CENTRE FOR ECONOMIC POLICY RESEARCH

CEPR PRESS

Edited by Christian Gollier and Dominic Rohner

Peace not Pollution

How Going Green Can Tackle Both Climate Change and Toxic Politics

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CEPR PRESS

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ISBN: 978-1-912179-74-9

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Foreword

Despite widespread concern over climate change and recognition of the need for a green energy transition, resistance often arises when faced with specific policy measures. While this disconnect may be influenced by factors including the 'not in my backyard' attitude, unrealistic expectations of a sacrifice-free transition and free-rider incentives, the challenge also lies in effectively communicating green policies while considering potential adverse distributional consequences. Failure to do so runs the risk that misconceptions concerning a lack of fairness could be exploited by populist politicians. The invasion of Ukraine has exposed the risks inherent in fossil fuel dependency and the intricate connection between energy and conflict, reinforcing impetus to act.

This eBook features contributions from leading economists and practitioners who provide a comprehensive overview of the challenges, initiatives and far-reaching impacts of 'going green'. Chapters discuss strategies to curb harmful energy consumption and production using green taxes, carbon pricing, and reducing fossil fuel subsidies. The authors stress that such policies must be redistributive and progressive to reduce potential inequalities. Meanwhile, decarbonisation policies should work in tandem to promote renewable energy and facilitate the greening of the electricity market. Concerns over affordability and sustainability can be alleviated if environmental regulations and the market design of the sector are well coordinated.

Other chapters discuss broader macroeconomic dimensions of the green transition, with authors questioning the short-term economic impact of 'green growth' and calling for structural reforms that could smooth the reallocation of factors of production and limit the adjustment costs. The securement of adequate financing presents novel challenges since market dynamics play a crucial role in shaping the adoption and growth of renewable energy sources.

Furthermore, the political consequences of fossil fuel dependence, including corruption and conflicts, are often overlooked, but transitioning away from these fuels presents an opportunity to create a safer and better-governed world, although the challenge lies in avoiding negative impacts associated with the extraction of alternative minerals.

This eBook provides a clear and balanced overview of what it might take to achieve an equitable and sustainable green energy transition and why reducing energy consumption is crucial for ensuring future peace. While many obstacles remain, policymakers can draw on the insights and strategies within to tackle both climate change and toxic politics.

CEPR is grateful to Christian Gollier and Dominic Rohner for their expert editorship of the eBook. Our thanks also go to Anil Shamdasani for his skilled handling of its production.

CEPR, which takes no institutional positions on economic policy matters, is delighted to provide a platform for an exchange of views on this important topic..

Tessa Ogden
Chief Executive Officer, CEPR
June 2023

CHAPTER 1

Championing the green energy transition without playing into the hands of populists

Christian Gollier and Dominic Rohner
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The path to environmental disaster is paved with paradoxes. On the one hand, a wide majority of people are worried about climate change and many agree with the scientific reality that the world's current addiction to fossil fuels is unsustainable and is leading straight to catastrophe.[1] The need for a green energy transition is indeed widely understood and benefits from wide (abstract) support. Yet, on the other hand, the devil is in the detail, and when faced with concrete policy measures advocated by specialists, large-scale resistance often materialises (e.g. Gollier and Tirole 2015). Maybe surprisingly, in many cases binding prescriptions of behaviours may actually trigger less fierce resistance than arguably more flexible and often more efficient policies put forward by economists. The route from the abstract understanding of the problem to finding concrete solutions resembles a leaky pipeline, where along the way many well-intentioned citizens are lost.

While the disconnect between the abstract support for 'tackling climate change' and the frequent popular rejection of concrete policy proposals may be partly due to the well-known 'not in my backyard' (NIMBY) attitude, the utopia of a happy and sacrifice-free transition and free-rider incentives, these are unlikely to explain the whole extent of the phenomenon. Clearly, we also have a big problem when it comes to communicating green policies based on monetary incentives. The goal of such green levies is to discourage environmentally harmful consumption or production. To get the incentives right, people or firms that pollute less will be rewarded and those that pollute more are supposed to pay the actual price for their pollution when taking into account the negative externalities they impose on the rest of the society. While such measures seem fair from the perspective of the polluter-pays principle, they may – if ill-designed – still have adverse distributional consequences.

1 Surveying more than 125,000 people across 121 countries, the World Risk Poll 2021 found that slightly above two thirds of respondents judge climate change to be a "very serious" or "somewhat serious" threat (Gallup 2021).

EXPLAINING PROGRESSIVE GREEN LEVIES WELL

Climate change and inequalities are intrinsically linked (Chancel 2022). In particular, as documented for example by Douenne and Fabre (2020), green taxes are often criticised as regressive (i.e. increasing inequality). For example, the '*gilets jaunes*' movement in France emerged as a mobilisation against announced fuel price increases in 2018, based on the notion that rich urbanites would typically not suffer as much from higher levies on gasoline as poorer households in rural areas. While the former do not need a car in everyday life, the latter have fewer options to avoid using a car and hence may well end up spending a much larger share of their incomes on transport. A similar argument about unequal treatment between urban and rural areas and high versus low incomes contributed to the narrow rejection of a major carbon tax reform in Switzerland (the 'CO_2 Law') by popular vote in June 2021. More generally, because the demand for energy has an income elasticity of less than 1 in Europe, the lower-income deciles of the population devote a larger fraction of their incomes to energy expenditures. This implies that increasing the price of energy is regressive. Strikingly though, unintended distributional effects are by no means unavoidable and in fact any green tax can be made redistributive and progressive, if designed in such a way. Clever design of a given levy can ensure that poorer households face less of a fiscal burden and/or receive a greater share of the fiscal revenues. Thus, a carbon tax with a targeted redistribution of the 'carbon dividend' is actually able to fight climate change and inequality. On this front of social inequalities, this is much better than many other climate policies. Feed-in tariffs for solar electricity raise the price of electricity without any fiscal revenues to compensate the poor, whereas the relatively high guaranteed electricity tariff only benefits those who own their roof. Similarly, norms and standards raise costs and prices for carbon-intensive goods and are more regressive than a carbon tax (Levinson 2029). And a bonus for purchasing an electric car benefits only those who are rich enough to acquire one.

Similarly, green levies are often portrayed by opponents as 'yet another tax', increasing the total fiscal burden. Again, this does not have to be the case – one can design a green levy where the entirety of the revenues are redistributed back to the population. For example, one can easily design a levy that is paid disproportionally by heavy polluters and entirely redistributed to the population in a progressive fashion (i.e. with poorer households receiving relatively more than richer households). Such a measure does not alter the overall fiscal burden and reduces inequality. The tricky part is of course communication (Dechezlepretre et al. 2022, Ewald et al. 2022). It is not easy – yet crucial – to inform households in an easily understandable way that the environmentally conscious among them may actually get back much more in return than they contribute under a newly introduced green tax. The only 'losers' would be households that are well-off and that pollute disproportionally; all other households may be on the receiving end overall. Paradoxically, *actual* unfairness is perhaps easier to tackle in many cases than *perceived* lack of fairness. If a tax is actually unfair, regressive and hurts one group of society proportionally more, this can be quite easily remedied by improving its design, as

discussed above. In contrast, it may be harder to convince the population that an actually fair tax is not regressive, especially when populist politicians have stirred up wrong beliefs. This highlights again the key role of communication.

Various actions should be implemented to improve the social acceptability and fairness of climate policies. For example, governments should not allow for exemptions to the polluter-pays principle when they implement a carbon tax. Exemptions destroy efficiency, but also transparency and credibility. The best illustration is kerosene, a fossil fuel which has long been almost tax-free around the world. Because it is used preferably by wealthier households, there is an argument to impose a larger carbon tax on kerosene (in particular, for private jets) than on gasoline at the pump (Cremer et al. 2003).

It is important to keep in mind that the key role of fairness is not only confined to domestic green tax policies. When it comes to the international sharing of the cost of the green transition, it is again crucial that any solutions proposed are perceived as fair, even if this may at times come at the cost of efficiency. The current climate crisis has been caused by reckless and irresponsible behaviour by the rich world, and bullying the current or future generations of poor nations to bear the costs of this would be morally repellent. On top of this, if rich democracies are seen as phony and selfish, their political clout will further decline – and we are moving closer to a world of ruthless autocratic great powers imposing their will on smaller countries in their supposed sphere of influence. If we want to live on a planet where each and every one of us can choose how, where and with whom to live, strengthening global democracy seems the only way forward. And a key aspect of convincing countries around the world of the merits of rules-based order is to display solidarity and generosity in situations of crisis, whether during pandemics or in the realm of climate change. Up to now, the track record of the rich democracies' in that respect has been far from stellar, to say the least.

A BALANCED FOCUS ON BOTH ENERGY SUPPLY AND DEMAND

Another political economy aspect of the green transition that is often overlooked is its effect on prices. Many individual activists, intellectuals and non-governmental organisations (NGOs) favour climate actions aimed at reducing the supply of fossil fuels (divestment from the fossil sectors by activist funds, universities and banks; opposition events at general assemblies of oil companies and banks; a moratorium on exploration for new (shale) gas and oil fields; opposition to new fossil infrastructures; etc.). If climate action is very narrowly geared towards, say, reducing 'dirty' energy supply by starting with bans of fossil fuels without tackling excess demand for energy, this can have side effects that constitute a jackpot for cynical yet cunning populists. As shown in Figure 1, when policies focus solely on a rapid ban of dirty energy production (Panel A), the demand curve will not move while the supply curve will shift to the left. While this entails the desired reduction in the quantity of energy used, this supply-side climate policy also leads to a price spike (from P* to P*′), as observed for example during the recent energy

crisis in Europe. This price spike can be exploited by populist parties that are against green policies. Accusing green measures of raising price levels is trick 101 in the populists' playbook when fishing for votes among the disenchanted. To avoid a backlash against the green transition, it is better to have a more balanced approach that reduces energy supply from fossil fuels and at the same time aims at reducing energy demand. There are two strategies to attain this objective.

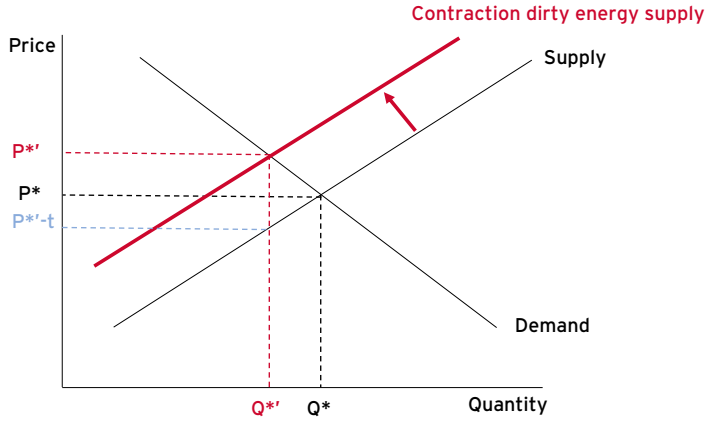
The easiest solution is the one promoted by a vast majority of economists since Pigou (1920). Rather than imposing a reduction of supply from Q* to Q*' on the oil majors, let the government impose a carbon tax, t. The new market equilibrium also generates the same increase in consumer price to P*′, and therefore the same reduction in consumption to Q*′. Yet, the price received by the producers is lower, as it is limited to P*′-t (displayed in blue in panel A of Figure 1) – where the difference between consumer and producer prices corresponds to the tax t. This carbon pricing approach yields exactly the same environmental outcome and the same consumer loss as the supply-side policy presented above, but it differs with respect to the way in which the oil rent is redistributed.[2] The carbon pricing policy has the advantage that it transfers the oil rent t(Q*-Q*′) from the shareholders of the brown industries to the coffers of the state, which can use it to compensate vulnerable consumers. It is a mystery why economists have struggled to convince a solid majority of climate activists and the population at large to support carbon pricing – a policy which unambiguously dominates the aforementioned supply-side policy. This is particularly puzzling given the fact that the supply-side policy raises the oil rent of the rich in a context in which most activists favour redistribution on top of mitigation.

The alternative method to carbon pricing is to combine a 'sobriety' policy on the demand side with the original supply-side policy (as displayed in Panel B). Concretely, supply-side measures (such as closing gas power plants) should be combined with demand-side measures (subsidising envelope renovations, communication fostering sobriety, etc). In this way not only does the supply curve shift to the left but also the demand curve, leading to an even bigger decrease in the quantity of dirty energy but without resulting in large short-run price spikes that are unpopular and play into the hands of populists and climate change deniers. Obviously, it goes without saying that a rapid stepping up of green energy supply will also play a key role in avoiding extreme (and unpopular) price spikes, as illustrated in Panel C. This being said, there are of course some limits to how fast one can go (for example, building new hydro power plants is a matter of several years rather than a few months), hence in the short run this stepping up of green energy supply may still be quite moderate. In the long run, however, the effect could obviously be massive, more than compensating for the drop in dirty energy.

