increases the threshold of profitability, in this specific example from USD 50/bbl to USD 55/bbl.

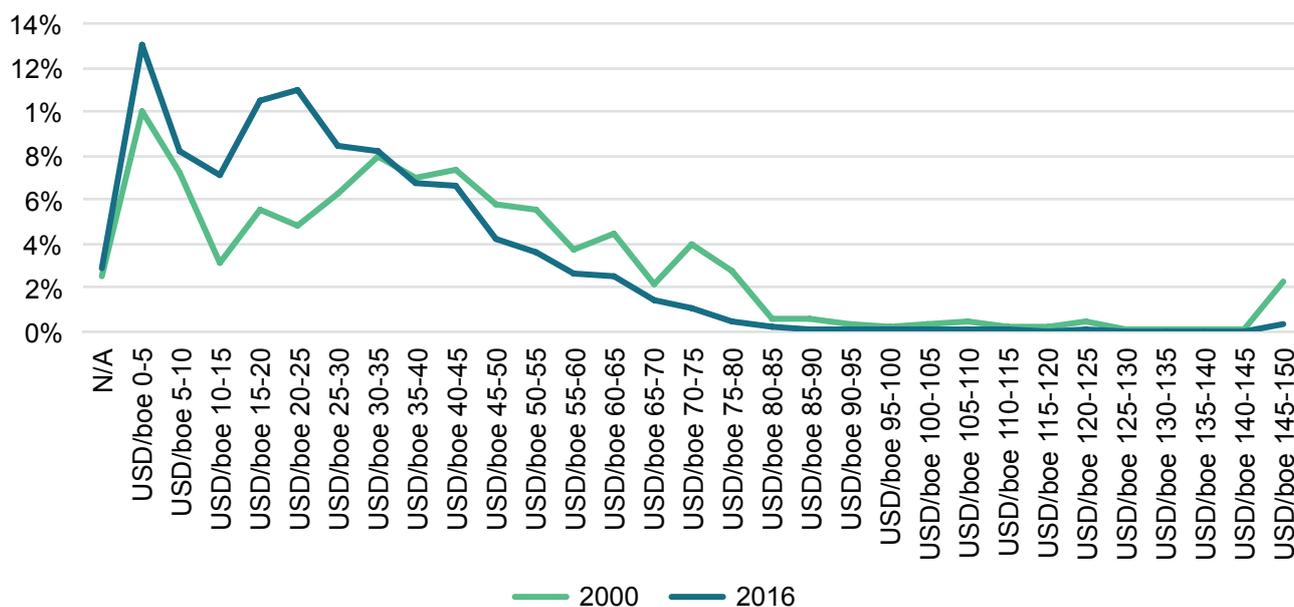


Figure B5. Share of production by breakeven price, 2000 and 2016.

Source: Authors’ diagram based on Rystad Energy, 2016.

³ In view of sunk costs, desired IRR would be higher for marginal fields that have not yet been developed and lower for those that companies already started developing.



We consider both production and proved reserves because the potential production that could be uneconomical refers to fields that have already been, or are being developed (with capital costs already sustained), while the estimation of the potential amount of reserves that would become uneconomical includes also fields that may not be ready for production at this stage.⁴ This is done to validate the model and its projections, and avoid overestimating the impact of subsidy removal on current and future fossil fuel production.

In order to estimate the production and reserves that could be jeopardized by the removal of subsidies, we utilize curves that map (1) breakeven price to cumulative production and (2) breakeven price to cumulative reserves. In other words, these curves present how much production and reserves would be economical for any given breakeven price level. When we then compare the results of the simulation for the baseline scenario (which includes subsidies) and alternative scenarios (which assume the removal of production subsidies) we obtain the amount of production and reserves that could become uneconomical to produce when subsidies are removed. This calculation assumes that the entire cost curve shifts upwards, but the amount of reserves that might not be produced is only estimated for reserves at the margin of profitability (these fields are the most vulnerable to subsidy removal, and hence prime candidates for halting production). This also implies that those fields that are already uneconomical, but have been, or are being developed, will continue to produce even if subsidies are removed.

Once the amount of reserves that could become uneconomical is estimated, it is subtracted from the amount of “recoverable reserves” estimated by the model, which takes into account the availability of reserves and resources, as well as technology. This leads to a reduction in potential production of a given fossil fuel, because a smaller amount of reserves is economically recoverable.

Production is then estimated to be the smallest value between potential supply (which is affected by recoverable reserves) and demand. As indicated earlier, the decline in supply (which is smaller than the decline in reserves that can be produced economically) has an impact on oil price (increasing it, if demand does not decline). An increase in market price would in turn lower demand (through impacts on GDP, which would affect energy demand from all sectors and sources).

⁴ The long-term breakeven price (i.e., with capital recovery and desired IRR of 15–20 per cent or higher) would seem to affect only fields for which no capital has yet been deployed. For producing or near-producing fields to become uneconomical, prices would need to drop below—or costs would need to rise above—short-term breakevens, which would be lower, and likely include an IRR lower than 10 per cent as well (since producers might see some return as better than nothing). However, GSI-IF (p) model cannot address these nuances with confidence.



B3 Literature Review: Cost curves

Several cost curves can be found in the literature, across fossil fuels and regions. The values presented in these cost curves are generally quite diverse, given that production costs are affected by a variety of variables, including geological characteristics of the areas, distance to markets, technology utilized and the availability of reserves. These variables also explain the differences observed in cost curves published over time, because, among other factors, technology evolves and reserves become depleted.

The following is a brief review of the main cost curves currently available at the global level, i.e., curves that aggregate the cost of production and availability of reserves across field and countries, to obtain a global average of the cost of production for a given level of reserve extraction.

Rogner (1997) includes global cost curves for oil, gas and coal. This paper has been extensively used for the creation of more up-to-date cost curves, also used in IIASA's Global Energy Assessment. Despite the date of creation of this paper (1997), the shapes of the curves presented are found in several other publications, being quite stable over time. In other words, the extraction of oil, gas and coal becomes more and more expensive over time, since the cheapest reserves are generally produced first. At the same time, several dynamic elements underlie the data shown in a cost curve. As an example, non-price-induced technology changes, such as learning-curve effects, are determined by cumulative production volumes (i.e., the more we produce the more we optimize the process, reducing costs and increasing effectiveness). As a result, expectations about technology development can have an important impact on the shape of cost curves.

B3.1 Oil Production

In the case of oil production, cost curves are reviewed from McCollum, Bauer, Calvin, Kitous, & Riahi (2014), the IIASA Global Energy Assessment (a 2012 update of the 1997 paper authored by Rogner), McGlade & Ekins (2015) and the Rystad database.

- McCollum et al. (2014) provide a comparison of different cost curves included in a subset of the Integrated Assessment Models (IAMs) participating in the EMF27 exercise of the Energy Modeling Forum. The authors find that since estimates of available fossil fuel resources vary significantly in the literature (BGR, 2009, 2010, 2012; BP, 2010; USGS, 2000; WEC, 2007), the supply curve assumptions in the models also differ significantly. As an example, at USD 100 per barrel, the ReMIND model assumes the least amount of oil available (15 zeptojoules [ZJ]) while the GCAM model has the most (91 ZJ). In addition, a major factor influencing fossil resource consumption (and thus the challenge of mitigation) relates to fossil fuel prices. McCollum et al. also show (for several EMF27 models) the evolution of oil prices (globally averaged) as a function of cumulative extraction in the Base FullTech and 450 FullTech scenarios. Because of the lower demand for fossil fuels that climate policies will motivate, fossil prices are, in general, lower in the 450 FullTech scenario. There are marked differences in price developments across models, however, as well as between fuels.
- IIASA Global Energy Assessment (GEA), Chapter 7 (Rogner, 2012) includes data by country and aggregated for 18 regions for oil reserves and resources, and presents a global cost curve for current time (2007 data are used) and 2050. Figure B6 shows an aggregate (of the 18 GEA regions) global oil supply cost curve. The curve plots the potential long-term contributions from conventional resources and non-conventional resources against their 2007 and projected 2050 production costs. The 2050 supply curve is net of a hypothetical cumulative production between 2005 and 2050 based on the historically observed production growth rate between 1995 and 2007. The resources exploited during the period up to 2050 are no longer available after 2050. Despite upstream innovation and technology change, the 2050 supply cost curve is higher, as resource extraction until 2050 is expected to exploit lower-cost occurrences first. Figure B7 presents a similar curve, with a disaggregation by oil type.

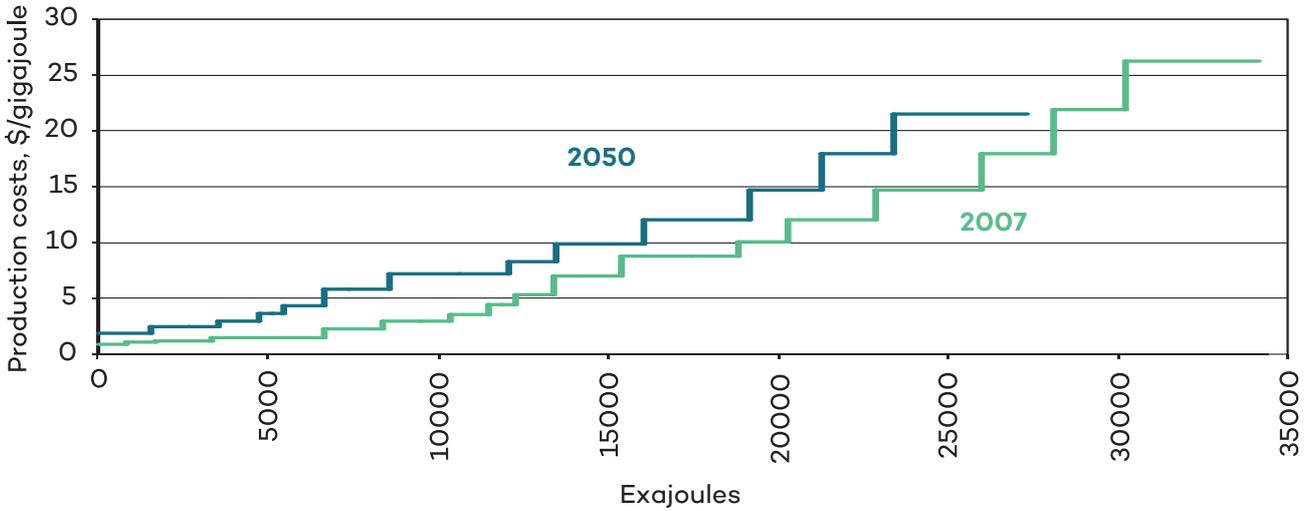


Figure B6. Long-term oil supply curve – combined global conventional and unconventional oil reserves and resources.

Source: Rogner, 2012.