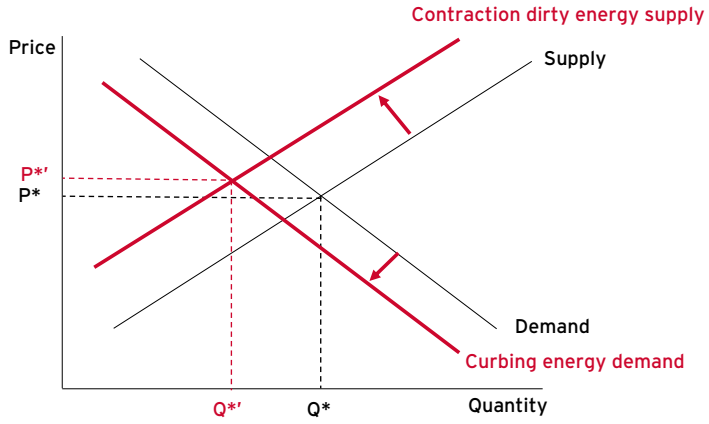
2 Another inefficiency of the supply-side policy compared to pricing carbon comes from the potential misallocation of the rationing scheme. It is desirable to cut first the production of infra-marginal oil fields (Coulomb et al. 2021).

FIGURE 1 PRICE EFFECTS OF THE GREEN TRANSITION

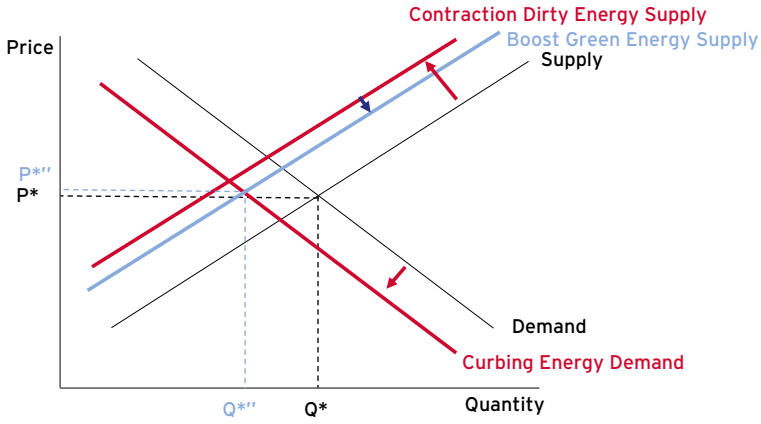
a) Supply-side climate policy



b) Contraction dirty energy supply and curbing energy demand



c) Contraction dirty energy supply, curbing energy demand and boosting green energy supply



TOXIC POLITICS

Another widely ignored aspect of our fatal fossil fuel addiction is its political consequences (Ross 2012, Rohner 2023). As discussed in this eBook, there are various dimensions of toxic politics that are fuelled by fossil energy. First of all, there is large-scale empirical evidence that, on average, corruption is much more likely in the presence of fossil fuels. Further, oil and gas also threaten peace. As shown by a variety of papers, fossil fuels are associated with more frequent civil wars and atrocities committed against minority groups, and even interstate wars (Ross 2012, Dube and Vargas 2013, Esteban et al. 2015, Caselli et al. 2015). By getting unhooked from oil, gas and coal, we have the potential to make the world a safer and better governed place. A key challenge that has also received much attention in this book is the need to avoid replacing the 'oil curse' with a 'mineral course', as getting off fossil fuels will typically require more minerals. Unfortunately, there is evidence that when the value of mines increases, this triggers a spike in political violence (Berman et al. 2017). The chapters in the final section of the book propose concrete measures to reduce the risks of such harmful side effects.

Yet the production of minerals needed for batteries is not the only dimension where we need to be watchful of the consequences of the green energy transition in terms of armed conflict. Beyond mineral extraction, we also face the general challenge of avoiding the fatal attraction of energy rents. Picture a pharaonic-sized solar park in the middle of an arid region. If the electricity that this park produces is very valuable, then we may not expect very different incentives for an armed group to capture an oil well or mine, on the one hand, versus capturing this solar park on the other. Put differently, the fact that energy is green does not preclude any armed appropriation. Thankfully, as argued by Dominic Rohner in his chapter in this book, by following a handful of core principles, these risks can be substantially attenuated. First of all, energy production should be decentralised (Rohner et al. 2013). If, say, much of the solar energy were produced via rooftop solar panels, it would be much harder to appropriate energy rents than if production were concentrated in a huge solar park. Similarly, having a wide range of different hydropower plants in various parts of a country makes this form of energy production decentralised enough to avoid triggering the greed of rebels or crooked politicians. Decentralisation also helps a country to ensure energy security if it is under attack by a foreign power, as argued by Tatyana Deryugina in her chapter. Beyond decentralsation, it is important that energy production is managed locally and that the local population benefits from it directly. If the windfall from electricity production is enjoyed mostly in other parts of the country, it is likely that local groups will suffer grievances and mount resistance against green energy projects. In contrast, if new green energy projects create jobs, boosting the local labour market, and the revenues are to a substantial part distributed locally, then new green projects will gain local support more easily.

STRUCTURE OF THE EBOOK

The chapters of this eBook all connect to the various aspects mentioned above. A key point that we stressed earlier is that the demand for energy must be reduced, and this is precisely the focus of the first section of the book. Thomas Sterner, Jens Ewald and Erik Sterner kick this off in their chapter by providing a big-picture overview of the key issues surrounding carbon taxation. They draw, among others, on the European experience of taxing fuels in the transport sector, with a special emphasis on distributional consequences and political feasibility. Drawing on a computational general equilibrium model, Laurence Kotlikoff, Simon Scheidegger and Andrey Polbin quantify the (large) potential gains from carbon taxation. While they study a benchmark with equal gains vis-à-vis the (very unequal) status quo starting point, their methodology is also able to compute other scenarios where, for example, poor countries get a much higher welfare weight than the rich. In fact, taxing carbon could generate such gains that even with a tax schedule where the lion's share of these gains went to the world's poorest, implementing the taxes would still be attractive to all countries around the globe.

Questions of the social acceptability of carbon pricing are also at the heart of the chapter by Simone Borghesi and Albert Ferrari. They focus on the EU Emissions Trading System (ETS) and discuss, among others, how the distribution of ETS revenues can be designed to ensure that the system is progressive (i.e. that it reduces inequalities). The chapter by Estelle Cantillon is nicely complementary to this analysis. She explicitly takes political feasibility constraints into account and shows that phasing-out policies can increase popular acceptance of green change, by avoiding unfair redistributive effects (without phasing-out, those stuck with old equipment pay a much larger share of the reform burden than those who were lucky enough to have to replaced their equipment at the time of the reform).

The two remaining chapters in the first section study alternative measures to curb energy demand. Katheline Schubert investigates 'sobriety' policies aiming at behavioural changes, brought about by information, 'nudging', habit formation and social norms. Finally, Sébastien Houde focuses on specific information-based policies. He pinpoints interesting interaction effects – for example, sensors and connected devices are best combined with mandatory performance standards and energy information disclosures. Further, an ideal moment to launch an information campaign is during a period of high prices, where price signals need to be better explained. This stresses the complementarity between information measures and other green policies.

The second part of the book focuses on boosting green energy supply. Aude Pommeret investigates the scope and challenges for promoting solar energy. In particular, she accounts for the role of critical raw materials and explores the importance of technological progress and industrial policies In a complementary analysis, Dominique Bureau looks at electricity production and markets, with a focus on Europe. He discusses both decarbonization and regulation, with a special emphasis on supply security and

wholesale markets. He highlights that a key element of long-run efficiency is that the carbon price is as close to its social cost as possible. While Bureau's chapter focuses on wholesale electricity markets, the following chapter by Claude Crampes zooms in on retail electricity markets, with a special interest in how much exposure to spot price fluctuations may be optimal for households. The author highlights that contracts indexed on wholesale prices may have regressive effects and that stable agreements may therefore be preferrable. In the last chapter of the second part of the book, Phoebe Koundouri, Haris Papageorgiou and Conrad Landis focus on innovation, which is a key aspect of boosting green energy supply. In particular, they perform an evaluation of the European Union's research and innovation funding programme H2020 with regards to its support for projects centred around sustainable development, climate change and biodiversity.

The third part of the book is devoted to macroeconomic issues linked to the green energy transition. Pierre-Louis Girard and Agnès Bénassy-Guéré provide an illustration of the complex web of transition channels linking higher carbon prices to demand, supply and price shocks. They conclude that while there are upside opportunities, overall the green transition is likely to entail a net adjustment cost. International cooperation and structural reforms are helpful in smoothing these costs. Related to this, Ian Parry focuses on the inequality dimension from a macroeconomic standpoint. Higher energy prices in the short run triggered by the green transition risk hurting poorer deciles of the income distribution more. Hence, Parry stresses the need for careful policy design and specific support measures for vulnerable groups. The final three chapters in this section are all penned by Francesco Paolo Mongelli, who starts off with a big-picture overview of the background of and main hurdles faced by the green energy transition, focusing among other things on the distinction between orderly versus disorderly transition models. He then investigates the macroeconomic impacts of carbon pricing on a variety of dimensions. Finally, he provides a tour d'horizon of sustainable finance and green investments.

The fourth and final part of the book is devoted to a series of particular political economy aspects of the green energy transition. This part is kicked off by Tatyana Deryugina, who points out the extent to which the move towards green energy has the positive 'side effects' of improving energy independence (for example, by reducing dependency on gas imports from a neighbouring country) as well as energy security (for example, renewable energy installations may be more decentralised and hence a harder military target for an aggressor). Next, Jérémy Laurent-Lucchetti and Evelina Trutnevyte highlight how tough a challenge it will be to produce enough of the minerals and metals needed to produce and stock renewable energy. They document the detrimental effects of mining on a series of outcomes, including armed conflict, and argue that the social cost of metal and mineral production should be priced it, for example through a mineral tax (similar to a carbon tax). Rabah Arzeki and Rick van der Ploeg complement this by focusing on the geopolitics of critical materials for the green transition. They study the mounting demand for metals and minerals through the lens of economic and political competition

between the United States and China. Mathieu Couttenier also addresses the political consequences of surging demand for minerals and metals, but with an emphasis on artisanal and small-scale mining – an often overlooked part of the mining sector. Finally, Dominic Rohner focuses on reducing the political risks of renewable energy production, stressing the key importance of decentralised production (to attenuate appropriation incentives), labour-intensiveness (to avoid lower opportunity costs of legal work) and local empowerment (to prevent mounting grievances).

ECONOMICS NEEDS TO STEP UP ITS GAME

The aspects of the political economics of the green transition discussed above suggest that while the natural sciences have done their job and produced reliable estimates of the extent of climate change and potential measures to attenuate it, economics and the other social sciences still have a fair amount homework to do. Put differently, while we have a good idea of what measures should be taken for a rapid and wide-ranging green transition, we still have not found a way to convince a solid majority of people to engage in a set of far-reaching policies that would be a real game changer. As a small step in this direction, the purpose of this eBook is to pinpoint the key role of these political economics issues. The stakes could hardly be higher – a successful green energy transition will yield the double-dividend of not only saving the world from looming environmental disaster, but also combatting toxic policies and reducing the risk of armed conflict around the globe.

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Christian Gollier's research spans the fields of economics of uncertainty, environmental economics, finance , insurance, and cost-benefit analysis, with a particular interest in long-term sustainable effects. He founded the Toulouse School of Economics with Jean Tirole in 2007 and has been its director since 2009 (with a hiatus in 2015-2016). He has published more than a hundred articles in international scientific journals. He has also published 10 books on risk, including *The Economics of Risk and Time* (MIT Press), which won the Paul A. Samuelson Award (2001). In 2012, he published a book entitled *Pricing the Planet's Future* with Princeton University Press, which he presented at the 6th Arrow Lecture at Columbia University. Christian Gollier is one of the authors of the 4th and 5th reports of the Intergovernmental Panel on Climate Change. In addition, he regularly advises several governments on their public investment evaluation policies. He is president of the European Association of Environmental Economists. His recent

book for the general public, Le Climat après la fin du mois (PUF 2019), deals with the importance of taking action in the face of climate change and has been a great success in France.

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PART I
CURBING ENERGY DEMAND

CHAPTER 2

Taxing carbon

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University of Gothenburg

CLIMATE AND ENERGY

Carbon dioxide emissions, primarily from the combustion of fossil fuels, are the main cause of climate change. Methane emissions (from fossil fuels, livestock, waste management, etc.) are the second largest contributor. A worldwide tax on carbon emissions and other greenhouse gases (GHGs) from all sectors would be one of the most obvious and efficient instruments to lower emissions. Estimates of the appropriate tax level, the 'social cost of carbon', are in the range of €50-200 per tonne of CO_2 (EPA 2022, Hänsel et al. 2020, Nordhaus 2019).

Though many economists have argued forcefully that such a tax on emissions would be the best climate policy, they have been met with considerable resistance. Agreeing on such a policy – or any solution – is very difficult for several reasons. First, there is the problem of time: damages related to climate change occur mainly in the future, while the costs of mitigation must be faced today. Our political systems and politicians are not well equipped to deal with problems that stretch over decades or centuries. Second, there is a geographical problem: countries will be *affected* by climate change differently and also *contribute* to the problem to different extents. This leads to conflicts over energy-related issues. The current war in Ukraine is to a significant extent a climate war. Natural gas pipelines have been sabotaged, electricity grids have been targeted and fighting has even taken place inside nuclear power plants. Energy supply has become an arm of the war: strategically refusing to supply energy in the winter months has been used to inflict industrial damage and human suffering.