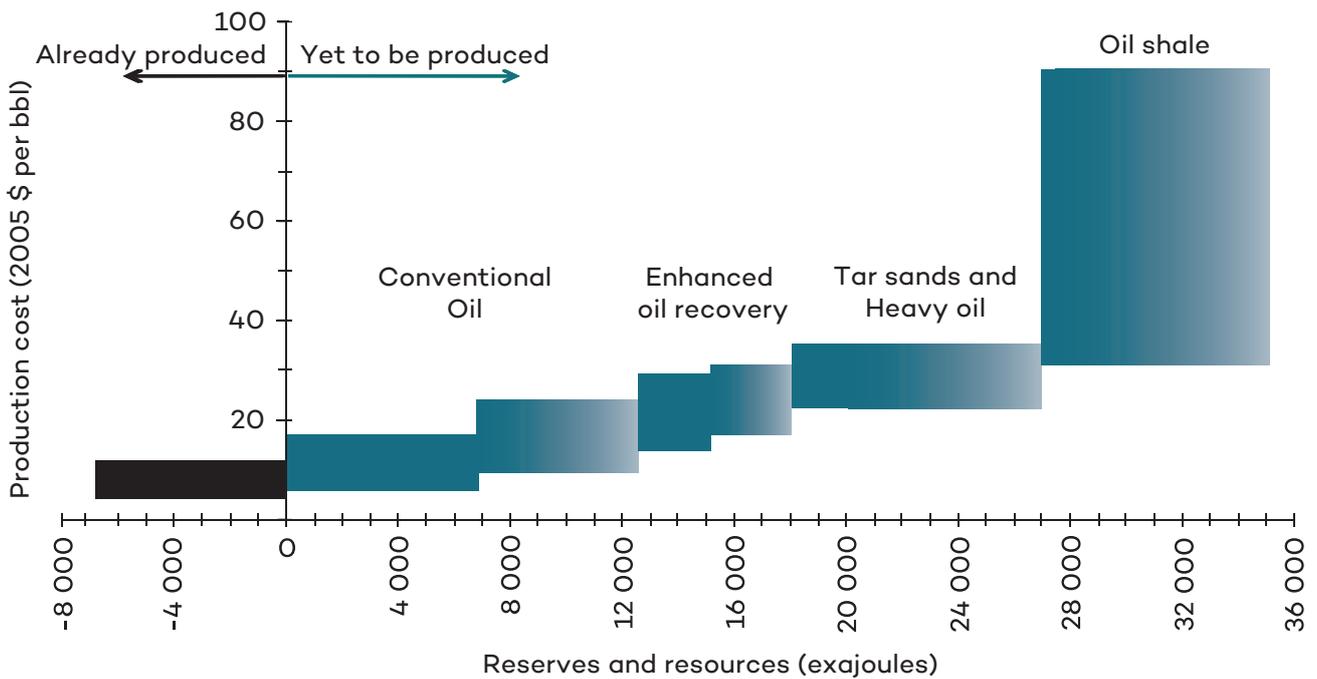


Figure B7. Liquid fuel supply potential and production costs.

The green bars represent the economic cost of extracting fuels. The black bar to the left of the vertical axis represents cumulative past oil production (about 157 Gt). The height of the bars represents the degree of uncertainty of the production costs. The widths of the bars represent how plentiful the resource is, and the lightness of the bars reflects the degree of uncertainty of resource availability.

Source: Rogner, 2012, adapted from Farrell, 2008.



- McGlade & Ekins (2015) provides information on the cost of production (2010 USD/barrel of oil) for the remaining ultimately recoverable resources (URR). The paper includes resources disaggregated by type (11 categories).
- The Rystad database provides instead annual production (until 2050) and recoverable reserves,⁵ all disaggregated by breakeven price (in USD 5/bbl brackets, up to USD 150/bbl and over). A production cost curve can be created using annual production data, to map cumulative production and the breakeven price of each year (Figure B8). Data show that the breakeven price has declined between 2000 and 2016 (year in which the cumulative production of 500 billion barrels of oil is reached), confirming that several factors are at play in determining the shape of cost curves. In this case a gradual reduction in the growth rate of demand (which has pushed prices lower), coupled with technological and other improvements in extraction and subsequent cost reductions (allowing production to increase, in absolute and relative terms for low-cost oil fields, see Figure B5) have had the combined effect of reducing the breakeven price until 2016. Because the Rystad database also provides data on the amount of oil reserves in each breakeven price bracket for the year 2000—2050, a cost curve can be created and compared with those presented earlier (Figure B9). Given that annual data are provided, annual cost curves can be created. Figure B9 presents curves for the year 2000 and 2050, where it can be clearly seen that production in 2050 will take place at a higher cost than in 2000, primarily due to the depletion of low-cost fields in the earlier period of exploitation.

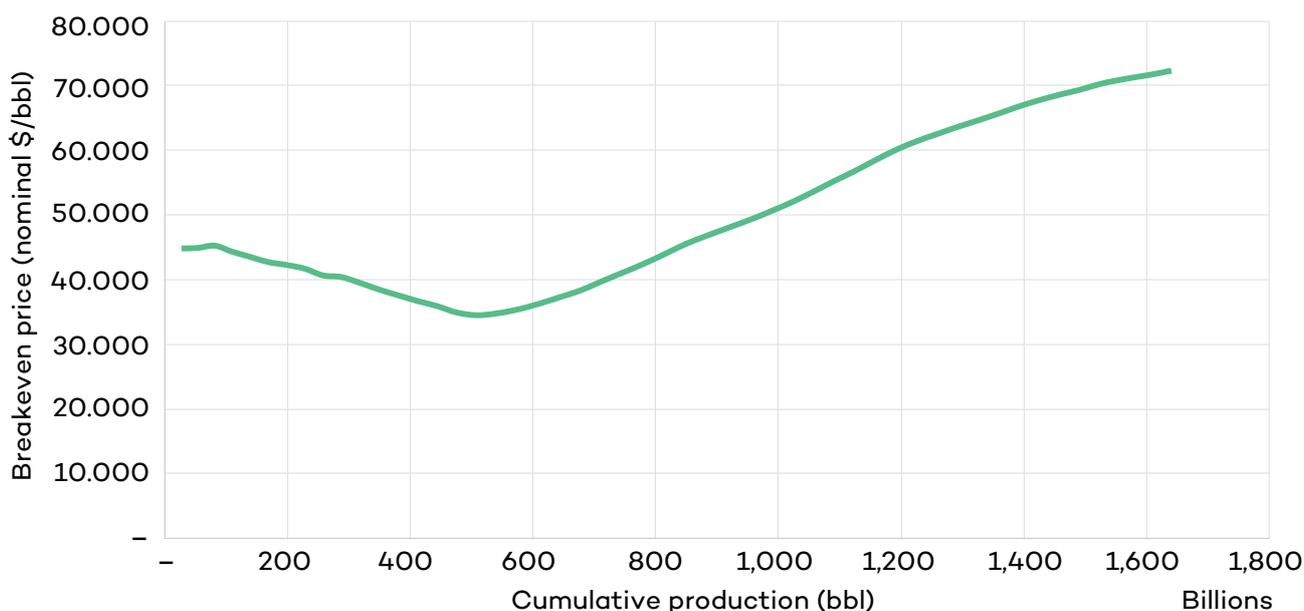


Figure B8. Mapping cumulative production and annual breakeven price (2000–2050).

Source: Authors’ diagram based on Rystad Energy, 2016.

⁵ The Rystad UCube Upstream database publishes data on “resources,” which are defined as follows: “Resources are the remaining economically recoverable reserves. The Resources value for a specific year is identical to the sum of the future production for the given selection. Use the Resources value for a specific year to see the January 1st remaining reserves for that year.” As a result, we refer to “resources” in the Rystad database as “recoverable reserves” for consistency with the terminology used in others studies.

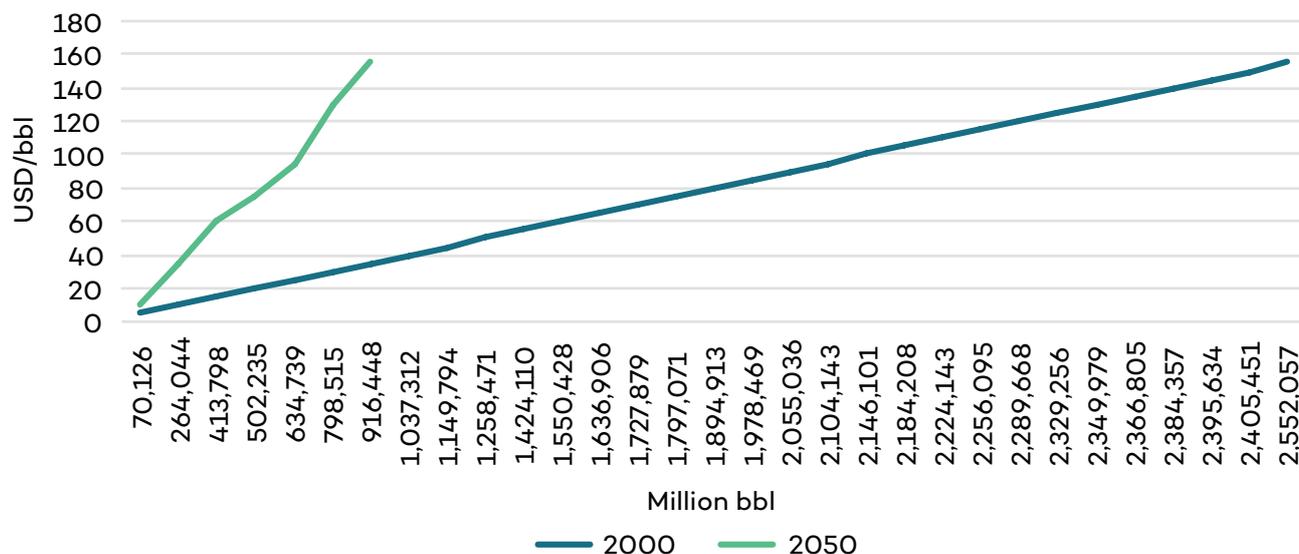


Figure B9. Supply cost curves for oil, years 2000 and 2050.

Source: Authors' diagram based on Rystad Energy, 2016.

- The Carbon Tracker Initiative report “Fossil Fuel Supply in a Carbon-Constrained World” (2015b) presents a global cost curve for liquid fuel production, LNG and world export seaborne coal for the period 2015–2035. The curves include an indication of the amount of supply that would be required under two scenarios of energy demand: (1) the 450 scenario from the International Energy Agency and (2) the Carbon Tracker Low-Demand Scenario (LDS).

B3.2 Natural Gas Production

- The IIASA Global Energy Assessment, Chapter 7 (Rogner, 2012) includes data by country and aggregated for 18 regions for natural gas reserves and resources, and presents a global cost curve for current time (2007 data are used) and 2050. The curve plots the potential long-term contributions from conventional resources and non-conventional resources against their 2007 and projected 2050 production costs. As in the case of oil, the 2050 supply curve is net of a hypothetical cumulative production between 2005 and 2050 based on the historically observed production growth rate between 1995 and 2007. The resources exploited during the period up to 2050 are no longer available after 2050. Unlike the case of oil, upstream innovation and technology change keep costs at a similar level for mid-priced fields. On the other hand, low-cost production is more expensive than with current technology, and depletion of fields leads to higher costs for the upper end of reserves and resources.
- McCollum et al. (2014) provide a comparison of different cost curves included in a subset of the Integrated Assessment Models (IAMs) participating in the EMF27 exercise of the Energy Modeling Forum. As in the case of oil, the authors find that since estimates of available natural gas resources vary significantly in the literature (BGR, 2009, 2010, 2012; BP, 2010; USGS, 2000; WEC, 2007), the supply curve assumptions in the models also differ significantly. The study includes the evolution of gas prices (globally averaged) as a function of cumulative extraction in the Base FullTech and 450 FullTech scenarios from several EMF27 models. Because of the lower demand for fossil fuels that climate policies will motivate, fossil prices are, in general, lower in the 450 FullTech scenario. There are marked differences in price developments across models, however, as well as between fuels.



- The report “Global Natural Gas Markets Overview” (Leidos Inc., 2014) presents two curves (2007 and 2011) mapping marginal capital cost and reserves additions. The change in slope for the curves is significant, which is due to technology improvements. In fact, technology improvements in shale gas and tight sands development are largely responsible for recent significant shifts in the amount of natural gas reserves available at a given cost. For example, a reserve addition of 800 Tcf has capital costs of about USD 7.00/Mcf to produce in 2007, while the capital costs for production of the same size reserve are USD 3.50/Mcf in 2011.
- McGlade & Ekins (2015) provide information on the cost of production (2010 USD/MMBTU) for the remaining ultimately recoverable resources (URR). The paper includes resources disaggregated by type (seven categories).
- The Rystad database, as in the case of oil, provides annual production (until 2050) and resources, all disaggregated by breakeven price (in USD 5/bbl equivalent or 1 USD/kcf brackets, up to USD 150/bbl and 15 USD/kcf and over). Using annual production data, a production cost curve can be created to map cumulative production and the breakeven price of each year. This figure shows that the breakeven price has declined between 2000 and 2016 (year in which the cumulative production of 1.8 billion Mcf is reached). Given that Rystad database also provides data on the amount of gas resources in each breakeven price bracket for the year 2000–2050, a cost curve can be created and compared with those presented earlier (Figure B10). Given that annual data are provided, annual cost curves can be created. Figure B11 presents curves for the year 2000 and 2050, where it can be clearly seen that production in 2050 will take place at a higher cost than in 2000, primarily due to the depletion of low-cost fields in the earlier period of exploitation.