Considering the technical context is key. Many energy technologies tend to be comparatively big and 'lumpy', with long lead times making them prone to large profits, monopolisation and dramatic variations in price. Resources such as fossil fuels, hydropower and uranium are also unevenly distributed across the globe. Production costs for oil vary from practically zero in Saudi Arabia to very expensive in the sea north of Norway. Since the product is homogeneous and fairly cheap to transport, there is a single world market price, resulting in enormous profits for low-cost producers. These extraordinary profits often lead to special political cultures and a strong tendency to create cartels or monopolies. The oil industry was historically characterised by strong cartels such as the Achnacarry Agreement and later the Organization of Petroleum

Exporting Countries (OPEC). Today, OPEC is reinforced by collaboration with Russia and other producers in 'OPEC+'. During the winter of 2022/23, this group of countries successfully reduced supply to press up the price of crude oil.

Investments in fuel exploration, extraction, refining and transport are also substantial, with long lead times and large indivisibilities (i.e. investments are only done on a very large scale – or not at all). This situation can also be seen in electricity generation, as well as steel, and cement manufacturing that use fossil fuels. When both supply and demand have such characteristics and are partially oligopolised, it is common to get strong cyclical variations in price, which has historically been the case for oil. When there is a glut of fossil fuels and prices are low, there is not much incentive to increase supply, but there are strong incentives to use the fossil fuels. When large-scale investment plans with long gestation periods are finally made and then actually implemented, the situation flips and suddenly there is more demand than supply. Both supply and demand curves are almost vertical in the short run.

As was the case in 2022, this leads to dramatic price increases and a rush for new sources of supply. The average production costs of most energy (for example, Saudi oil or, in the domestic context, existing nuclear power or renewable energy) are comparatively low. A combination of capacity constraints – including the temporary closure of most French nuclear reactors, cartel behaviour, restrictions in supply of oil and gas from Russia (and OPEC) resulting from the Ukraine war, and increased demand after COVID – caused prices to soar. European gas prices jumped by a factor of 20 between 2020 and 2022. If such prices persist and are fully passed on to consumers, a heating bill of a €100 per month turns into €2,000, which is excessive for most people. Though prices have soared, average costs did not go up so much. Thus, the high prices are matched by the highest profits in history for energy companies. Ideally, these profits would be used to speed up the transition to renewable energy, electricity transmission and storage, for insulating buildings, and so on. In reality, they will most likely be paid out as giant dividends to shareholders. Demonstrating this point, in the spring of 2023, big oil companies announced that they will be scaling back investment in renewables.[1]

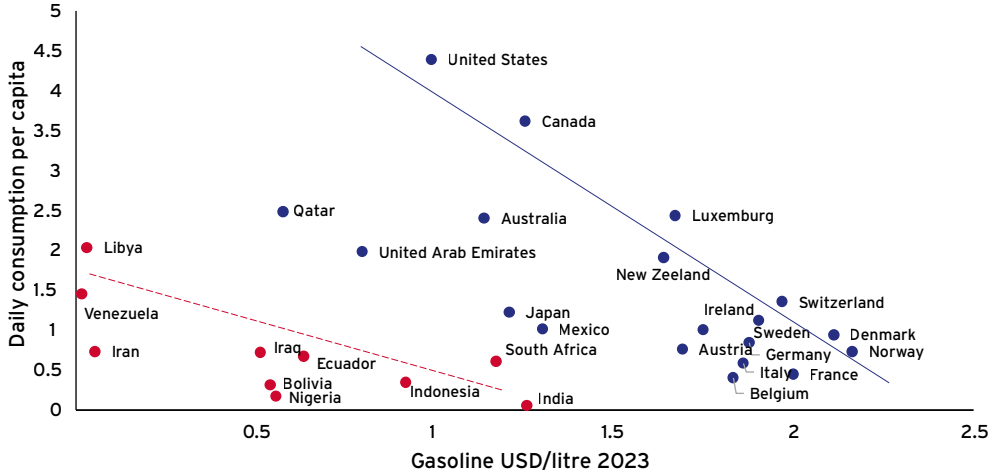
Many countries – notably, the big producers of fossil fuels – view climate policy as a hostile tax on their business. If importing countries impose taxes on fossil fuels, producing countries may even offer subsidies to counter the effect and increase demand. Timing a carbon tax can also be very problematic, even in importing countries, particularly when prices are already high. Though economists view a carbon tax as actually trying to take back monopoly profits from exporters such as OPEC or Russia, the general public may end up blaming politicians for the high prices and voting them out of power.

1 For example, www.dw.com/en/shell-bp-boost-profit-sink-investment-in-renewable-energy/a-64656800

THE EUROPEAN EXPERIENCE WITH FUEL TAXES IN THE TRANSPORT SECTOR

Global efforts at implementing a price on carbon have failed. However, there have been successful national and regional policies, which should be carefully studied. The debate on climate policy in the spring of 2023 has been dominated by the mega-packages of the Inflation Reduction Act in the US and Fit for 55 in Europe. The focus is on extending emission trading schemes in Europe, parts of the US and China. We would argue that some of the most long-standing and successful climate policies are actually the fuel taxes that most European countries have had in place for decades. Even though these policies often had prime motives other than climate change, a tax should arguably be primarily defined by its effect rather than its original motivation. The long-term effect of high gasoline and diesel prices is that consumers and firms use less fuel. For decades, the fuel price for transport in Europe has been three to four times the average price in the US or on the world market. The effect is that consumption levels per capita have been less than half or a third of the levels in the US. Figure 1 shows that the negative relationship between price and quantity exists for both high- and low-income countries. Though numerous other factors play a role in the process (such as population density, culture, availability of public transport and income), many hundreds of studies have shown that the long-run elasticity of demand for gasoline is approximately -0.7 (Dahl and Sterner 1991, Labandeira et al. 2017). If the fuel price goes up by 10%, consumption will eventually go down by 7%. If the entire OECD were to tax fuels at European levels, fuel use across these countries would be lowered by more than 50% compared to if US prices were used (Sterner 2007).

FIGURE 1 THE RELATIONSHIP BETWEEN GASOLINE PRICE AND CONSUMPTION ACROSS COUNTRIES

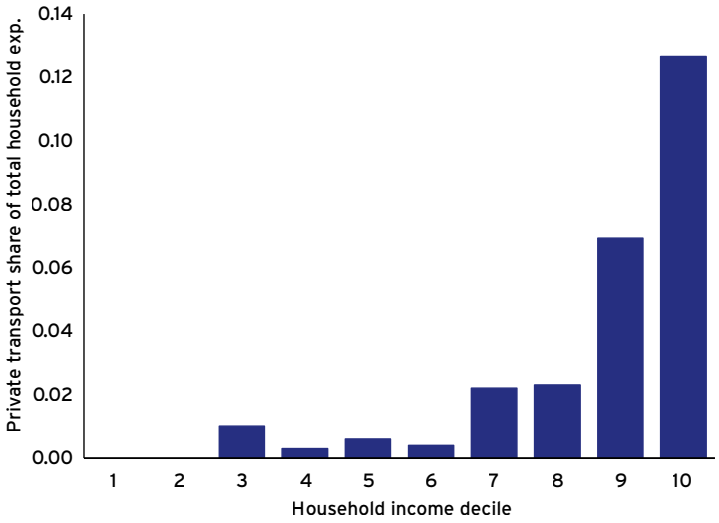


Source: The U.S. Energy Information Administration and UN data.

DISTRIBUTIONAL EFFECTS OF FUEL TAXES IN EUROPE

Fuel taxes do work where they are implemented. The question is whether they are acceptable or if public resistance is so strong as to render them unusable. The argument that fuel taxes are regressive may be true in some places, for instance in the US. In most countries, however, the opposite is true. For example, in low-income countries in the Global South, only the very richest individuals have cars. As a result, fuel taxes in those countries are strongly progressive. Figure 2 demonstrates this case for Kenya.

FIGURE 2 TRANSPORT EXPENDITURE IN KENYA BY INCOME DECILE



Source: UPTS data and KIPPRA 2004-2005.

In many European countries, expenditures resulting from fuel taxes are roughly proportional (the curve is flat) – i.e. they are neither regressive nor progressive (Sterner 2012). Even when all kinds of carbon use (all energy carriers plus embedded carbon in consumption goods) are considered, carbon taxation in most European countries is neutral or even weakly progressive at a national scale (Feindt et al. 2021). Low-income countries like Bulgaria, Poland and Romania would, however, pay much more per capita than higher-income countries such as France. If the whole of the EU were treated as one country, a tax would be judged as regressive for the very lowest (European) deciles. Feindt et al. (2021) also showed that a small share of the tax revenues (less than 10%) would more than compensate for any regressivity if used for targeted transfers.

In the debate over carbon taxes, the wrong type of fairness issues often come to the fore. As discussed above, a carbon or fuel tax may have some negative effects on the poor within a nation, though on the whole carbon tax payments are roughly proportional to

income. The biggest fairness issue, however, is *across* nations and the effects on low-income countries. International climate policy hence ought to include large transfers from rich to poor countries.

POLITICAL FEASIBILITY

The feasibility of implementing taxes does hinge to some extent on distributional issues, which are often highlighted in the debate. Experience has shown, however, that arguments claiming the unfairness of a tax, or in favour of subsidies, can be used even in contexts where there is little empirical support. Countries like Nigeria and Indonesia have had large protests over plans to abolish fuel subsidies – the benefits of which go to the richest consumers.

Also in European countries, which have decades of experience with fuel taxation without significant protests, protests have increased – for example, the '*gillets jaunes*' in France managed to stop a proposed tax hike. Protesters highlighted concerns about growing levels of economic inequality (Jetten et al. 2020) and the belief that such taxes are neither environmentally effective nor progressive (Douenne and Fabre 2022). Given the success of the protests, it is crucial to understand why individuals protest and what factors might make fuel taxes more acceptable.

Sweden has had high carbon taxes for a long time with little criticism, but a '*gillets jaunes*' type movement has also begun there. There have been no violent demonstrations – the main activity is a Facebook page – possibly reflecting some slight differences in political culture between France and Sweden. The Facebook page does, however, have more than half a million visitors, which is huge in such a small country. Importantly, the Swedish '*gillets jaunes*' are generally not climate deniers (Ewald et al. 2022). Across the whole Swedish population, close to 50% of people state that climate change is very important; the corresponding figure for the yellow vest sample is 43%. However, protesters do generally have less trust in the government and believe less in the Pigovian mechanism (defined as believing that the role of a tax is to change behaviour). Instead, they think the purpose of a tax is to collect revenue. Only if that revenue is used for climate purposes will they consider it a climate tax and perhaps accept it. Significant support was found for earmarking the revenues for climate purposes (climate research and renewable energy, but not necessarily electric vehicles), and only limited support for refunding.

In summary, we find that carbon taxes are needed and do work. They are, however, often contested for the assumed unfairness of their distributional effects. These arguments may often be unfounded but are still powerful. A strong argument for earmarking can be made if support for carbon taxation can be increased as a result. By default, economists do not approve of earmarking. In the current case, however, it is clear from the large climate policy packages that states will be spending massively on the energy transition regardless. In that context, earmarking has no extra cost.

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CHAPTER 3

The fast track to global carbon taxation

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INTRODUCTION

Whether it be atmospheric rivers deluging California, a snow-less winter in the Alps, a record heat wave in India, extreme flooding in Pakistan, a massive ice melt in Greenland, exceptionally powerful hurricanes in Florida, receding glaciers in Patagonia, or unprecedented wildfires in Siberia, the climate is rapidly changing, far outpacing humankind's limited efforts to reduce the common cause for these and other natural calamities – carbon emissions. Yes, the Paris Agreement pledges its 194 signatories to cut their emissions radically. However, the 2015 Accord is being honoured in the breach. This outcome was foreordained, as the Accord's country-specific emission reduction pledges have no enforcement mechanism. This has led, and continues to lead, countries with more to lose than gain to simply pay lip service to their obligations.

Yet, the situation is far from hopeless. There is a clear path to accelerating the green transition. It lies in economics' century-old answer for efficiently dealing with negative externalities: tax bad behaviour but achieve Pareto improvements (winners without losers), by having winners compensate losers. In the climate context, any old Pareto improvement will not do to secure global carbon tax buy-in from the world's 195 countries. What is likely needed is a uniform win-win, that is, a path of carbon taxation coupled with generation- and region-specific compensation (positive or negative) that equalises consumption-equivalent percentage gains in the lifetime welfare of all newborns and future generations as well as the remaining welfare levels of those currently alive. This *uniform* welfare-improving (UWI) win-win would provide all countries the same positive incentive to immediately enact carbon taxation. This incentive is the uniform gain the carbon tax would provide to each country's current and future cohorts, indeed, the largest possible UWI gain. Taken together, Kotlikoff et al. (2021c) and Kotlikoff et al. (2021a) suggest a maximum UWI gain of 10%.

1 We thank Felix Kubler for useful conversations and comments. Simon Scheidegger thanks the Swiss National Science Foundation (SNF), under project ID "Can Economic Policy Mitigate Climate-Change?". Simon Scheidegger acknowledges financial support from the University of Pennsylvania.

How can today's cohorts benefit from carbon taxes that will raise their energy bills? One way is to receive direct or indirect payment from an international agency – say, for example, the World Bank – overseeing the policy. As detailed below, the World Bank could finance these payments by selling general obligation (redeemable by all) green bonds and selling country-specific (redeemable only by specific country citizens) red bonds to enforce repayment.