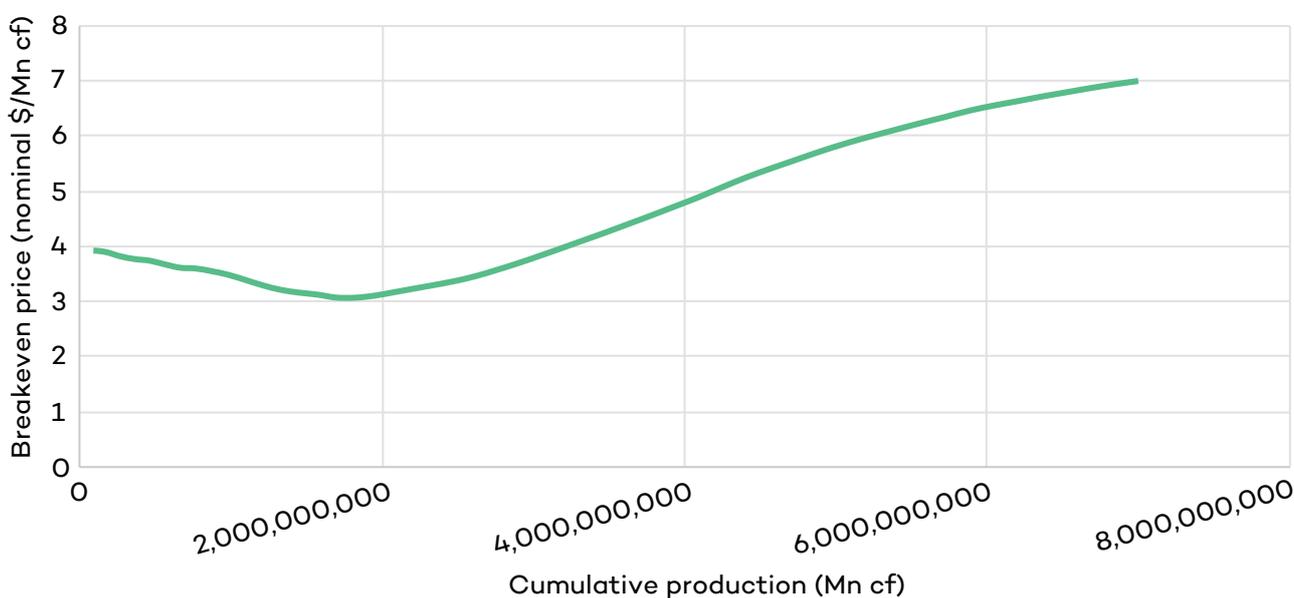


Figure B10. Mapping cumulative production and annual breakeven price (2000–2050).

Source: Authors’ diagram based on Rystad Energy, 2016.

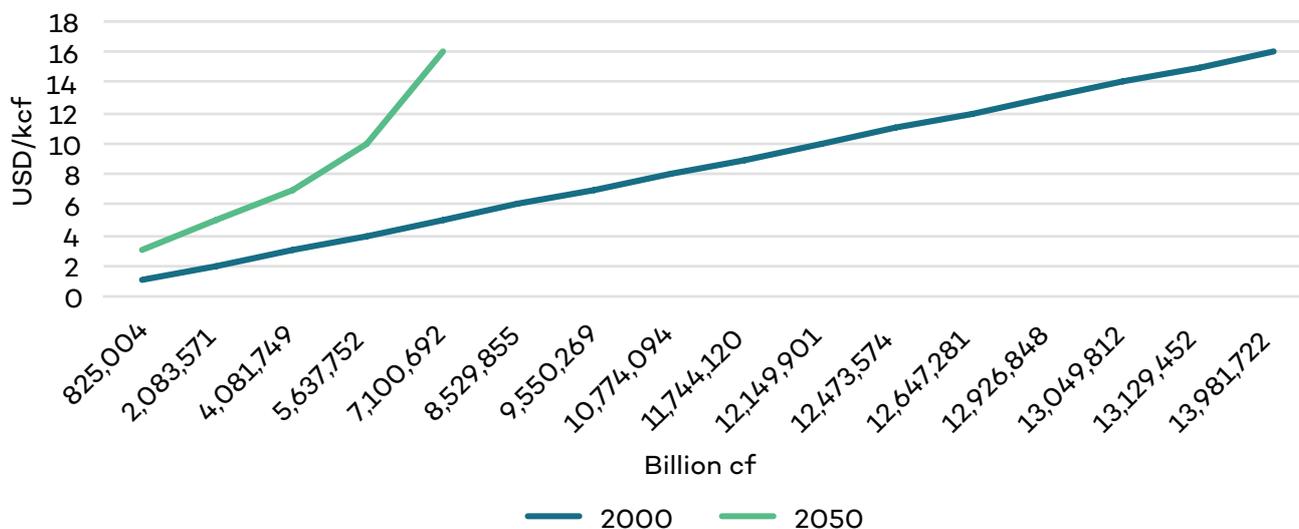


Figure B11. Supply cost curves for natural gas, years 2000 and 2050.

Source: Authors' diagram based on Rystad Energy, 2016.

- The Carbon Tracker Initiative (2015b) presents a global cost curve for liquid fuel production, LNG and world export seaborne coal for the period 2015—2035. The curves include an indication of the amount of supply that would be required under two scenarios of energy demand: (1) the 450 scenario from the International Energy Agency and (2) the Carbon Tracker Low-Demand Scenario (LDS).

B3.3 Coal Production

- Aldina (2013) presents a seaborne cost curve for coal (considering the period up to 2025), mapping reserves and production cost. The values provided are disaggregated by country, allowing the creation of cost curves for the United States and for the rest of the world. This cost curve is the same as what we get from McGlade (i.e., reserves and relative breakeven) and does not describe the current mix of production by country and relative cost.
- IIASA Global Energy Assessment, Chapter 7 (Rogner, 2012) includes detailed data (18 GEA regions) for reserves and resources, both for hard coal and lignite/brown coal. As in the case of oil and gas, the data are from 2007 and the chapter presents two global cost curves: current and 2050 technology. Future supply cost curves are a function of the energy content of coal deposits, geomining conditions, technology changes, overall coal demand and inflation. Further dividing the cost range per geomining category into four classes and applying these classes to the coal reserves of each of the 18 regions in a fixed proportion (60 per cent, 25 per cent, 10 per cent, and 5 per cent) leads to a global hard coal supply cost curve. This report includes two supply curves—one for current reserves based on performance, productivity and costs of current mining technology and one for the reserves, performance and mining technology expected by 2050. The differences between the two supply cost curves reflect the tendency to extract coal first from deposits having more favourable geomining conditions, which will result over time in a reserve shift toward more unfavourable geomining conditions. While this is the dominant factor for hard coal, the reduction in cost for lignite/brown coal stems from a more aggressive assumption on the annual rate of technology change (1.5 per cent vs 1 per cent). The reserves in 2050 exclude any replenishment from coal resources potentially made possible by technology change and different market conditions but reflect the coal produced between 2007 and 2050 (assuming constant 2007 production levels).

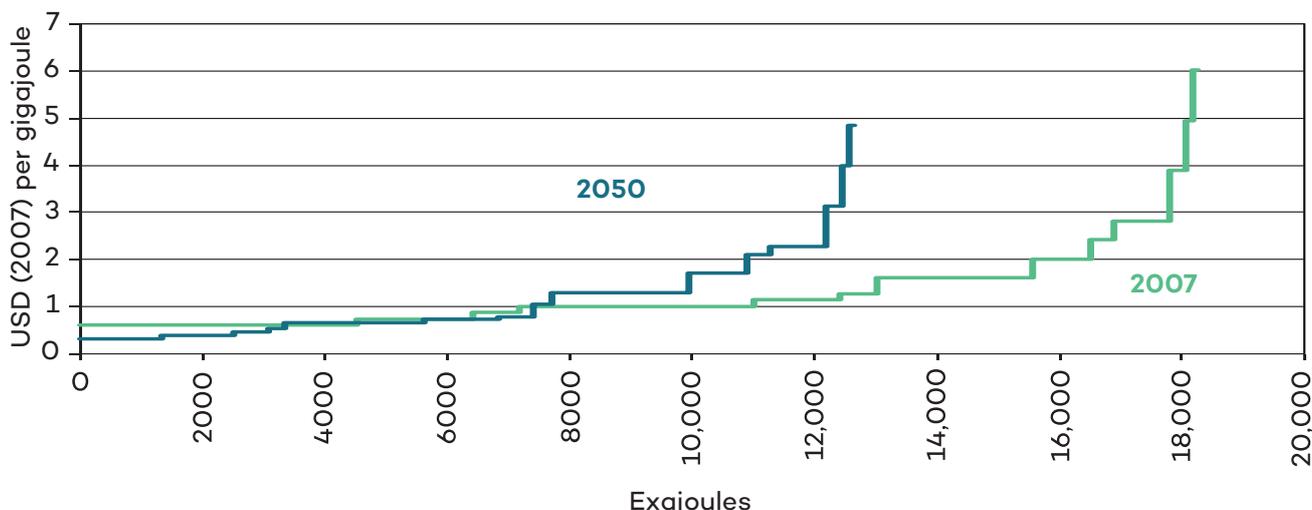


Figure B12. Global coal supply cost curve (2007 and 2050), hard coal.

Source: Rogner, 2012.

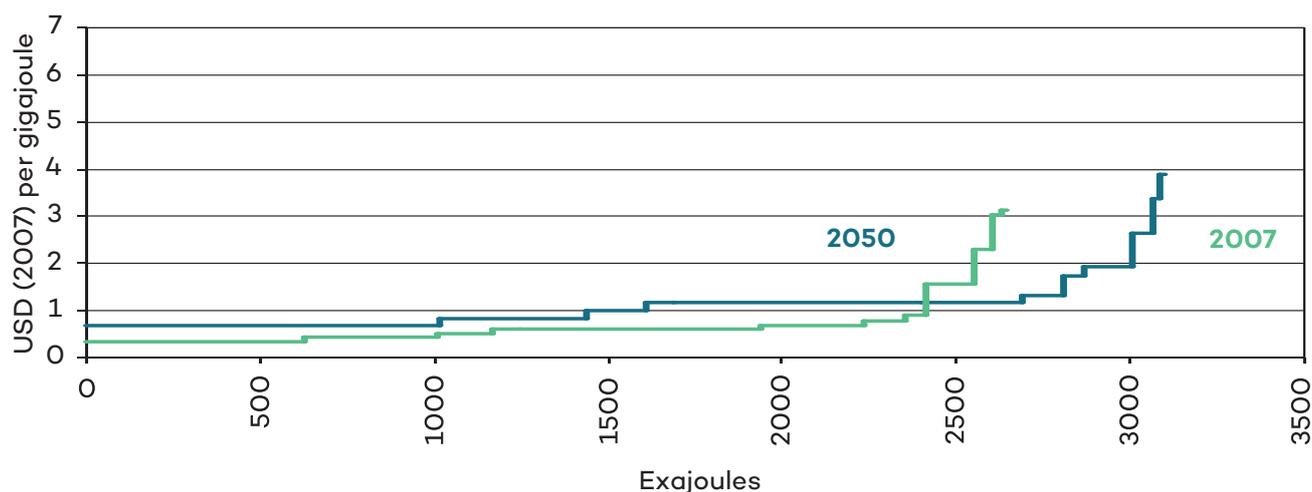


Figure B13. Global coal supply cost curve (2007 and 2050), lignite/brown coal.