Our recent research calculates win-win policies in global, regional, deterministic, and stochastic models (Kotlikoff et al. 2021a, 2021b, 2021c). This chapter briefly summarises our work and considers how UWI policy can be sustained. We also stress the efficiency of carbon taxation over picking green energy winners. To highlight the remarkable capacity of global carbon taxation to curb emissions, we compare the emissions reduction from optimal UWI taxation with that of a counterfactual, namely, eliminating all Russian fossil fuel resources from the global totals. As shown, carbon taxation has a major impact on global emissions, far beyond what would arise under the counterfactual. But, to be clear, optimal UWI policy limits – but does not eliminate – climate change. Future generations will still be significantly affected by global warming, but to a far smaller degree than would otherwise be true.

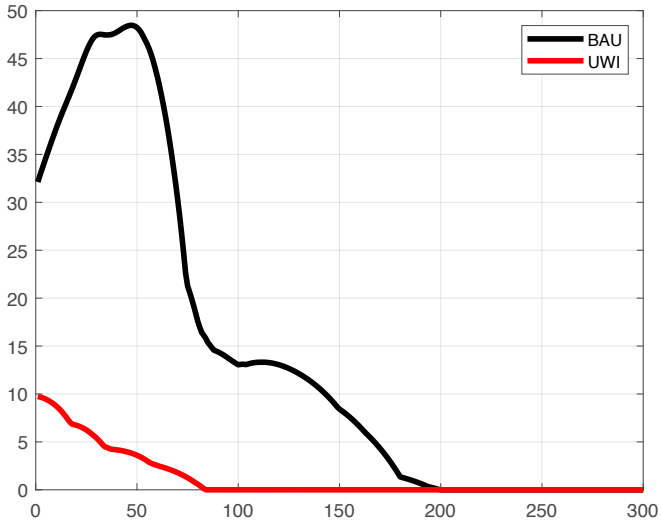
Adopting the optimal UWI solution would represent a momentous global achievement. However, this does not preclude industrialised and rapidly industrialising countries from paying reparations to further assist countries facing the largest climate losses. Yet, a quarter of a century has passed since the Kyoto Protocols sought voluntary restrictions on carbon emissions by industrialised and industrialising countries. Several countries have jointly or individually taken such steps over these many years. Presumably, they have done the most that their conscience and altruism directs. If so, further carbon mitigation will require win-win solutions providing such emitters an economic incentive to further limit their global climate damage. UWI is a natural starting place to discuss mutually beneficial means of impeding emissions. But, as we show, Pareto-improving policies that deviate from strict UWI by, for example, differentially benefiting parties like India, which are at grave risk, very poor and, historically, low-level emitters, are available and inexpensive. Stated differently, such policies would come at a modest cost to regions not given preferential treatment.

GETTING TO YES

According to Kotlikoff et al. (2021c), optimal UWI carbon policy is potentially extremely powerful, reducing global emissions by two-thirds immediately and by 90% within 50 years (Figure 1). In addition, the policy would substantially limit the massive harm facing the most vulnerable regions. For example, the win-win policy reduces year-2100 damage to India's GDP from over 40% to roughly 25%. Furthermore, a carbon tax will do double-duty by reducing climate risk. As modelled in Kotlikoff et al. (2021b), this is climate change's second major negative externality. Unfortunately, it is one that is rarely

discussed, even though it is simple to appreciate. Intuitively, if party *A* puts party *B* at risk, party *A* is damaging party *B*, from the relevant welfare perspective, namely, ex-ante expected utility. Kotlikoff et al. (2021b) shows that the gains from carbon taxation, as measured by the size of the optimal UWI carbon tax, can be as large as the gains from reducing average carbon damage, were such damage to occur for sure.

FIGURE 1 GLOBAL CO_2 EMISSIONS (ABSENT OF LAND EMISSIONS, AND MEASURED IN $GtCO_2$) IN OUR HIGH-DAMAGE SCENARIO AS A FUNCTION OF YEARS (STARTING IN 2017)



BACKGROUND

Climate economics is now a half-century old. This is thanks to Nobel Laureate William Nordhaus (e.g. Nordhaus 1979, 2017), who first realised not only its occurrence, but also its major economic threat. A host of influential studies, including Acemoglu et al. (2016), Cai and Lontzek (2018), Cai et al. (2013, 2018), Golosov et al. (2014), Hassler and Krusell (2012), Jensen and Traeger (2014), and Stern (2007), extended Nordhaus' blueprint for a global carbon tax that would reduce carbon emissions and the associated rise in the planet's temperature.

For all its foresight and originality, the Nordhaus approach sidestepped the clear source of the carbon externality – generational self-interest. Instead, it appealed to a social planner. Other economists reframed Nordhaus' model by assuming infinitely lived, altruistic dynasties, that is, agents who care deeply for their progeny but not for other dynasties, domestic or foreign. This approach transformed the climate externality into an intragenerational rather than an intergenerational problem, with domestic and foreign dynasties free riding on one another in emitting carbon. The dynasty literature

also assumes that all dynasties weigh their future members' welfare based on an identical time preference rate. The resultant optimal carbon tax policy depends critically on the posited size of this single preference parameter. However, the choice of this parameter is normative, not positive.

With some economists (e.g. Stern 2007, Arrow 2007) arguing for a low time-preference rate, and others (e.g. Nordhaus 2008) arguing for a high rate, mainstream climate economics has, unfortunately, devolved into a moralistic debate, with those weighing future generations more heavily (specifying a low time-preference rate) 'deriving' a high 'optimal' carbon tax, and those espousing opposite preferences 'deriving' a low 'optimal' carbon tax. The debate has rendered the words 'carbon taxation' synonymous with 'generational conflict' for a simple reason. Generations are not, in the main, intergenerationally altruistic, and when told they should sacrifice for the next generation based on some academic's sense of fairness, their response is a quick "*no thank you*".[2] Yes, the single-agent, infinitely lived model can deliver quick and important insights on issues that do not involve generational trade-offs. However, that is hardly the case for climate change, deficit policy, infrastructure investment, and a host of other issues that pit generations against one another. Moreover, if one includes clan intermarriage, the standard dynastic, altruistic model implies that all clans are altruistically linked (e.g. Kotlikoff 1983, Bernheim and Bagwell 1988), that is, the separate dynasties devolve to one. This, of course, rules out a climate problem since a single, global, altruistically linked dynasty would already have fixed it. The standard model also ignores the ability of clan members to refuse transfers that are smaller than desired (Kotlikoff et al. 1990). Incorporating this option transforms altruistic clan members into partially selfish life-cycle agents.

MODELLING MATTERS FOR OPTIMAL CARBON POLICY

The ongoing use of the dynastic model for climate policy analysis would be of less concern were it to prescribe the same or similar path for carbon taxes as the life-cycle model. This is not the case. Kotlikoff et al. (2021a) present an apples-to-apples comparison of the two models. Their dynasty model is identical to their life-cycle model except for the assumption that agents' utility depends on the utility of their children. The optimal initial value and growth rate of the carbon tax differ dramatically between the two models for all assumed time-preference rates.[3]

2 The evidence against such behavior appears overwhelming (e.g. Boskin and Kotlikoff, 1985, Altonji et al. 1992, Abel and Kotlikoff 1994, Hayashi et al. 1996, Altonji et al. 1997).

3 Note that there is a set of Negishi (1994) weights that, when applied to the dynasty model's valuation of future generations' utilities, can replicate the UWI life-cycle model outcome. However, this is a theoretical equivalence, not a practical one, since dynastic climate modelling does not solve for and apply such weights. Stated differently, one needs to posit and solve the life-cycle model's UWI solution to discern the proper Negishi weights to 'derive' the UWI solution in the dynastic model.

EXTERNALITY ECONOMICS 101

At their heart, externalities constitute missing economic markets. In the climate context, future generations are not present to, for example, pay current generations not to emit carbon or require current generations to pay them for the right to emit carbon. Regardless of who had the property right – the right to emit or the right to prohibit emissions – the market solution, if one were feasible, would entail that emitters face the proper extra cost, at the margin, of emitting carbon. Arthur Pigou clarified, in 1921, how governments could use taxes and subsidies to substitute for missing markets and correct externalities.

When combined, Pareto's and Pigou's work prescribes setting the efficient time path for the global carbon tax. However, this has to be done in the context of taxing winners and subsidizing losers. In the climate context, the UWI solution satisfies both Pareto's and Pigou's criteria. Moreover, the UWI carbon policy can be readily administered. An international body, such as the World Bank, could issue a general obligation (repayable to all), green bonds, and use the borrowed funds to make region-specific transfers to generations that stand to lose from the carbon tax. As Kotlikoff et al. (2021c) show, such losers comprise current generations in regions facing future, but not current, climate damage, as well as current and future generations in very cold regions. Canada and Russia are such regions. They would otherwise benefit from global warming.

MODELLING SELFISH GENERATIONS

Acknowledging intergenerational and interregional selfishness leads one to look for ways that future generations can compensate current generations and dirtier regions can compensate cleaner regions. Kotlikoff et al. (2021a, 2021b, and 2021c) do this. Each finds the optimal UWI tax and net compensation policy. Kotlikoff et al. (2021a) consider a deterministic, dynamic global, OLG economy. Kotlikoff et al. (2021b) add shocks to productivity, climate damage, and climate change. Finally, Kotlikoff et al. (2021c) ignore shocks but disaggregate the world's 195 countries into 18 separate regions (see Table 1 and Figure 2), each with its own temperature and damage transitions.

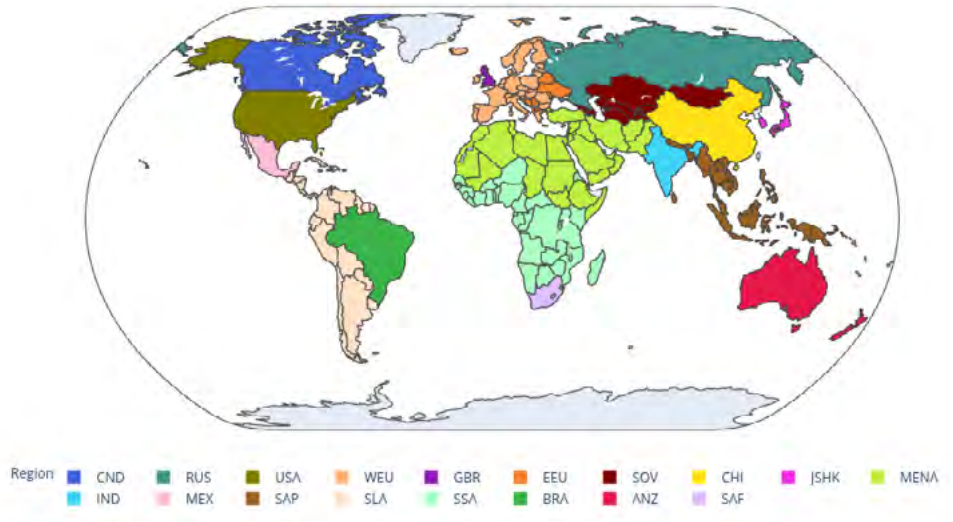
Including regional differences makes UWI compensation policy region- as well as generation- specific. Hence, Kotlikoff et al. (2021c) relates directly to the ongoing debate, raised most recently at COP27, over cross-country compensation. Such compensation appears the sine qua non for motivating poorer countries to limit their emissions. Unfortunately, the often-heated exchange missed the point that compensation is central to achieving a uniform win-win.

TABLE 1 REGIONS AND THEIR ACRONYMS

Acronym	Region
BRA	Brazil
CND	Canada
CHI	China
EEU	Eastern Europe
GBR	United Kingdom
IND	India
JSHK	Japan, South Korea and Hong Kong
MENA	Middle East and North Africa
MEX	Mexico
RUS	Russian Federation
SAF	South Africa
SAP	South Asian Pacific
SLA	Latin America (excluding Mexico and Brazil)
SOV	Former Soviet Central Asia
SSA	Sub-Saharan Africa
US	United States
WEU	Western Europe

Note: Excludes countries modelled independently.

FIGURE 2 OUR GLOBAL MODEL'S 18 REGIONS



CURRENT CARBON POLICY

The current state of carbon abatement largely comprises ad hoc initiatives. The list ranges from subsidising the purchase of electric vehicles, to underwriting the installation of solar panels, to authorising the construction of nuclear reactors. This picking of green 'winners' is inevitably influenced by political considerations and by politically convenient timetables that ensure that what is done is done too late. Relative to having global green energy decisions guided by a single price of 'dirty energy' – namely, the cost of dirty energy plus the present value of global damages arising from additional carbon emissions (i.e. the social cost of carbon) – the current approach both under-provides green energy and delivers an inefficient mix of green energy abatement and climate mitigation. In contrast, carbon taxation lets the market decide the best way to produce energy and lower emissions, taking into account carbon's social cost.