Source: Rogner, 2012.

- McCollum et al. (2014) provide a comparison of different cost curves included in a subset of the Integrated Assessment Models (IAMs) participating in the EMF27 exercise of the Energy Modeling Forum. As in the case of oil and natural gas, the authors find that estimates of available natural gas resources vary greatly in the literature (BGR, 2009, 2010, 2012; BP, 2010; USGS, 2000; WEC, 2007), yet the supply curve assumptions in the models do not differ very significantly.
- McGlade & Ekins (2015) provide information on the cost of production (2010 USD/GJ) for the remaining ultimately recoverable resources (URR). The paper includes resources disaggregated by type (four categories), with reserves reaching approximately 20 ZJ and resources adding over 55 ZJ.
- The Carbon Tracker Initiative (2015b) presents a global cost curve for liquid fuel production, LNG and world export seaborne coal for the period 2015–2035. The curves include an indication of the amount of supply that would be required under two scenarios of energy demand: (1) the 450 (50 per cent chance of 2°C) scenario from the International Energy Agency and (2) the Carbon Tracker Low-Demand Scenario (LDS).



- Another study by the Carbon Tracker Initiative, carried out in collaboration with ETA, IEEFA and Earth Track and titled “Assessing Thermal Coal Production Subsidies” (Fulton, Buckley, Koplou, Sussams, & Grant, 2015) presents cost curves for Australia export thermal, and Powder River Basin (PRB) domestic thermal coal. Both curves are based on September 2014 data and have been adjusted for transport costs based on EIA estimates compared to the curve derived in September 2014.

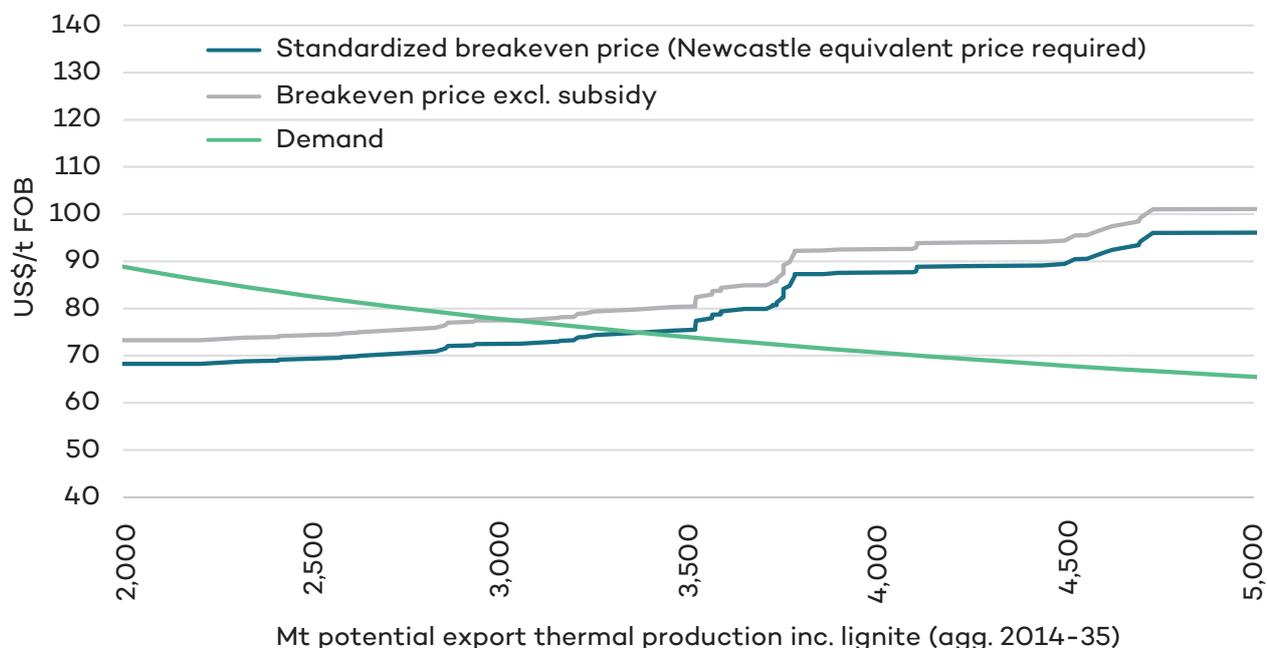


Figure B14. Australia export thermal breakeven price (Sep. 2014), subsidy at USD 4 per tonne of coal.

Source: Fulton, Buckley, Koplou, Sussams, & Grant, 2015.

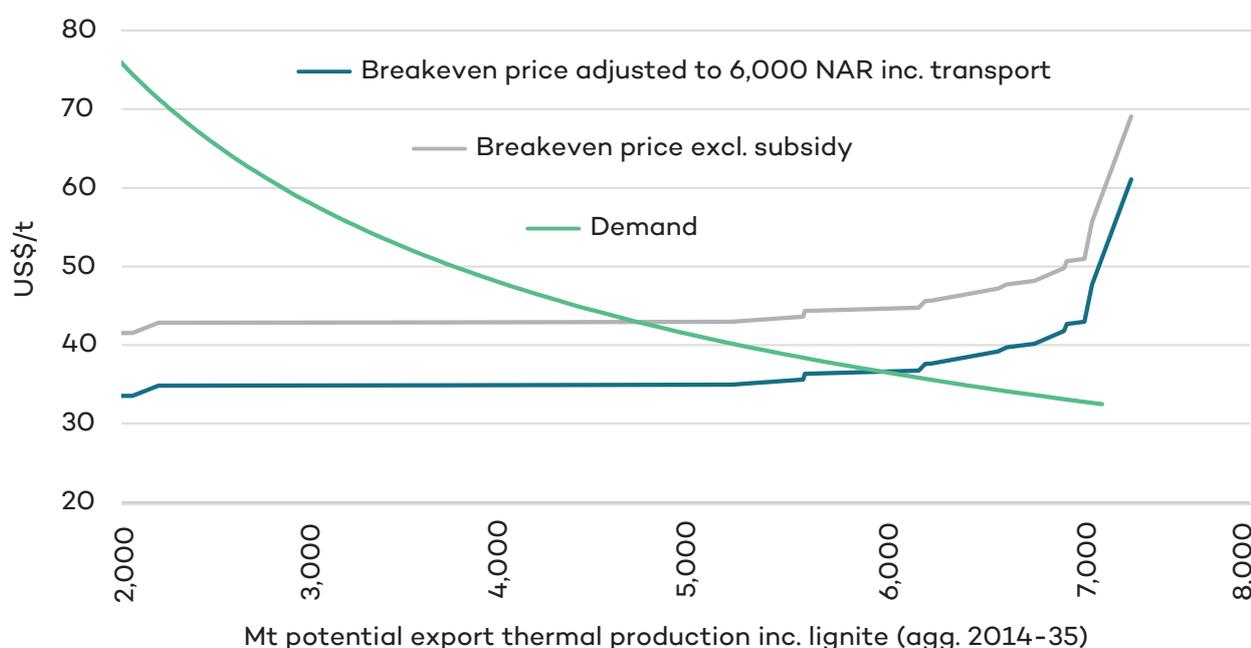


Figure B15. Powder River Basin (PRB) domestic thermal breakeven price (Sep. 2014), subsidy at USD 4 per tonne of coal.

Source: Fulton, Buckley, Koplou, Sussams, & Grant, 2015.



B4.0 Model Documentation

B4.1 Overview of the Model

This section of the report briefly describes the structure of the sectors of the Global Subsidies Initiative's Integrated Fiscal (production)—or GSI-IF(p)—model that are most relevant to analyzing the impact of fossil fuel producer subsidy removal. The GSI-IF(p) is a global model and, as a thought experiment, simulates a simultaneous removal of fossil fuel production subsidies in all countries, which therefore captures leakage effects.

The GSI-IF(p) model uses System Dynamics as a methodological foundation (Sterman, 2000). It integrates sectoral knowledge in a single framework of analysis, incorporating the energy sector with social, economic and environmental sectors and indicators. The model runs differential equations in semi-continuous time and creates “what if” scenarios. It differs from Computable General Equilibrium (CGE) models in that it does not optimize the system (it uses simulation rather than optimization), and also has a much broader cross-sectoral coverage. It achieves this by using stocks and flows of biophysical and economic variables, and by explicitly accounting for feedback loops, delays and nonlinearity.

These sectors of GSI-IF(p) that are of most relevance to estimating the impact of fossil fuel producer subsidy removal include (a) energy demand, (b) fossil fuel production, (c) fossil fuel prices and (d) emissions.

The Energy Demand modules estimate energy demand for the residential, commercial, industrial, transportation, agriculture, fishery and forestry sectors. Sectoral energy demand is disaggregated into five energy sources (i.e., renewables, coal, petroleum, natural gas and electricity), following the IEA classification. The drivers of energy demand are population, GDP, energy prices and technology (energy efficiency). Energy conservation and fuel switching are also included in the model. Elasticities are used to forecast energy demand in relation to economic growth and energy prices—the change in the price of a specific energy source relative to others is considered, rather than an absolute change in price. The Energy Demand modules of the GSI-IF(p) model are similar to those used in the GSI-IF model previously used by the Global Subsidies Initiative (GSI) to estimate emission reductions from the removal of fossil fuel consumer subsidies (Merrill, Bassi, Bridle, & Christensen, 2015).

Fossil fuel production is estimated for oil, natural gas and coal. The structure of the Production and Price modules for oil, gas and coal is similar. In order to avoid repetition in model description, we use the modules related to oil as an example.

The Oil Production module estimates world oil production by considering production capacity from investments and reserves and resource availability. This module calculates oil production and keeps track of both world fossil fuel resources and reserves (which are affected by the URR and technology). The approach used for modelling fossil fuels and non-fuels minerals resource in place is based upon the main groups of the McKelvey box: undiscovered resources and identified reserves (see Figure B16 below).

The purpose of the Oil Price module, again taken as an example for oil, natural gas and coal prices, is to calculate international oil price (prioritizing the medium- and long-term trend). The main factors affecting fossil fuel prices are the availability of reserves and resources (affecting the long-term trend), and the demand-supply balance (affecting the medium-term trend).



The Emissions module calculates fossil fuel emissions for all types of GHGs including CO₂, N₂O, SO_x and CH₄. This is a broader scope, since some of the models, indicators and policy discussions focus on CO₂ only. The calculation of emissions is based on fossil fuel consumption and conversion factors from energy to emissions. GSI-IF(p) model does not take into account changes in emissions resulting from the impacts of subsidy reform on fossil fuel extraction process (for instance, methane leakage, gas flaring or higher emissions from extraction from high-cost fields).

Several additional modules are included in GSI-IF(p). For example. The electricity generation module takes into account production capacity (measured in MW), load factors for each technology, as well as efficiency for thermal generation. The model includes also economic activity (GDP as well as households and government accounts), which are affected by energy productivity (consumption and prices). More detail on fossil fuel production is provided in the next section.

B4.2 Fossil Fuel Production Modules

The model described here is largely based on the one described in Sterman and Richardson (1985). The model employs the System Dynamics approach to simulation (Forrester, 1961; Richardson & Pugh, 1981). Other applications of System Dynamics to energy include (Naill, 1977; Backus, Greene, & Masevice, 1979; Choucri, 1981; Sterman, 1983; Fiddaman, 1997). As shown in Figures B16 and B17, the fossil fuel production modules primarily focus on (1) exploration; (2) production; (3) technology; (4) revenue and investment; and (5) demand and substitution.

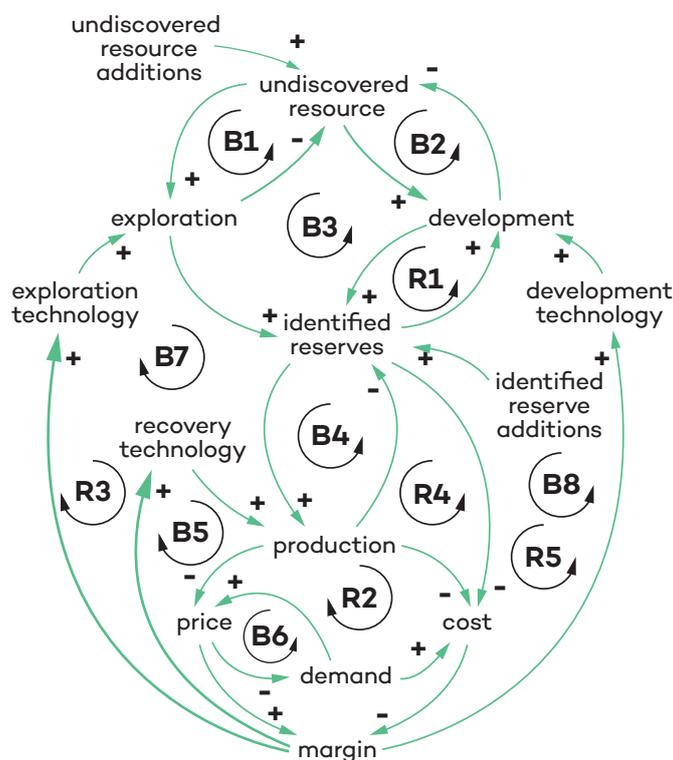


Figure B16. Causal Loop Diagram representing the main feedback loops influencing fossil fuel (oil) exploration, discovery and recovery.

Source: Bassi & Davidsen, 2013.



The availability of oil resources and reserves and their consequent recovery is influenced by many feedback loops. The loops B1, B2, B3 and B4 consist in the balancing effect produced by the utilization of a limited resource: the more is discovered, the less is left to discover and in turns discovery will be smaller than otherwise it would have been. The reinforcing loop R1 refers to the process of development of an oil field. The larger the identified reserve, the higher the probability to find additional oil in the proximity of the field. In addition, the higher the discovery, the larger the identified reserve. The balancing loops B5, B7 and B8 and the reinforcing loops R2, R3 and R5, identify the mechanisms of technology improvement: the higher the (profit) margin, the higher the investment in recovery/exploration/development technology. Technological improvements increase production, which in turn decreases price and cost (e.g., due to a more efficient utilization of the capital in place). The reduction of price and cost influences the margin, which in turn—depending on which factor is dominant—triggers a positive or negative loop for technology improvement. The loop B6 represents the relationship between price and demand: the higher the price, the lower the demand, and also when demand declines, so does price (all else equal). The remaining loop is reinforcing loop R4, which identifies the effect of identified reserves on production costs. The lower the amount of identified reserves, the higher the cost (e.g., when few reserves remain in the reservoir the inner pressure reduces, and water or gas injection is required to keep the pressure high). The higher the cost, the lower the margin (than it otherwise would have been). As mentioned above, a smaller margin reduces the investment in technology and therefore a lower amount of resources will be discovered and consequently added to the identified reserves. This reinforcing loop represents the increasing cost of producing oil due to depletion of resources and reserves.

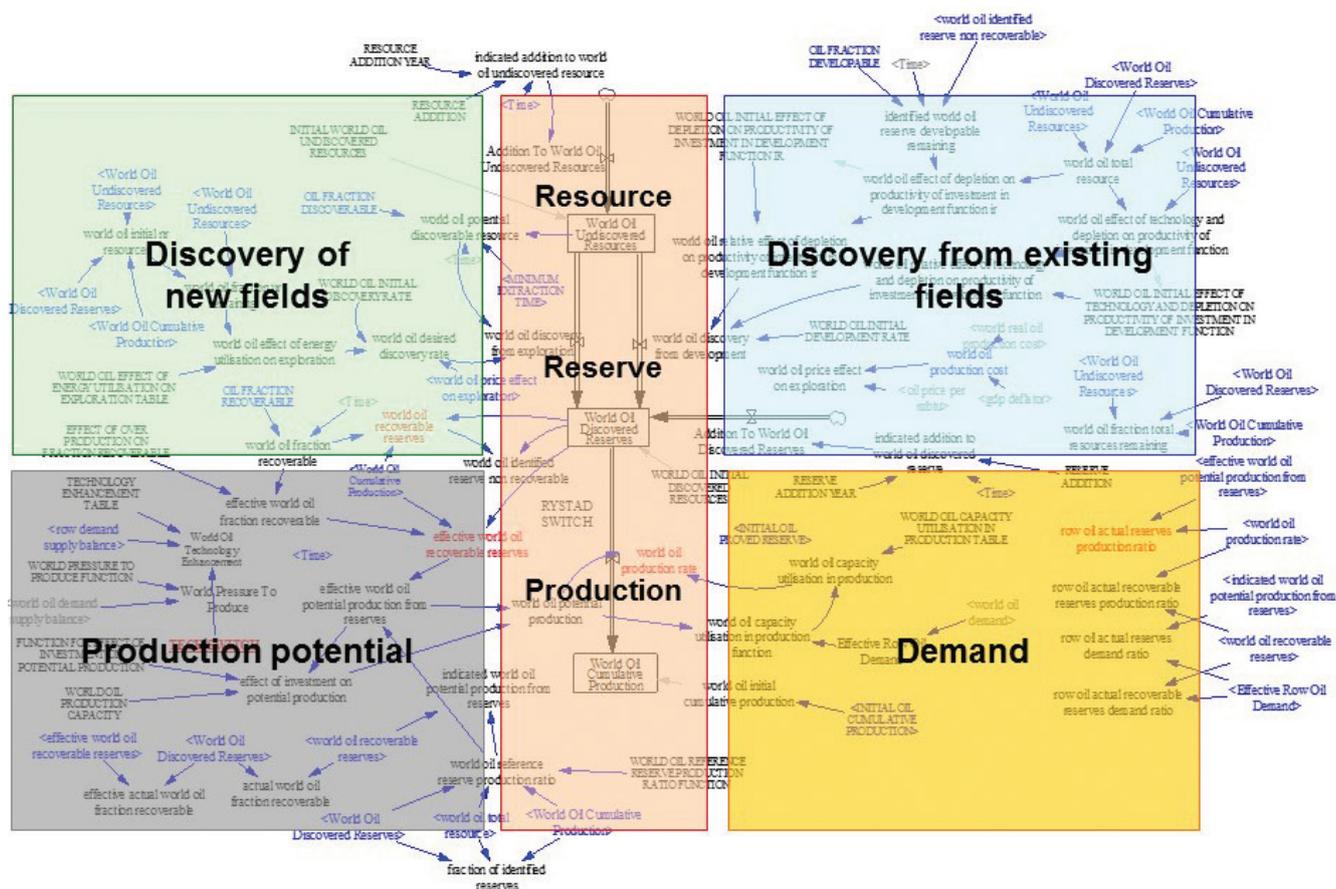


Figure B17. Oil supply module, main building blocks.

Source: Authors' diagram.



The model divides the total quantity of oil-in-place into three basic categories: undiscovered resources, identified reserves (all of which can be produced economically), and cumulative production. The disaggregation of the resource base follows the standard resource classification shown in the McKelvey box format (USGS, 1976) and is consistent with the classification used by Rystad (the GSI-IF(p) model includes the Ultimate Recoverable Reserves, and Resources).

B4.3 Key Feedback Loops Affecting Fossil Fuel Supply and Demand

The main feedback loops existing among energy and the other modules, sectors and spheres of the model are summarized below.

- **Energy prices** influence economic production. A higher energy price can be seen as a higher cost for businesses and households (in fact, when energy prices increase, the purchasing power of households is reduced, all else equal). When energy prices rise, expenses increase while revenues remain constant. These effects generate a decrease in the growth of production, which provokes a reduction in energy demand and a subsequent decline in energy prices (at least in the short term, before depletion becomes the strongest factor driving the behaviour of energy prices).

Energy prices also influence energy demand and technology development for exploration and recovery.

- **Energy demand** depends on energy prices, GDP, technology and population. Demand for energy is influenced by GDP in two ways: the higher the income, the higher the demand and consumption, and at the same time the higher the demand, the higher the investment in technology (which increases consumption efficiency) given the limited availability of resources. Energy demand influences energy prices, investment, production and fossil fuels emissions. Energy investment and production generate feedbacks acting through prices.
- **Energy technology** is influenced by prices and availability of resources, and it affects energy demand and supply. Technology associated with consumption and production needs to be improved when energy prices increase or stabilize over a sustainable threshold and when new energy sources need to be introduced in the market due to depletion of conventional ones (renewables for fossil fuels). Different kinds of technology require consideration (e.g., consumption, exploration, development, and recovery) due to the nature of their impact on environment, society and economy. Three balancing loops characterize the development of energy technology: the faster its improvement, the smaller the demand for energy (consumption technology) and the more efficient the production of energy (exploration and recovery technology). Both effects reduce energy prices and therefore the need for improved technology. On the other hand, when production becomes more efficient, depletion is still in place, indicating the need for further technology development.
- **Energy production** is influenced by investments (capital installed), technology (exploration and recovery), demand and availability of resources. These factors can be organized in potential production (capital and resource availability, which is equal to recoverable reserve, obtained by the combination of technology and resource in place) and demand. Energy production affects resource availability (depletion), generation of fossil fuels emissions, and revenues of the government. Fossil fuel production (extraction of coal and especially oil and gas) as well as consumption of gasoline and other fossil fuels are taxed by the government, though the level of taxation is different in different countries. Thus, both fossil fuel production and consumption can represent a source of revenue that contributes to national economic growth, and hence energy demand and production.



- **Energy resources** are influenced by energy production: the higher the production, the faster the depletion process of fossil fuel reserves. The availability of resources and reserves affects energy prices technology and production.
- **Emissions** are influenced by energy consumption (the minimum between demand and production). As mentioned above, fossil fuels emissions affect population (life expectancy) and health (air quality). In addition, emissions generate GHGs, which, according to a growing number of studies (IPCC, 2007), strengthen the actual process of climate change.

B5.0 Scenarios

Several scenarios were simulated with GSI-IF(p) to better understand the impact of fossil fuel subsidy removal on emissions.

The main variables utilized to create these scenarios can be summarized as follows:

- **Subsidy amount:** The amount of subsidies considered in the various scenarios is the same, and it is based on the average unit subsidy provided by G20 countries to oil, gas and coal production. It is assumed that the same amount of subsidy per unit of fuel produced is given to all other production worldwide. Three assumptions are used to estimate the subsidy amount used in the model: a capex multiplier of 3 (Removal 3), a capex multiplier of 2.5 (Removal 2.5) and no multiplier (Removal).
- **Subsidy removal:** All scenarios assume that production subsidies are removed at once. As a result, from the year 2017 there will be no fossil fuel production subsidies.
- **Cost curves:** Various cost curves are utilized in the analysis. Global cost curves from Rystad Energy UCube Upstream database are employed for oil and gas production. A global cost curve for hard coal (Rogner, 2012) (World) and two additional cost curves for US Powder River Basin (PRB) and Australia Export (AUS) (Carbon Tracker Initiative, 2015b) are used for the analysis of coal production subsidies.
- **Underlying energy demand:** Assumptions about demand are based on the IEA Current Policies projection (IEA, 2015) considering existing policies that have been formally approved—which would result in warming significantly beyond the limits enshrined in the Paris Agreement.

We do acknowledge that using assumptions that are simplified and generalized across regions and countries (such as, for instance, global cost curves) requires a careful interpretation of the results of the simulations. For instance, subsidy dispersion across projects may be quite different, leading to a larger amount of reserves becoming uneconomical than what the model forecasts; impacts on particular regions or geology types may be masked, as there may be cases where trade is possible (e.g., oil, where impacts of subsidy removal may be overstated) and where it is highly constrained (e.g., coal, where impacts of subsidy removal may be understated).

The results of the various simulations are presented in the following pages. To illustrate how the scenarios were created, the “default” explanatory option is the case of subsidy removal with a multiplier of 3 for capex (*Removal 3*), using the PRB cost curve for coal (PRB).