Despite the clear advantage of carbon taxation, only about one quarter of countries tax the use of fossil fuels. The US is not on the list. The reason? US politicians appear reluctant to advocate increasing taxes of any kind. However, the UWI carbon policy involves short- run net tax cuts, not net tax hikes. Specifically, the policy can be explained to the public as combining a tax on emissions with a larger, in terms of revenues, reduction in income, payroll, or other general taxes. The policy can be conveyed as cutting taxes on balance and thereby accumulating more government debt (running larger deficits), whose principal and interest payments will be left for carbon-tax beneficiaries (i.e. future generations) to cover. Thus, a new carbon policy paradigm, which emphasises win-win and short-run net tax cuts, can provide the political support needed in the US and other countries to adopt a carbon tax. UWI policy can be run in a host of different ways. As described below, one would be under the auspices of the World Bank. In this case, the Bank would send money, in the short run, to the US government, which it could disperse to current US citizens to more than compensate them for accepting a carbon tax.

ENSURING COMPLIANCE WITH UWI POLICY

Servicing the general obligation, green bonds, requires levying taxes on those benefiting from the carbon tax. But how does an international agency like the World Bank, which lacks taxation power, ensure compliance? Consider the following mechanism: the World Bank provides a service (e.g. securing the adoption of the global carbon tax) to unborn Party A whose costs it needs Party A to help cover once Party A is born and is old enough to pay. Assume that Party A will be born in the country K and, when she reaches working age, needs to pay X_t annually, where t references year and the annual payments cover A's share of the cost of the UWI policy. Let Party A stand for all citizens of country K who need to pay (make compensation payments) that collectively total X_t in year t. The World Bank would bill country K's government for X_t in year t. In such a way, the World Bank would never directly interact with citizens of country K. However, then country K would have the incentive to renege. This is true, unless doing so comes at an offsetting

cost. To generate a default cost, the World Bank would sell, in year $t - 1$, $\$X_t$ country-*K*-specific, one-year, zero-coupon red bonds. The country-*K* red bonds would be sold to country *K*'s citizens at an above-market interest rate. The higher-than-market rate would compensate purchasers of the red bonds for accepting the red bond's special features.

What are these features? First, country-*K*-specific red bonds could only be redeemed by citizens of country *K*. Second, servicing by the World Bank of country-*K*-specific red bonds would be contingent on country *K* paying its $\$X_t$ obligation to the World Bank. Thus, the World Bank gets paid back by the government of *K*, thereby covering Party *A*'s obligation, and the government of K realizes that reneging on paying X_t will cost other citizens of country *K* the amount, $\$X_t$.[4]

Would the World Bank break even? Yes. At any point in time, the present value of all country-specific X_t payments would equal the value of outstanding green bonds. The World Bank could invest the proceeds of its sale of red bonds in, say, US Treasuries, so it would always be able to redeem those bonds. This red bond enforcement mechanism may seem novel, and perhaps it is with respect to enforcing policies of this kind. However, the marketplace routinely relies on the reluctance of nations to default on their own citizens. Take Argentina. On a periodic basis, Argentina is unable to borrow internationally. However, during such periods, it remains able to borrow domestically. The reason for this is that the Argentine government finds it politically far more difficult to default on domestic than on foreign bondholders. There are, nevertheless, exceptions. Russia's default in the late-1990s was a domestic, but not a foreign, default.[5]

CHANGING THE FRAMEWORK FOR CARBON TAX ANALYSIS

Economists naturally value analytical elegance. Boiling down complex issues into a small number of equations permits an easy and precise understanding of the issue at hand. However, oversimplifying climate change comes at a major cost. Golosov et al. (2014) is an example. By invoking infinitely lived dynastic agents and making a range of strong assumptions, the authors reduced optimal carbon taxation to one equation – as elegant a 'solution' as one would wish. In contrast, the Kotlikoff et al. (2021c) study, which spares few climate-change relevant details and solves for a uniform win-win, boils up

4 There is no guarantee that this solution will work. Country *K* could announce in advance that it will not pay its $\$X_t$ obligations independent of the World Bank's defaulting on country-*K* Red Bonds. This may preclude their purchase in the first place unless country-*K* citizens believe its government won't carry through on its threat. But there are other enforcement mechanisms. One is for country *K* to pay the present value of its future net compensation obligation to the World Bank at the time the carbon tax is enacted. The country could simultaneously issue bonds of an equal amount. Country *K*'s major importers could purchase and hold this debt, which might be British-type consuls. Default on those bonds would likely be meant by retaliatory tariffs. Indeed, the imposition of tariffs could be covenants of the bonds in the event of full or partial default. In short, since countries with positive net present value obligations will gain, on balance, to the same degree as all other nations from the carbon tax, they should be willing to pay for it. If they choose not to make an upfront payment, they could be excluded from the World Bank or otherwise sanctioned. This is, to be clear, a tough public goods problem, but the world is replete with public goods, including the World Bank itself, which have been successfully financed by multiple players with conflicting agendas.

5 Note that red bonds could be issued to enforce compliance with other social behaviours. For example, the World Bank could sell better-than-market-return bonds to citizens of, say, country R that would be repaid only if country *R* did not invade country *U*.

to over 3 million equations in an equal number of unknowns. Formulating, calibrating, and solving such a model is clearly feasible. Indeed, Kotlikoff et al.'s three million-plus-equation model can be solved on a laptop in a few hours.[6] As for its 'black box' nature, the model's millions of equations are each satisfied to extremely high precision. Moreover, one can readily test the model by checking that it responds to hypothetical policies, demographic changes, as well as preference and technology parameters in exactly the way common sense suggests and economic theory predicts.

Hence, climate economists can – and, in our view, must – stop looking for their keys under the street light.[7] Instead, they should model climate change as arising from its actual source: the actions of selfish life-cycle agents who live in very different regions and differ fundamentally with regard to technologies; demographics (current and projected); capacities to produce green energy; the potential for climate damage; usage of coal, gas, and oil; and so on. These regions face very different climate risks. They can and must be differentially compensated to secure their agreement to tax carbon through time at the optimum global rate.

OPTIMAL UWI POLICY

As described in Kotlikoff et al. (2021c), optimal UWI policy entails close to a $100 per tonne initial carbon tax, rising at 1.5% annually. As Figure 1 makes clear, this global carbon tax makes a huge difference to carbon emissions. And, as described in our paper, global long-term carbon damages are cut roughly in half. The impact on specific types of dirty energy, detailed in Figures 3 (oil), 4 (gas), and 5 (coal), is telling.

Coal production, for instance, comes to an abrupt end in most regions and to a quick end in others (Figure 5). As for the uniform welfare gain, it is 4.3%, calculated as a compensating consumption differential. Kotlikoff et al. (2021c) also generates the precise lifetime net tax payments owed by each generation in each region. Those with the most to gain (for example, Indians born in the next century) face the largest net taxes as a share of their lifetime resources. Their negative compensation is very high given the size of the more-than-offsetting welfare gains they derive from global carbon taxation. However, those generations facing particularly high UWI taxes are located – or will, when born, be located – in poor regions. Consequently, were the agreed carbon-tax policy to limit taxation on any generation to, say, 10% of lifetime resources, the uniform welfare gain to those not receiving special consideration would be little changed. As for those, like future Indians, who would enjoy a lower tax burden, their welfare gains would, of course, be higher than the UWI target. However, placing a limit on UWI carbon policy's tax burden will limit enforcement problems. Additionally, picking a Pareto solution that provides extra help to climate change's worst victims will also likely facilitate its global adoption.

6 Far more complex models can, these days, be solved in seconds if needed by invoking more sophisticated solution algorithms and parallel computation.

7 Nordhaus, understandably, used the social planner model because of its analytical convenience, not its economic realism.

FIGURE 3 OIL CONSUMPTION (MEASURED IN QUAD BRITISH THERMAL UNITS)

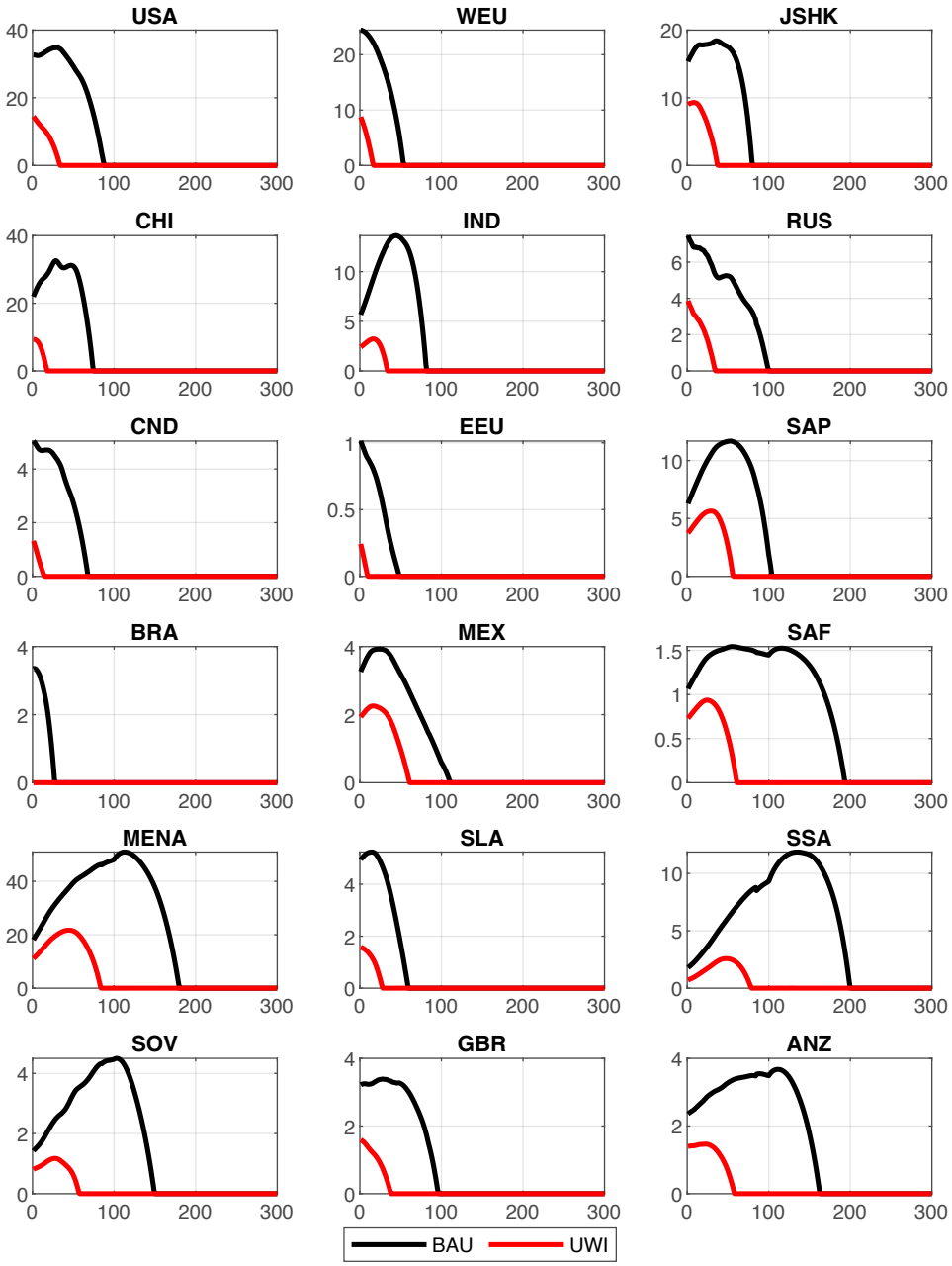


FIGURE 4 GAS CONSUMPTION (MEASURED IN QUAD BRITISH THERMAL UNITS)