B6.0 Results

The removal of production subsidies has several impacts on the energy sector and the economy as a whole. The two main impacts to consider are those on emissions and on economically recoverable reserves.

- Regarding economically recoverable reserves, since the removal of production subsidies increases production costs, certain reserves that are economical with the subsidy will become uneconomical without it. The assumption made in the modelling exercise is that the reserves that will become uneconomical with the removal of the subsidy are concentrated around the current breakeven price.
- Concerning emissions, producer subsidy removal leads to an increase in the cost of extracting fossil fuels. If these extra costs can be passed through to consumers, or if production declines as a result of higher production costs, the market price will increase. When energy prices increase, demand declines. This leads to a reduction in energy consumption and emissions.

Specifically, the relationship between reserves and production (and hence carbon that would be left in the ground and avoided emissions) can be described as follows. The removal of fossil fuel production subsidies is expected to increase production costs. An increase of costs—in the absence of changes in the market price—will lead to some reserves becoming uneconomical to produce. Out of all the reserves that become uneconomical, only a small portion will be produced in a given year. For instance, in the year 2000, only 1.9 per cent of the reserves in the breakeven price range of USD 40 to USD 45 per barrel were actually produced. This will lead to a relatively small (global) reduction in production and increase in production costs. The market price is therefore expected to increase when subsidies are removed, which will then affect demand and consumption. As a result, the removal of fossil fuel production subsidies is projected to have a large impact on reserves (and on the corresponding CO₂ content) and more contained impacts on the annual amount of emissions resulting from the burning of fossil fuels, for any given year.

If we assume that the market price of fossil fuels does not change over time, then the full amount of those reserves that become uneconomical following removal of production subsidies will stay in the ground. This approximates a scenario in which fuel switching lowers demand, keeping the market price low and reducing the profitability of production. If, instead, the market price increases over time, some of the reserves that were uneconomical due to the removal of subsidies will be produced (e.g., those uneconomical at USD 55/barrel in 2016 will be economical in 2020 if the price rises to USD 70/barrel), while others will become uneconomical if the subsidy is not reintroduced (e.g., the reserves with a breakeven price of USD 75/barrel are uneconomical if a subsidy of USD 5/barrel is not introduced when the market price is at USD 70/barrel).

As a result, our study indicates the actual amount of annual and cumulative emissions (up to 2050) that would be avoided due to producer subsidy removal, as well the corresponding amount of reserves that would not be produced. In addition, it provides information on the potential reserves that become uneconomical due to the removal of production subsidies.

With this in mind, it should be noted that the subsidy inputs that are used to estimate GHG emission reductions are likely to be an underestimate of the actual amount provided worldwide. This is because it was not possible to quantify many of subsidies of G20 and other countries, including fossil fuel subsidies in major producers such as Indonesia, Mexico and Saudi Arabia. For this reasons it can be expected that amount of GHGs avoided by the removal of production subsidies is also an underestimation of the potential real impact of such policy.



B6.1 Emission Reductions

The projected global reduction in GHG emissions from combustion of fossil fuels, if all production subsidies are removed in 2017, is projected to reach, cumulatively between 2017 and 2050 22.4–22.8 gigatonnes of GHG emissions in the Removal case,⁶ to 32.8–33.3 gigatonnes of GHG emissions in the Removal 2.5 case, and to 36.4–36.9 gigatonnes of GHG emissions in the Removal 3 case. The range provided on emission reduction is a result of the use of different cost curves for coal production (i.e., Australia export, PRB and a global cost curve). In fact, the model includes a certain degree of fuel substitution when fossil fuel production prices change.

This reduction in annual emissions resulting from the removal of fossil fuel production subsidies (in the Removal 3 case) is equivalent to 1.1 Gt of CO₂ per year, or 2 per cent relative to the baseline scenario. When considering current data, 1.1 Gt of CO₂ per year represents 3.4 per cent of the emissions of the year 2013, which corresponds to the total of international and domestic aviation (IPCC, 2014).

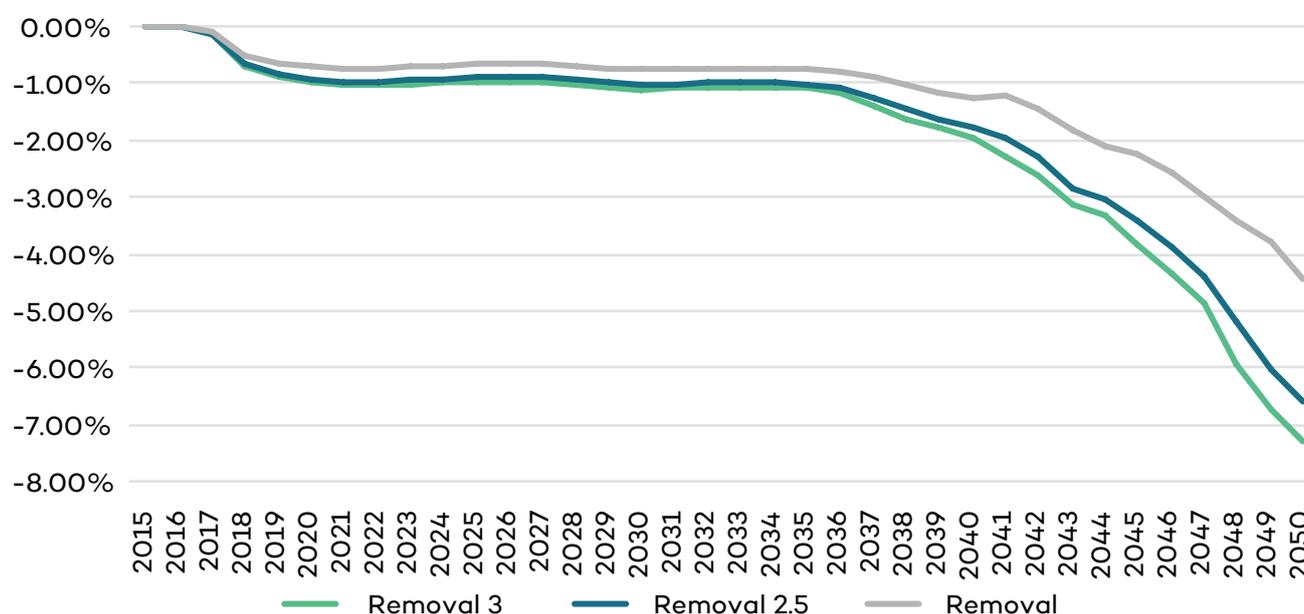


Figure B18. Global emission reduction due to production subsidy removal, relative to the baseline scenario, 2015–2050.

Source: Authors' diagram.

⁶ Authors' diagram, based on World Development Indicators World Bank, 2016.



BOX B4. PRODUCER SUBSIDY REMOVAL IMPACTS ON ENERGY PRICE

Energy prices are modelled endogenously in GSI-IF(p) and are formulated to take into account both short-term dynamics (concerning demand and supply) and long-term factors (based on technology and cost of production as well on expectations regarding the availability of reserves).

Fossil fuel prices are also affected by subsidy removal, as this influences production costs as well as the demand and supply balance. The following figures present the net impact (relative to the baseline scenario) that producer subsidy removal has on fossil fuel prices under various scenarios.

In the meantime, it can be noted that the fuels that are most constrained (e.g., oil) see an increase in price going forward (both because of growing production prices and for the tight demand and supply ratio). This can be seen for oil (Figure B19) and to a lesser extent for gas (Figure B20). The price of coal, on the other hand, given its vast availability of reserves at contained costs, is projected to decline (Figure B21). This is primarily due to the dominance of the demand effect (when demand declines while supply and recoverable reserves stay largely unchanged, the price declines).

We can also see that, after an initial increase in energy prices (due to the removal of subsidies) the change is mitigated by demand responses. The depletion of reserves, and increase of the production cost are then the main drivers of the medium- and longer-term price of fossil fuels.



Figure B19. Oil prices, percent change relative to the baseline scenario, 2015–2050.

Source: Authors' diagram.



BOX B4. PRODUCER SUBSIDY REMOVAL IMPACTS ON ENERGY PRICE (continued)

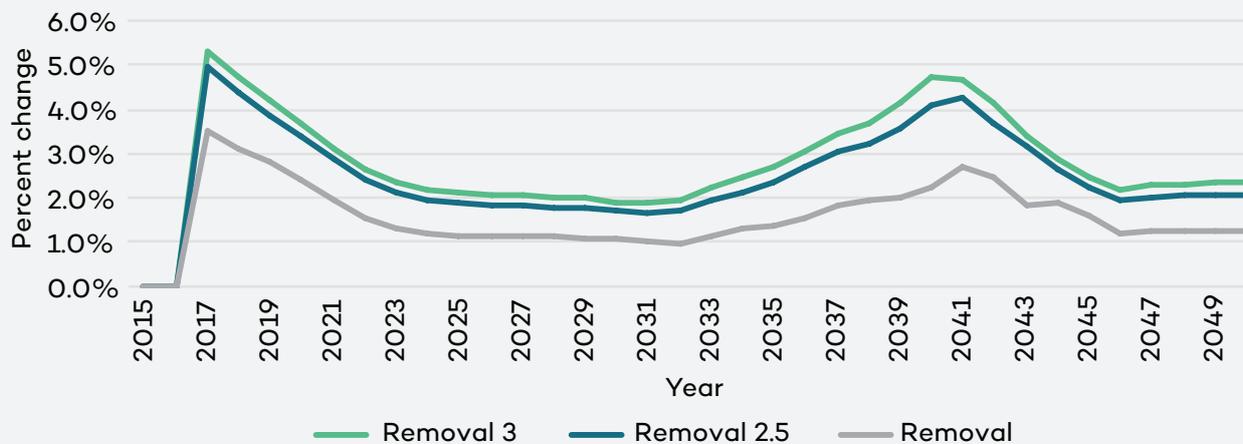


Figure B20. Gas prices, percent change relative to the baseline scenario, 2015–2050.

Source: Authors' diagram.

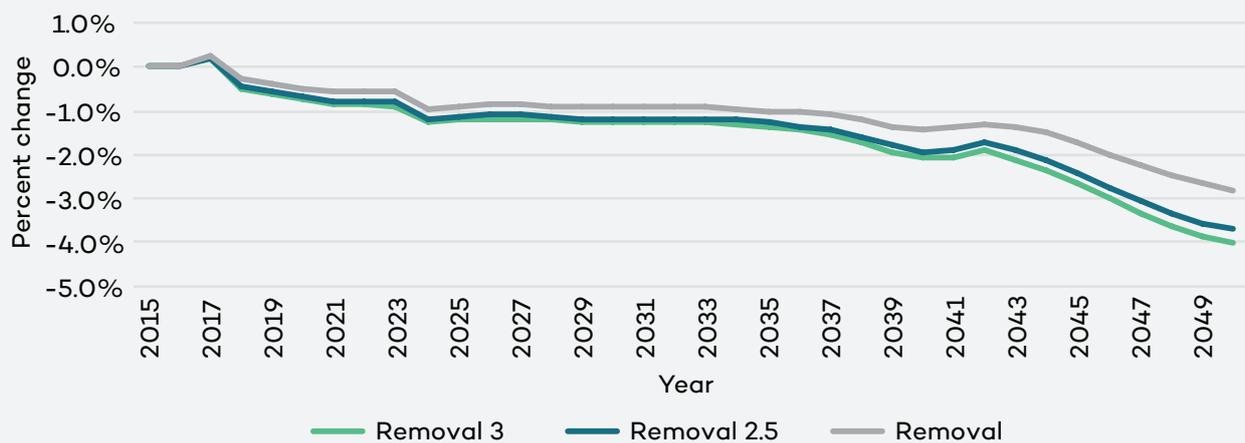


Figure B21. Coal prices, percent change relative to the baseline scenario, 2015 - 2050.

Source: Authors' diagram.



BOX B5. IMPACT OF PRODUCER SUBSIDY REMOVAL WITH EXOGENOUS MARKET PRICES.

All the results presented in this annex are generated by the model using an endogenous price formulation. New simulations were created using an exogenous price assumption to remove the demand response impact on prices and profitability, and assess the direct impact on production and costs in isolation.

Two additional scenarios were simulated for oil: low (3 per cent growth rate per year) and high market price (5 per cent growth rate per year). The low case approximates IEA's Low Oil Price Scenario, and the high one is in between the New Policies Scenario (NPS) and the Current Policies Scenario (CPS). For reference, the endogenous price estimated by the model is close to the NPS projection.

The results obtained from these simulations show:

- (1) A larger amount of reserves become uneconomical due to the removal of production subsidies relative to the simulations that use an endogenous price formulation. This is due to the lack of the balancing factor brought about by demand and supply when prices are endogenous. The change observed is in the range of 6.3-11.6 per cent more uneconomical oil reserves for the low and high oil price scenarios respectively, when compared with the endogenous price formulation.
- (2) No change relative to the baseline scenario is observed for oil consumption and production, because the market price is exogenous and it is not affected by subsidy removal.

B6.2 Reserves That Become Uneconomical to Produce

B6.2.1 Oil

With the phase-out of subsidies to fossil fuel producers, projections indicate that some oil reserves will become uneconomical to produce. This will have an impact on production and on the cost of production.

Relative to the Current Policies baseline scenario, oil reserves that become uneconomical to produce are projected to average 105,300 million barrels in the Removal case, 138,900 million barrels in the Removal 2.5 case, and 150,000 million barrels in the Removal 3 case.

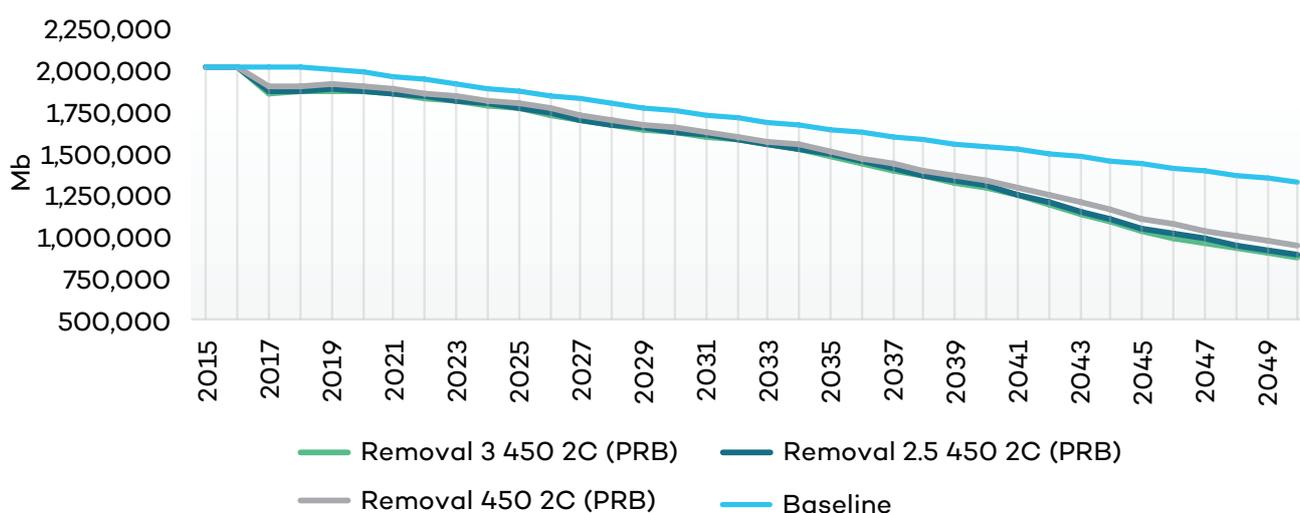


Figure B22. Oil recoverable reserves, 2015–2050.

Source: Authors' diagram.

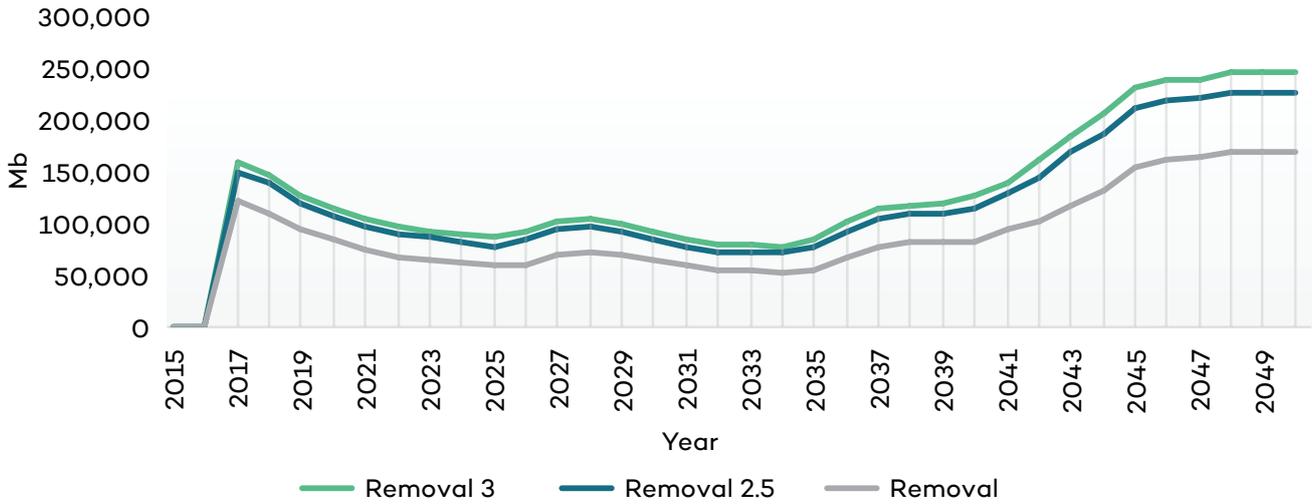


Figure B23. Oil reserves that become uneconomical to produce, 2015–2050.

Source: Authors' diagram.

B6.2.2 Natural Gas

With the phase-out of fossil fuels subsidies, projections indicate that some natural gas reserves will become uneconomical to produce. This will have an impact on production and on the cost of production.

Relative to the Current Policies baseline scenario, natural gas reserves that would become uneconomical to produce average 324,100 billion cubic feet in the Removal case, 496,150 billion cubic feet in the Removal 2.5 case, and 549,200 billion cubic feet in the Removal 3 case.

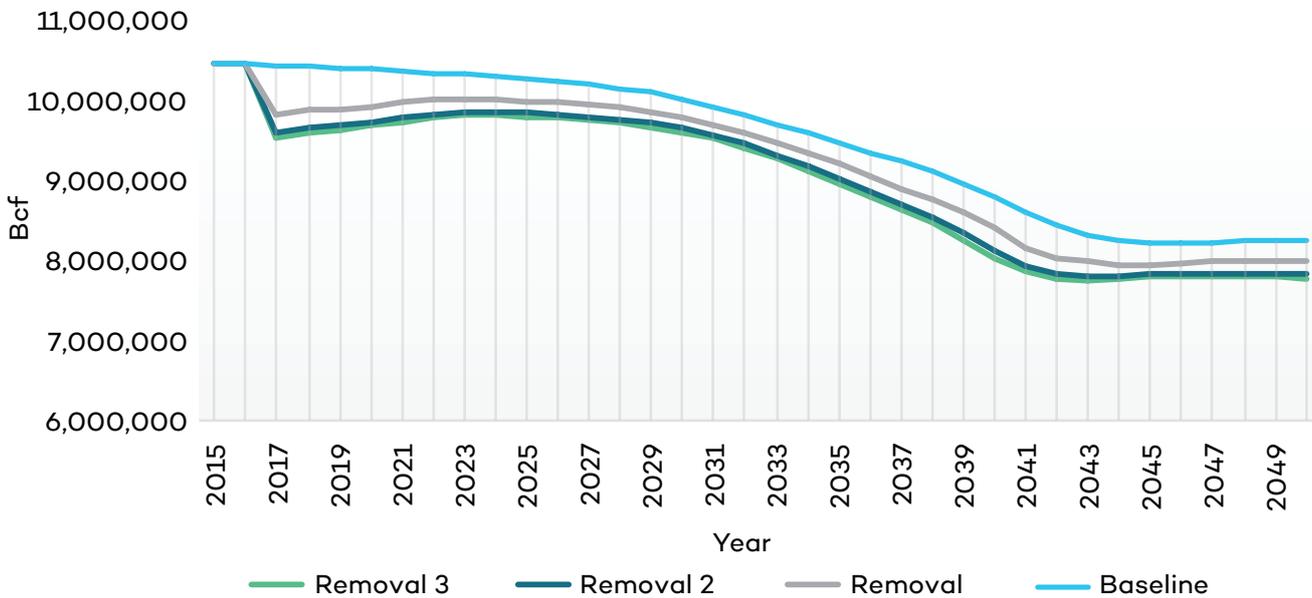


Figure B24. Natural Gas recoverable reserves, 2015–2050.

Source: Authors' diagram.

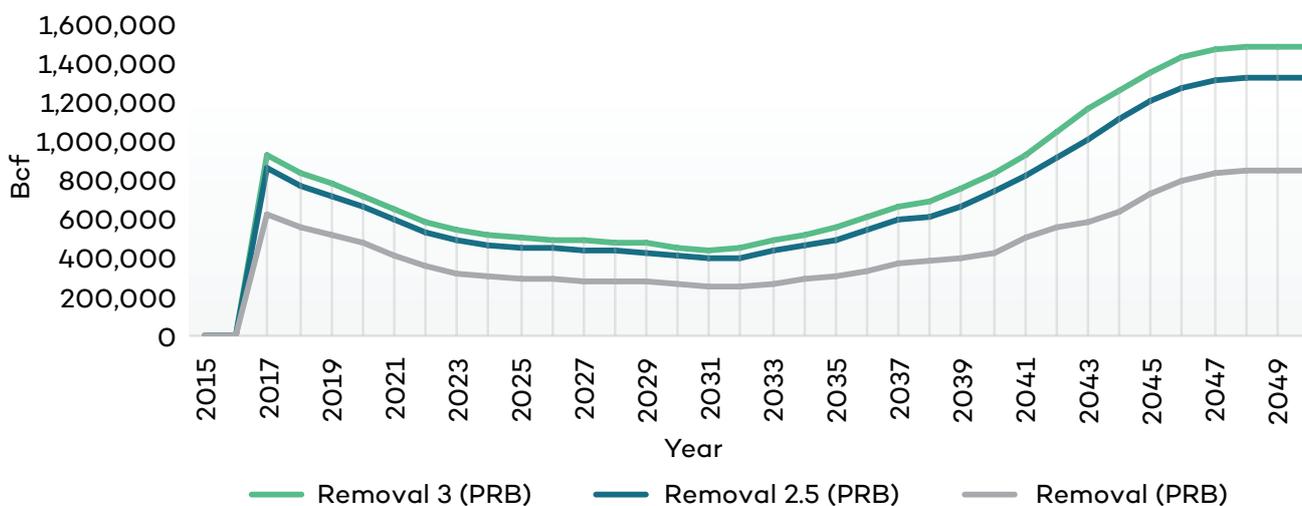


Figure B25. Natural Gas reserves that become uneconomical to produce, 2015–2050.

Source: Authors’ diagram.

B6.2.3. Coal

With the phase-out of fossil fuels subsidies, projections indicate that some coal reserves will become uneconomical to produce. This will have an impact on production and on the cost of production.

Three scenarios are tested for coal production, where different cost curves are used: Australia export, PRB and a global cost curve. The reason is that the expected changes could be closer to regional and national dynamics because the coal market is not global (or at least not to the extent that the oil market is). These cost curves are very different, both in terms of cost of production and shape. Further, while modifications to the curves were not made, it is observed that the potential to scale up production (when compared to current levels) is lower in the case of Australia export and PRB in relation to the global cost curve. In other words, even when scaling the production level to represent proportional impacts of the increase of production on costs, the cumulative production at the world level projected by the GSI-IF(p) model goes beyond the maximum value included in the two regional curves. This means that, in the PRB scenario for example, the breakeven price of coal will not change after 2040. Therefore, the results have to be correctly interpreted, as they represent a likely underestimation of the impact of fossil fuel producer subsidy removal on GHG emissions.