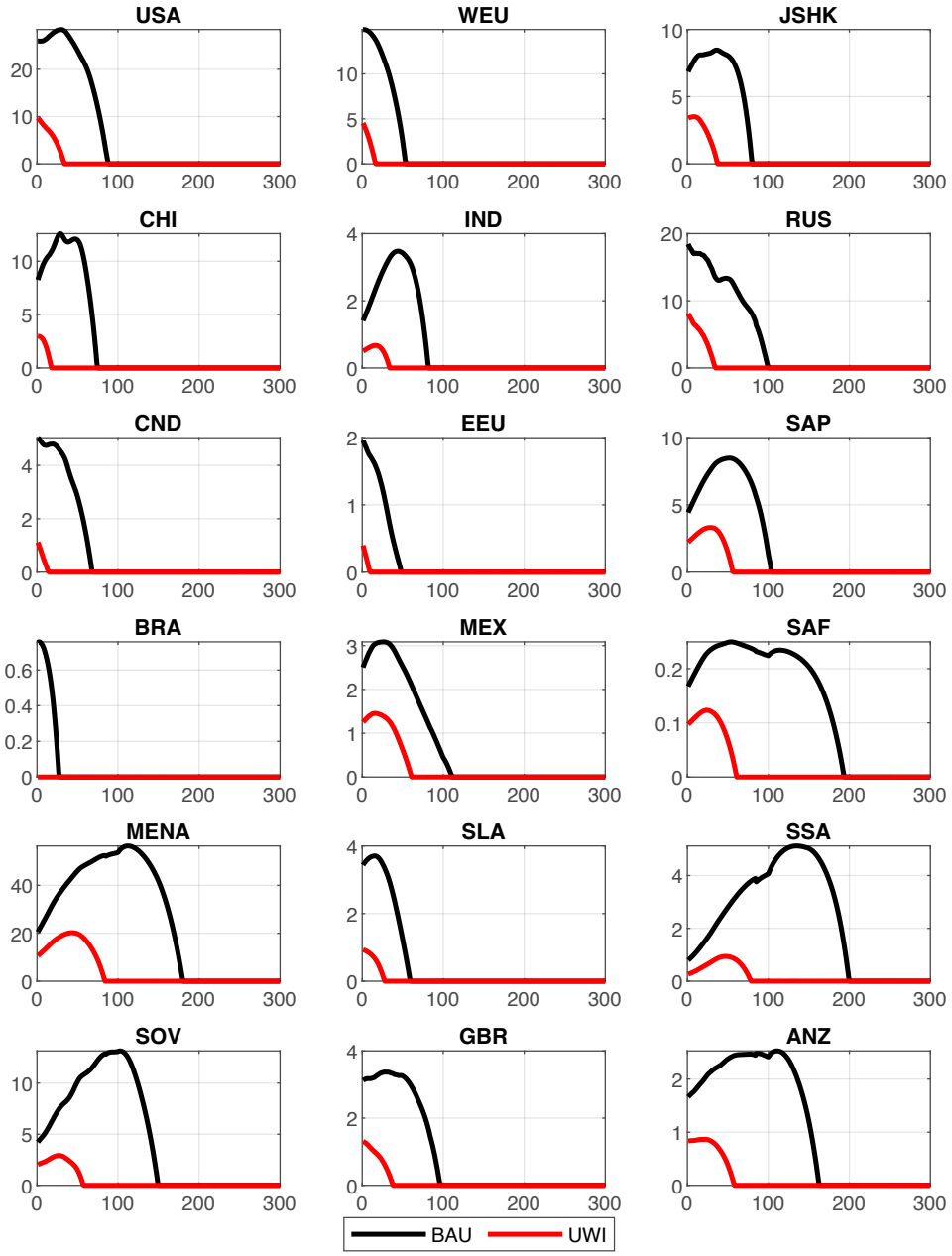
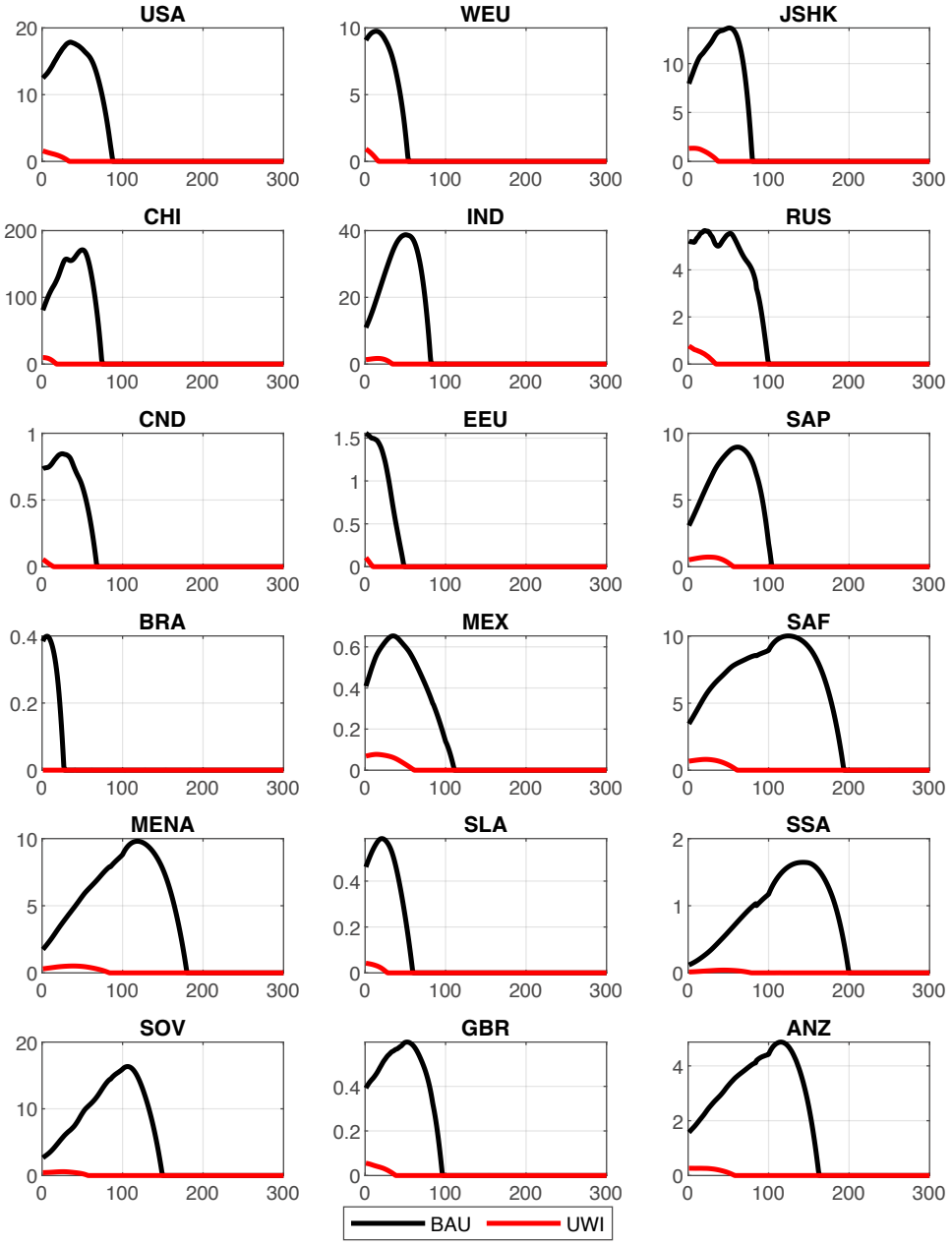


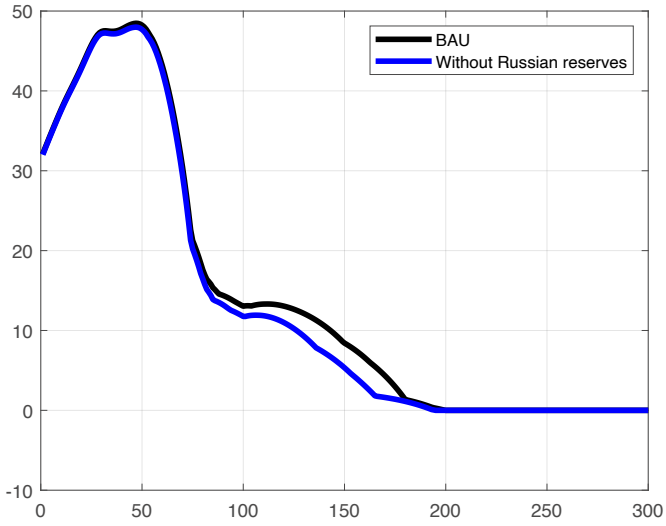
FIGURE 5 COAL CONSUMPTION (MEASURED IN QUAD BRITISH THERMAL UNITS)



COMPARING UWI CARBON TAXATION WITH A PERMANENT GLOBAL EMBARGO ON RUSSIAN FOSSIL FUELS

Figure 1, based on the model in Kotlikoff et al. (2021c), shows that the UWI carbon tax would make a big difference to emissions. Figure 6 considers an alternative carbon policy in the context of Russia's invasion of Ukraine. The policy is a complete and permanent embargo of Russian fossil fuels by all regions of the world. Setting aside the enforcement of such an embargo and the ability to maintain it through time, the figure shows that such a policy would make only a very small difference to global emissions. It would remove a significant share of global dirty energy reserves, but the induced higher price of energy would lead to more fossil fuel extraction by other regions. Indeed, there is essentially no change in global emissions over the next 100 years and a moderate reduction thereafter.[8]

FIGURE 6 GLOBAL CO_2 EMISSIONS (ABSENT OF LAND EMISSIONS, AND MEASURED IN $GtCO_2$) IN THE SCENARIO WITHOUT RUSSIAN RESERVES AS A FUNCTION OF YEARS (STARTING IN 2017)



CARBON RISK REPRESENTS A DISTINCT NEGATIVE EXTERNALITY

Carbon emissions are intergenerational and interregional, not intragenerational (e.g. across dynasty), externalities. Realising this is of paramount importance. However, so is considering the full scope of the carbon externality. If the externality entails a major, hidden, and generally unperceived cost, carbon taxes, if adopted, will potentially be set far too low. This will render the green transition slower than appropriate.

8 Nonetheless, such a policy might be chosen for political-economy reasons because it materially harms the Russian economy.

The extra hidden negative carbon externality involves risk – the difference between the climate damage that is eventually realised and the damage that is currently predicted. The *climate risk externality* is distinct from that featured in standard, deterministic climate models. It arises even where carbon emissions cause no economic damage, on average, and entail symmetric shocks. This is the illustrative case we study in Kotlikoff et al. (2021b), which, in turn, is predicated on the original insights of Cai and Lontzek (2018), Cai et al. (2018), and Cai (2020). As for our study, its economy features uncertainty in the rate of green technological improvement, the extent to which carbon raises the planet's temperature, and the extent of temperature-related damage. Each of these risks is modelled via parameterised distributions with zero means. For example, our model's green energy technological change can be negative as well as positive. On average, it is zero, with positive and negative shocks symmetrically distributed around zero.

The key takeaway from Kotlikoff et al. (2021b) is that the magnitude of the UWI carbon tax needed to handle climate risk appropriately when there is, on average, zero damage can be as large as the UWI carbon tax in the absence of risk, but with climate damages that are very high and that are sure to occur. This suggests that the UWI gain from the optimal policy derived in Kotlikoff et al. (2021c) may be twice as large as that reported.

Why do such uncertainties matter if their shocks are zero on average? The answer is risk aversion. Households are far more concerned with downside than with upside outcomes. No one would agree to win or lose half their income on a coin flip. Consequently, when party A puts party B at risk, they are imposing external damage. This damage is not visible, let alone easily measured. In fact, the only means of producing such measurements is via life-cycle models, like ours, that incorporate both risk and the households' aversion to risk.

What does the Kotlikoff et al. (2021b) study add to the path-breaking work of Cai and Lontzek (2018), Cai et al. (2018), and Cai (2020) and the impressive social welfare cost analysis of van der Ploeg et al. (2023) in modelling climate risk? This question is particularly salient given that these studies model climate risk far more precisely. The answer involves their assumption of intergenerationally altruistic dynastic agents who will naturally share climate risk across current and future dynasty members. Consequently, this within-family, intertemporal risk sharing will suggest a smaller carbon tax is needed than that prescribed in a life-cycle model.

CONCLUSION

Climate economics must start where the climate problem begins – with selfish life-cycle households living in selfish countries who need to be compensated (bribed) to support global carbon taxation. Such bribes are hard to advocate since they must be paid by future generations who are being victimised by current generations. However, paying these bribes is far better than the alternative – either a no-carbon policy or a half-hearted carbon policy. The benefits to future generations net of paying these bribes will make

them and everyone better off. To achieve universal support for global carbon taxation, bribes can be arranged such that every current and living human experiences the same percentage of welfare gain.

That is what theory – a theory that dates back a century — tells us, and what large-scale simulation modelling confirms. Given human heterogeneity, there will, of course, be those who gain somewhat more and those who gain somewhat less from the UWI solution. Additionally, with uncertainty, UWI policy needs to equalise ex-ante expected utility. The policy will not ensure that the climate produces, for example, the average number of hurricanes of average strength taking their typical paths. The change in climate change means we are living not just on a planet whose temperature is rising, but whose temperature is changing differently in different regions, producing, from our perspective, random – that is, unpredictable – global climate shocks. These shocks can be irreversible. If the sea level rises by, say, eight feet, it will take millennia to lower it back down by eight feet. Hence, uncertainty places a limit on UWI policy. We can, for a range of potential shocks, equalise the expected welfare (utility) gains by compensating regions and generations facing particularly high climate uncertainty. However, compensating, for example, island nations for disappearing due to sea level rise places a limit on the UWI policy, since the expected benefit to such inhabitants goes far beyond the uniform gain of a global carbon tax and is surely beyond their capacity to reimburse. Hence, the best that may be possible is to base UWI policy on expected climate damage, that is, make the calculations as in Kotlikoff et al. (2021c) rather than as in Kotlikoff et al. (2021b). Other policies can be developed to handle risk. An example is a global climate disaster insurance fund, to which countries pay premiums and from which they receive payment when they experience a localised climate shock.

Our bottom line? Climate change is exceedingly dangerous and urgent. There is only one way to limit its average damage, with the hope that doing so will limit the likelihood of its maximum damage. The answer is the immediate adoption of global carbon taxation. However, a global carbon tax has become politically sensitive. This is thanks, in large part, to climate economists who have transformed climate policy into an ethical decision as opposed to the solution to a major, but still standard, externality problem.

Where economists can help is in finding policies to which all can agree – policies that account for self-interest and that are designed to elicit support based on self-interest, not presumed goodwill. If, as UWI policy provides, every country and every citizen of each country benefits to the same degree, there should be close to universal adoption of global UWI carbon policy. Since available UWI policy gains get smaller and smaller the longer the adoption of the policy is delayed, everyone everywhere has a strong incentive to adopt the UWI policy immediately. Particular sectors and agents (for example, coal miners) in a given country would need extra compensation from their governments to ensure uniform intra-country welfare gains. And dirty energy-producing countries would surely oppose taxing carbon. Fortunately, the use, not the production, of fossil fuels, causes carbon emissions, and fossil-fuel producers are not major users. Moreover, if

major players – starting with the US, China, the UK, the EU, and Japan – sign on quickly under the auspices of the World Bank, others will surely do so as well. Their incentive will be to secure the compensation available to current generations that the UWI policy offers.