Considering the Australia export cost curve (AUS), relative to the baseline scenario, coal reserves that become uneconomical to produce are projected to average 9,430 million metric tonnes in the Removal case, 11,020 million metric tonnes in the Removal 2.5 case, and 12,280 million metric tonnes in the Removal 3 case.

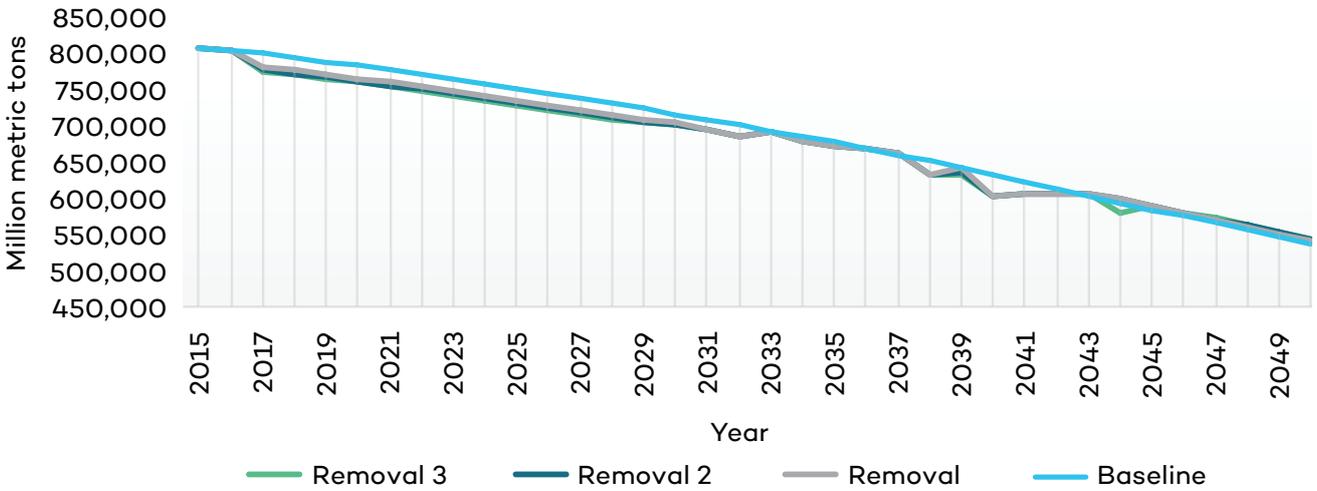


Figure B26. Coal recoverable reserves (AUS scenario), 2015–2050.

Source: Authors' diagram.

Using the cost curve for PRB production, relative to the baseline scenario, coal reserves that become uneconomical to produce are projected to reach 20,900 million metric tonnes in the Removal case, 21,000 million metric tonnes in the Removal 2.5 case, and 21,120 million metric tonnes in the Removal 3 case. The amount of uneconomical reserves in the PRB case is larger than in the Australia export case due to the lower cost of production, which has the removal of subsidies (same amount for both scenarios) resulting in proportionally larger price increases.

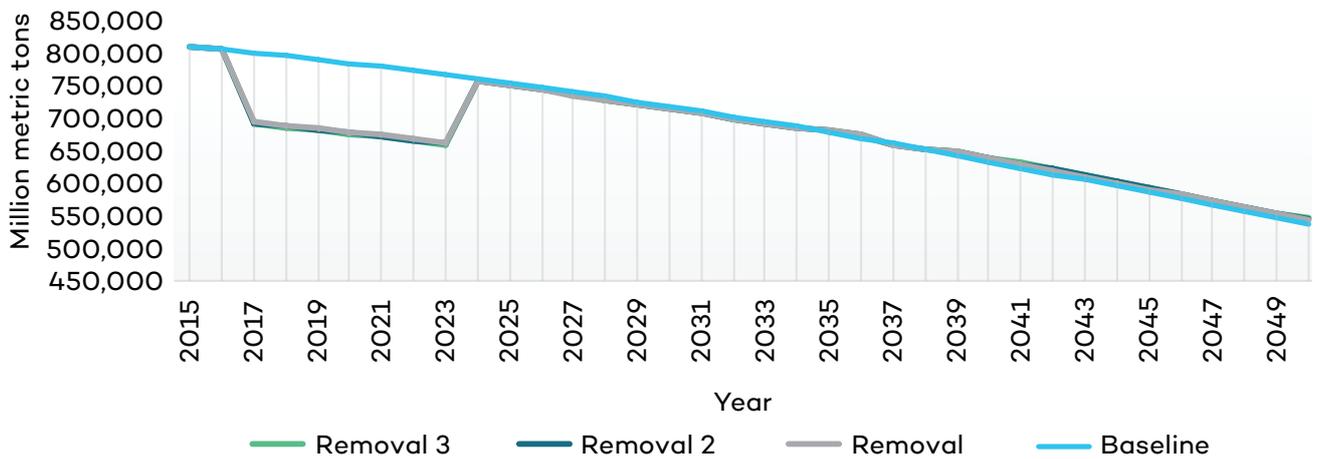


Figure B27. Coal recoverable reserves (PRB scenario), 2015–2050.

Source: Authors' diagram.

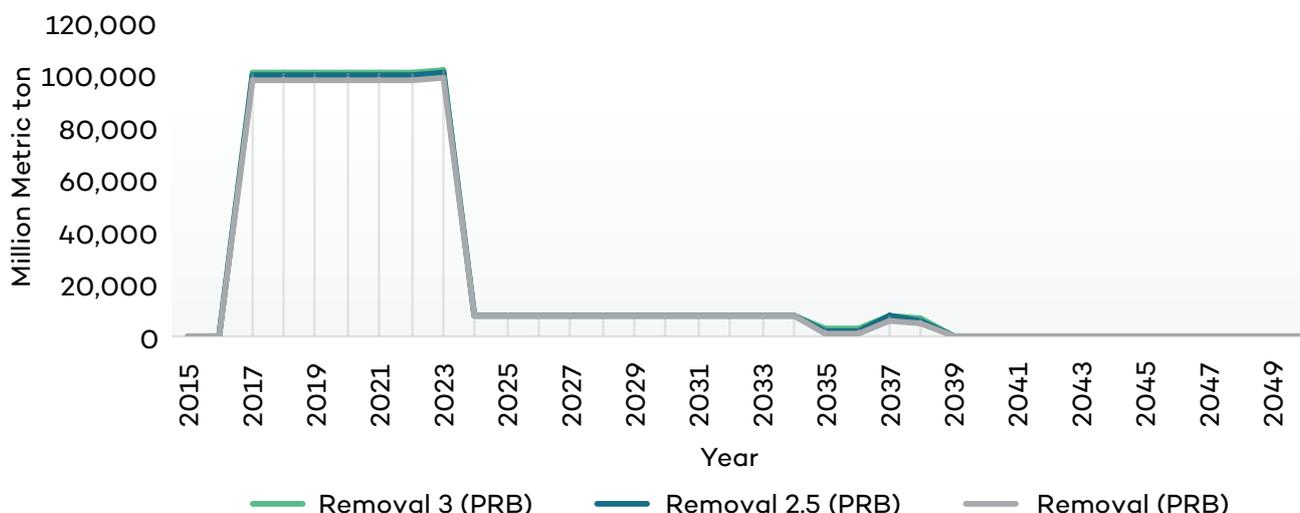


Figure B28. Coal reserves that become uneconomical to produce (PRB scenario), 2015–2050.

Source: Authors’ diagram.

Using a global cost curve for production, relative to the baseline scenario, coal reserves that become uneconomical to produce are projected to reach 925 million metric tonnes in the Removal case, 970 million metric tonnes in the Removal 2.5 case, and 1,000 million metric tonnes in the Removal 3 case. These forecasts are well below the values presented in the AUS and PRB scenario. This is primarily due to the shape of the global cost curve, which, including more reserves at low development cost than in Australia or Powder River Basin in the United States, remains flat until approximately 2030 and only slightly increases up to 2050. Further, on a global scale, subsidies to coal production (mining) that have been adequately quantified, and thus used in this analysis, are relatively low (many subsidies to coal mining globally are in the form of state investment in state-owned enterprises, which are not captured in this analysis). As a result, economic viability of reserves is virtually unaffected. This highlights why it is important to compare scenarios for global as well as regional or local production. The shape of the cost curves is very different, and a global curve implicitly assumes that there is full access to low-cost coal worldwide (e.g., it approximates the case of oil, which can be more easily transported across continents). On the other hand, the increase in cost forecasted with local cost curves is likely an overestimation when considering global production, and the impact on demand will also be mitigated when considering global access to coal, since trade (to a certain extent) is possible for all countries of the world.

**BOX B6. COMPARING RESULTS WITH CTI'S WORK ON COAL SUBSIDIES**

The result of projections on coal were compared with the study titled “Assessing Thermal Coal Production Subsidies: Policy Makers’ Briefing” by the Carbon Tracker Initiative (CTI) (Fulton, Buckley, Koplou, Sussams, & Grant, 2015), although with a number of caveats. We used the same cost curves (AUS and PRB), but the amount of subsidies provided for this production in the CTI study is higher than what we simulated using G20 subsidy data. As a result, new simulations were created, using both consistent (a) cost curves and (b) subsidy assumptions. Further, (c) the results of the GSI-IF (p) model were estimated for the period 2015–2035 (rather than 2050 for the original run of GSI-IF(p), for consistency with the CTI work. A comparison of results follows:

- In the CTI study the reduction in demand for US PRB coal is estimated between 8 per cent and 29 per cent. In the GSI-IF(p) study it is estimated that 84,700 million metric tonnes would be uneconomical (four times more than in the scenario in which G20 subsidy figures are used) and that global demand would decline by 0.8 per cent. However, in order to compare results, an additional calculation has to be made, given the closed nature of the PRB production system (and trade in the region) and the more systemic and integrated nature of GSI-IF(p). The projected reduction in recoverable reserves corresponds to approximately 10.8 years of production at current levels. When assuming that these reserves could not be produced until 2035, and that other (cheaper) coal could be imported, the potential reduction in supply is up to 54 per cent. Since it is unrealistic to assume that supply from PRB could be fully replaced with cheaper imports (and hence the reduction in production would certainly be smaller than 54 per cent), the results forecasted by GSI-IF(p) seem consistent with the range of 8 per cent to 29 per cent forecast by CTI.
- In the CTI study the reduction in demand for AUS coal is estimated between 3 per cent and 7 per cent. In the GSI-IF (p) study it is estimated that 33,300 million metric tonnes would be uneconomical (three times more than in the scenario in which G20 subsidy figures are used) and that global demand would decline by 0.8 per cent. The projected reduction in recoverable reserves corresponds to approximately 4.25 years of production at current levels. When assuming that these reserves could not be produced until 2035, and that other (cheaper) coal could be imported, the potential reduction in supply to be up to 21 per cent. Similarly to the PRB analysis, these results seem consistent with the CTI study, (a) being both smaller than what is observed for PRB, and with the GSI-IF(p) model representing a worst-case scenario on the supply side.

©2017 The International Institute for Sustainable Development
Published by the International Institute for Sustainable Development.

IISD Head Office

111 Lombard Avenue, Suite 325
Winnipeg, Manitoba
Canada R3B 0T4

Tel: +1 (204) 958-7700

Website: www.iisd.org

Twitter: @IISD_news

Global Subsidies Initiative

International Environment House 2
9 chemin de Balexert, 1219 Châtelaine
Geneva, Switzerland

Tel: +41 22 917-8683

Website: www.iisd.org/gsi

Twitter: @globalsubsidies