The promise of a win-win carbon policy is substantial. Relative to business as usual, its adoption, which entails moderately high and rising carbon taxes coupled with significant net side payments, can achieve a 5–10% welfare gain for everyone, everywhere, through time. This is a large enough benefit for people to strongly urge their politicians to adopt the policy. The available gains reflect the power of carbon taxation, as opposed to piecemeal green initiatives, to quickly and dramatically lower global carbon emissions.

Climate economics is now mired in generational conflict. This need not continue. Climate economists should pay attention to the well-established solution to negative externalities – compensate self-interested actors for being forced to pay, at the margin, the full price of their additional economic damage. The UWI carbon policy provides an opportunity to change the conversation. Older opponents of carbon taxation, who care more about energy prices than the welfare of their progeny, will be enticed to support carbon taxation because they will share in its gains. Climate deniers will be persuaded by the compensation and their realisation that their beliefs about climate change, even if correct on average, are exposing their children and grandchildren to substantial risk. In short, it is time for a new, two-word, global carbon-policy mantra – 'win-win'.

In closing, we add an important caveat. Although optimal uniform welfare-improving carbon policy, which raises the welfare of everyone, everywhere, through time, is a natural starting point for discussing Pareto-improving policy, it constitutes just one of a continuum of efficient reforms. Pareto policies that disproportionately benefit poor regions, like India, which are most vulnerable to climate change but bear very limited responsibility for its terrible trajectory, are available alternatives to UWI. In Kotlikoff et al. (2021c), we show that a carbon tax that affords such regions disproportionately larger shares of available efficiency gains is both feasible and would come at a remarkably small cost to all other parties.

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CHAPTER 4

Carbon pricing and social acceptability: Using EU ETS auction revenues for social expenditures in a changing world

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Achieving carbon neutrality requires increasingly stringent climate policies that, in jurisdictions with an emissions trading system (ETS), may lead to higher carbon prices, affecting industries, end-users and households. In the last few years, a rising carbon price trend has emerged in the leading carbon markets, which may partly be attributed to higher ambition. This rapid increase has provoked concerns about the social acceptability of more stringent climate policies among the population vulnerable to price changes. These concerns have been fuelled by the rise in energy prices, particularly after the outbreak of the war in Ukraine, which may hit the poor and jeopardise the successful post-pandemic recovery.

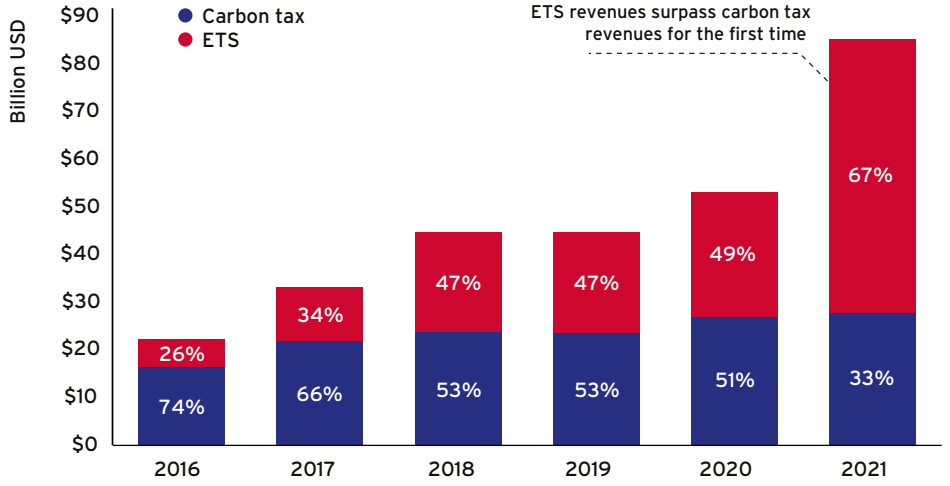
The viability of more stringent climate policies and the achievement of the climate neutrality goal also depend on the (re)distributional impacts of such policies and the way the population perceives these impacts. In this context, an ETS can play a role by raising revenues that can be used for redistribution purposes. It is, therefore, relevant to examine ETS revenues and the related expenditures performed by the governments. The EU provides a relevant case study. In 2022, new policies aiming at putting the EU on track to climate neutrality were agreed. This climate ambition was confirmed despite concerns about the high carbon price in the EU ETS and the distributional impact of high energy prices triggered by the invasion of Ukraine by Russia.

Higher energy and carbon prices are likely to have regressive effects. Lower-income households spend a bigger income share on energy- and carbon-intensive goods and face higher financial constraints to adopt energy- and carbon-efficient technologies. In addition, they are more prone to losing jobs in energy- and carbon-intensive sectors. The extension of carbon pricing to new sectors and the energy crisis risk exacerbating inequalities. Tackling the distributional effects of carbon pricing is fundamental to the success of our carbon neutrality ambition.

ETS REVENUES: SOME POLICY CONSIDERATIONS

Carbon revenues were about $84 billion worldwide in 2021, with ETS revenues ($56 billion) exceeding carbon tax revenues for the first time (Figure 1).

FIGURE 1 EVOLUTION OF GLOBAL CARBON PRICING REVENUES OVER TIME



Source: World Bank (2022).

ETS revenues correspond to the revenues raised by an ETS jurisdiction when allowances are auctioned to market participants. They are a function of the size of the jurisdiction's economy, allowance prices, the scope of emissions the ETS covers and the share of auctioned allowances.

ETSs can play a crucial role by raising revenues, and this is becoming an important consideration for policymakers. Although they are not the silver bullet in financing climate neutrality, ETS revenues can be instrumental in supporting the transition to net zero by impacting economic and environmental effectiveness and the political acceptability of the system, as well as consolidating fiscal resources of the jurisdiction (PMR 2019, ICAP 2019).

If allocated to the jurisdiction's budget, ETS revenues would be fed directly into the general budget without any identified end-use. This option offers many advantages. It increases the resource availability for public spending and can become an opportunity for improving the overall taxation framework. It provides a margin for manoeuvre as it is considered simple and flexible (PMR 2019).

Alternatively, ETS revenues can be earmarked, i.e. designated specifically for a particular purpose. Earmarking of revenues tends to increase support for carbon pricing by associating costs with benefits. Revenues can finance various categories of expenditures, such as climate mitigation, industry and innovation, social support, debt reduction, tax

reform and other programmes. Most ETSs earmark the majority of revenues towards climate mitigation, industry and innovation. A few ETSs already channel payments towards social support to low-income communities (Borghesi and Ferrari 2022).

The use of auction revenues depends on the general objectives of fiscal policies. It should fit in the political arbitrage between efficiency, long-run growth and equity. Jurisdictions should find their own recipe prioritising among expected benefits and taking into account their economic, legal and administrative contexts (PMR 2019). The establishment of dedicated funds is a good practice for allocating revenues.

The acceptability of carbon pricing policies also depends on how they are communicated (e.g. Carattini et al. 2017). In that respect, it is crucial to implement positive communication on the use of ETS revenues. This can be achieved by engaging with communities and stakeholders to design programmes and reporting the achieved impacts. In addition, jurisdictions can label funded projects with an explicit mention of the origin of the money.

THE USE OF THE EU ETS REVENUES BEFORE 2023

Revenues raised through the EU ETS were $36.7 billion in 2021 (ICAP 2022), amounting to about 41% of global carbon revenues (World Bank 2022). Auctioning revenues accrue to the budgets of member states. Most of the EU ETS revenues are redistributed to all member states based on their verified emissions. For solidarity reasons, 10% of revenues are distributed among the lower-income member states only. All member states should use at least 50% of revenues for climate and energy purposes.

Moreover, two EU investment funds were established. First, the Modernisation Fund supports investments in lower-income member states aimed at modernising energy systems, improving energy efficiency, and facilitating a socially fair transition to a low-carbon economy. The fund is capitalised with the auction revenues of 2% of the EU allowances. Second, the Innovation Fund supports innovative and breakthrough industrial technologies, such as green hydrogen and carbon capture, utilisation and storage. The fund is monetised through selling at least 450 million allowances and the remaining budget from the NER 300 programme.[1]

So far, most of the auction revenues have been directed to implementing energy efficiency and renewable energy programs in buildings, heating, and mobility (European Commission 2017). As Wiese et al. (2020) argue, efficiency and renewable energy programmes targeted at low-income households or communities help to reduce energy and mobility poverty. They can have a long-lasting effect by lowering their bills. In practice, member states differ in terms of shares of revenues aimed at climate and energy as well as measures undertaken. France, for instance, devotes most of its auctioning

1 NER 300 is an EU funding programme pooling together about €2 billion for innovative low-carbon technology, focusing on the demonstration of environmentally safe carbon capture and storage and innovative renewable energy technologies on a commercial scale within the EU.

revenues to improving households' energy efficiency and supporting low- and middle-income households (Krause et al. 2022). Hungary and Estonia focus on transport, using revenues to fund electric charging infrastructure and support the purchase of electric cars and buses. Germany devotes one part of its revenues to international climate activities. Another essential difference concerns whether member states have earmarked their revenues or added them to the general budget: ten states have earmarked auction revenues, eleven have not earmarked revenues, and six are using a hybrid approach (Figure 2).

FIGURE 2 EARMARKING APPROACHES OF EU ETS REVENUES BY MEMBER STATES

Source: Authors' elaboration created with MapChart based on data from Krause et al. (2022).

A RENEWED APPROACH FOR THE USE OF THE EU ETS REVENUES IN THE FIT FOR 55 PACKAGE

The recently adopted measures[2] of the Fit for 55 package (FF55) set forth by the European Commission in 2021 and of the REPowerEU strategy are expected to strengthen the EU's means to reach carbon neutrality and protect the most vulnerable citizens.

2 At the time of writing, the European Parliament and the European Council had reached provisional agreements on the main files related the Fit for 55 Package and REPowerEU. Those agreements need to be approved by each institution before the new directives come into force.

The FF55 foresees that member states shall spend 100% of their ETS revenues on climate-related activities. An additional 2.5% of auctioned allowances will be fed into the Modernisation Fund to finance the energy transition of low-income member states and support low-income households as well as the modernisation of energy systems. The Innovation Fund will be increased from 450 to 575 million allowances.

The FF55 also introduces a second emissions trading system (ETS 2) covering emissions from buildings and road transport to ensure these sectors contribute to the EU climate objectives. The ETS 2 should be operational by 2027, but it may be postponed until 2028 if energy prices are exceptionally high (European Parliament 2022a). Some experts argue that this might hit low- and middle-income households more severely (Feindt et al. 2021), although evidence is still mixed. The impact assessment of the FF55 indicated that "*while initial impacts* [of the ETS 2] *can be mildly regressive, revenue recycling can, in theory, fully resolve the distributional issues which arise*" (European Commission 2021: 129).

The possible income loss of low- and middle-income households may be counterbalanced by the proposed creation of a Social Climate Fund (SCF) supporting vulnerable households, micro-enterprises and transport users particularly affected by energy and transport poverty. The SCF will be operational from 2026 (i.e. one year before the ETS 2) thanks to the auction of 50 million EU ETS allowances (approximately €5 billion). Then, the SCF is expected to provide approximately €86.7 billion of funding to member states – 75% originating from the auctioning revenues of the ETS 2 and 25% from member states. The SCF will support only measures and investments that respect the principle of 'do no significant harm [to the environment]' and aim to reduce fossil fuel dependency. Member states must submit Social Climate Plans to the European Commission after consulting local authorities, economic and social partners, and civil society. The Social Climate Plans will cover two types of initiatives: (1) structural investments, including building renovation, renewable energy integration, purchase and infrastructure for zero- and low-emission vehicles, public and shared transportation; and (2) direct income support measures – up to 37.5% of the total cost of each Plan – to tackle the increase of fuel prices in the ETS 2 sectors (European Parliament 2022b). Therefore, the actual distributional effects of the ETS 2 could be much lower than perceived in public opinion.

REPowerEU: HOW SHOULD ETS REVENUES CONTRIBUTE TO TACKLING THE ENERGY CRISIS?

Within the REPowerEU strategy, the European Commission had proposed to unlock and auction part of the allowances (equivalent to €20 billion) in favour of the Recovery and Resilience Facility to promote the REPowerEU objectives. This was motivated by the exceptionally high energy prices following the Russian invasion of Ukraine, which has required mobilising all available resources to accelerate the transition away from Russia's fossil fuels. However, it raised questions about whether the means are appropriate for the purpose and how to proceed with a view to unlock more ETS revenues. Although initially

planned as a release of allowances from the Market Stability Reserve, the final agreement between the European Council and Parliament is to finance it through different sources (European Council 2022): 60% originates from the Innovation Fund, and 40% comes from frontloading ETS allowances (i.e. anticipating the auctioning of allowances otherwise scheduled from 2026 onwards) (Montel 2022). This will be distributed to member states, considering their energy dependency rate and share of fossil fuels.

CONCLUDING REMARKS: CARBON PRICING AND DISTRIBUTION AT THE TIME OF THE WAR

The combined effect of the Ukraine war and the still uncertain recovery from the COVID-19 pandemic can bring us closer to a new period of stagflation if not promptly addressed. What is more, the energy price hikes may affect public support for climate policies. The increase in energy prices shows the need to accelerate the transition process to set free from the current energy dependence, but it may have severe regressive effects and hinder climate policies that tend to increase carbon prices. In this context, can ETS revenues fix the distributional challenge of carbon pricing? It appears so. Studies have estimated that even a limited share of revenues allocated to low-income households (17% according to Berry 2018; 11% according to Mathur and Morris 2014) may be sufficient to compensate for the adverse effects of carbon pricing.

The present complex international scenario raises new questions both for policy and research. In today's world, the increase in revenues generated under the EU ETS represents a unique opportunity to reinforce the EU's green budget and contribute to the objective of reaching carbon neutrality by 2050. The FF55 and REPowerEU proposals on the use of ETS revenues are going in the right direction, but a clear policy framework is to be put in place for ETS revenues to actively support the EU's carbon neutrality objective. The social acceptability of high carbon prices can be increased by clearly devoting and earmarking a higher share of ETS revenues to 'green' social expenditures. The destinations of revenues could be adjusted to address changing challenges and priorities (higher energy and carbon prices, climate neutrality, new sector coverage). Communicating to the public with a transparent reporting on the use of revenues is crucial to facilitate acceptability.

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CHAPTER 5

Phase-out policies

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Phase-out policies are policies that rule out the use or sale of specific technologies or products by a certain date. They have been increasingly popular since the Paris Agreement. Examples include urban low-emission zones that exclude the use of some vehicles in specific areas, bans on the sale of fossil-fuel boilers, bans on internal combustion engine cars, bans on coal-based electricity production and exits from coal mining.

Phase-out policies vary in their design. They typically come with some advance notice allowing owners and producers to plan and adjust to the policy. Investment subsidies for the technologies not phased out are common. When stranding of assets is involved, owners are sometimes compensated. What is common across all phase-out policies, however, is an explicit account for the time dimension of the problem at hand.

In this chapter, we explore the case in favour of phase-out policies for physical capital that uses fossil fuels.[1] This is important because energy consumption, and hence greenhouse gas (GHG) emissions, is largely driven by the type and energy-efficiency of the equipment we use, and these have long investment cycles.[2] Fossil-based equipment can then lock in emissions for a long time. We will argue that the main advantage of phase-out policies is redistributive: they can drive out fossil-based equipment without imposing excessive charges on those consumers who are temporarily (due to their current equipment) dependent on fossil fuels. Phase-out policies are therefore particularly attractive in contexts where redistribution and political feasibility are salient concerns.

A FIRST LOOK AT THE ECONOMICS OF PHASE-OUTS

The following example will help crystalise how phase-out policies work and how they compare with other policies.[3] Consider a piece of equipment that comes in two varieties. One relies on fossil fuels for its operation (let's call it the 'brown' technology). The other

1 We will therefore abstract from bans on fossil fuel extraction, as the economics differs somewhat from the economics of fossil-based equipment phase-outs.

2 In the EU, around 55% of GHG emissions are driven by capital stocks: emissions from electricity production represent about 26% of total GHG emissions, road transport accounts for 16% of emissions, and heating in the residential and commercial sectors represents another 13% (data source: European Environmental Agency).

3 From a theoretical perspective, phase-out policies are a special kind of standard command-and-control policy instrument. Unlike mandates, they do not impose a choice of technology but simply rule out specific technologies. Because the banned technology will typically be the most polluting, they can be seen as an extreme version of a performance standard, one that cannot be met by the banned technology.

one does not produce emissions when used (let's call it the 'green' technology). The green technology is more expensive to buy, but cheaper to operate. Assume for now that usage is independent of the chosen technology (you need to heat your home, you need to drive to work, etc).

When deciding between the two technologies, a well-informed and rational consumer who is not financially constrained will consider the total cost of ownership, which includes the investment and (appropriately discounted) operating costs. If the total cost of ownership for the green technology is lower, then the consumer will choose the green technology, otherwise they will choose the brown technology.

Suppose that in the absence of a policy, the brown technology has lower total cost of ownership. A ban on new purchases of the brown technology will ensure that this technology is nevertheless gradually phased-out. For example, if the typical lifetime of the equipment under consideration is 20 years, we can expect about 5% of the existing stock to be renewed every year and therefore the green technology to be the only used technology after 20 years.

Alternatively, we could put a price on carbon and thereby increase the operating cost of the brown technology up to the level that the total cost of ownership of the green technology is lower. That policy will lead to exactly the same outcome: consumers will select the green technology at the end of the life of their current (brown) equipment, and if the price is set exactly at the level to tilt the investment decision in favour of the green technology, it will not affect the decisions by owners of brown equipment before the end of the lifetime of their equipment. These will prefer to keep their equipment even if the operating costs have increased.[4]

The main difference between a phase-out policy and a carbon price in this simple example is the financial impact on consumers and public finances. In the case of a ban on the brown technology, consumers incur a higher cost when renewing their equipment. In the case of a carbon price, all owners of the brown technology equipment incur an extra cost of operations, even if it is not economical to change their equipment. They are 'locked-in' to the brown technology. On the other hand, the carbon tax generates financial resources for the state that can be used for redistribution.

Equity concerns are central in the context of the energy (and thus climate) transition. Energy represents a higher fraction of expenses for lower-income households. Higher energy prices – or equivalently (in today's world where the carbon intensity of energy remains high), higher carbon prices – are therefore regressive. In principle, the money raised from the carbon tax could be redistributed to ease the financial pain borne by these households. Such redistribution should be independent of actual consumption to keep incentives right, but administrative, political or legal constraints often make this

4 Intuitively, they benefit from the service provided by the equipment until the end of its lifetime, without having to incur capital costs (which are sunk by then).

impractical. In the case of our simple example, one would want to exempt locked-in consumers but apply the carbon tax to all users of new equipment, an administrative and legal conundrum.

This example suggests that a phase-out policy can have the same effect as a price on carbon, with less negative distributional impact. To further reduce the negative distributional impact of phase-out policies when the green technology is more expensive, phase-out policies can be combined with means-tested investment subsidies.

VARIATIONS ON PHASE-OUTS

Table 1 describes existing phase-out policies in different geographical jurisdictions for heating in buildings and road transport.[5] The first row describes the recommendations derived by the International Energy Association (IEA) from their net zero emissions trajectory aligned with the Paris Agreement (IEA 2021). For buildings, the IEA trajectory requires that all new buildings meet high standards of energy efficiency and either use biomass or an energy supply that can be fully decarbonised by 2050, such as electricity or district heat. This effectively rules out all fossil fuel boilers in new buildings by 2030. For road transport, the IEA recommends a ban on new internal combustion engine vehicles by 2035.

The table shows that the measures approved at the EU level as part of the Fit for 55 package are largely in line with the IEA recommendations. The Netherlands and the UK are implementing earlier phase-outs. Germany is implementing a more aggressive target and is phasing out fossil-based heating in existing buildings as well. Norway has banned new fossil-based heating installations since 2017 and has banned the use of oil for heating since 2020.

This variety of policies illustrates how the speed of the technology phase-out can be tailored according to national ambitions. A ban on new installations in new buildings is easiest to implement, but the renewal rate of housing stock is low (around 1% in the EU) and new additions to the building stock varies across countries. Next comes a ban on new installations in existing buildings, as these might involve significant renovation work (more radiators or floor heating). Finally, a ban on the use of the fuel, as in Norway, effectively comes down to forcing existing oil-based installation into early retirement (stranding).

5 See Kerr and Winskel (2022) for a description and discussion of other phase-out policies.

TABLE 1 EXAMPLES OF FOSSIL FUEL PHASE-OUT POLICIES ACROSS THE WORLD

	Heating	Road transport
IEA net zero benchmark	Mandatory zero-carbon-ready building energy codes for all new buildings by 2030; retrofits to make all buildings zero-carbon ready by 2050.	No new internal combustion engines by 2035
EU (Fit for 55 package)	No fossil-based heating in new buildings by 2030 (2028 for new buildings owned by public bodies)	By 2035, all new cars must be zero-emission
Germany	No new fossil-based heating in buildings (existing and new) by 2026	-
The Netherlands	No new fossil-based installation by 2026	Local bans for internal combustion engine vehicles by 2030
UK	No fossil-based heating in new buildings by 2025 (2024 in Scotland)	No new petrol and diesel cars by 2030; sale of hybrids possible until 2035
Norway	Ban on fossil-based heating installation since 2017, ban on the use of oil for heating in new and existing buildings since 2020	Ban for new passenger vehicles by 2024
China	-	Ban for new private vehicle by 2035, earlier in some provinces
US	Some local bans for new buildings (e.g. New York City by 2024)	Some local bans for new vehicles (e.g. California by 2035)

Notes: Zero-carbon-ready buildings are highly energy efficient building that either use renewable energy directly (biomass) or use an energy supply that will be fully decarbonised by 2050 such as electricity or district heat. Some of these policies are combined with investment subsidies.

Source: Author's compilation from IEA (2021), Braungardt et al. (2022) and different public sources (official websites and news).

Vehicles have shorter life times than heat boilers and thus a ban on only new vehicles can rapidly decrease emissions. This lower inertia explains why the IEA's recommended phase-out dates are later for internal combustion engine vehicles compared to fossil-based boilers. However, some local jurisdictions are banning the use of internal combustion engine vehicles, or at least the most polluting ones, earlier. These take the form of low-emission zones and are typically city initiatives.

ADDITIONAL CONSIDERATIONS

Of course, the real world differs from our simple example. First, consumers have some agency as to the intensity of use of their equipment. Higher operating costs will lead to a less intense use of the technology. In this case, a price on carbon can perform the double duty of both impacting use (the intensive margin) and investment decisions (the extensive margin), whereas phase-out policies only impact investment decisions.

Second, at the time policies are decided, there typically remains significant uncertainty about future economic conditions, technology costs and consumer behaviour. Such uncertainty breaks down the equivalence between a carbon price and a phase-out even in our simple example (Weitzman 1974). A drop in fossil fuel prices or a higher-than-expected price for the green technology may fail to tilt investment decisions towards the green technology if the price of carbon is not sufficiently high. Likewise, a phase-out policy on new purchases may lead consumers to keep their old polluting equipment longer if the green technology is too expensive. In both cases, the climate target may not be met. The received wisdom, from Weitzman (1974) and the follow-on literature, is that phase-out policies are likely to be better at delivering quantity targets, though both approaches will benefit from being part of a policy mix that somewhat adjusts to observed behaviour. So, for example, both policies can be combined with investment subsidies for the green technology.[6]

A third dimension in which the real world differs from our simple example is that consumers are typically short-sighted and may be financially constrained. Short-sightedness is a robust psychological bias (DellaVigna 2009). When evaluating an investment, current expenses are salient and future operating costs are less so, leading consumers to opt for less energy-efficient equipment even when its total cost of operations is higher (the seminal paper here is Hausman 1979). Uncertainty about future operating costs and financial constraints exacerbate this bias. Unlike carbon pricing, which leaves full choice to consumers, phase-out policies are immune to these behavioural biases but, as noted previously, may nevertheless lead consumers to inefficiently postpone the acquisition of new equipment if they are financially constrained.

A related concern is the split-incentives problem that arises when the person buying the equipment is not the same as the person using it, as is commonly the case in residential rental markets (e.g Gillingham et al. 2012). The presence of split incentives reduces the effectiveness of carbon pricing as a way to push out the brown technology because owners do not incur the operating costs of the equipment, and these tend to be only partially reflected in the rent they get. By contrast, phase-out policies operate independently of the way ownership and use is split.

6 These investment subsidies can also be rationalised as a subsidy for research and development when the green technology is still immature (Acemoglu et al. 2012).

Finally, some studies suggest that early retirement of some equipment will be necessary to meet the objectives of the Paris Agreement (IPCC 2022). This will be all the more likely if ambitious climate action continues to be delayed as currently. Phase-out policies and carbon prices operate differently in these circumstances. Early retirement of equipment can be implemented under a phase-out policy by banning the use of the most polluting (typically older) part of existing stocks. Low-emission zones operate exactly in that fashion for cars. Partial early retirement requires monitoring and enforcement, however, and may not be feasible – or at least not feasible at the required level of granularity – for all types of equipment. It is more difficult for domestic boilers, for example, even if technicians performing annual maintenance can play a role. On the other hand, a high enough carbon price can also push brown technologies into early retirement. If all vintages of the brown technology are equally polluting, equipment owners will decide to strand their brown equipment and invest in the green technology independently of the residual lifetime of their equipment.[7] When older vintages are also more polluting and therefore more costly to operate with the carbon tax, older vintages will be pushed out first.

A BROADER PERSPECTIVE ON PHASE-OUTS

So far, we have applied standard economic reasoning to the analysis of phase-out policies as a policy instrument. Phase-out policies also have advantages from a political and industrial policy perspectives.

Politically, phase-out policies put everyone on the same footing. They apply to the rich and the poor. You cannot 'pay your way out of it' like carbon taxes. When they apply to new purchases, they only impact a fraction of the population and avoid impacting locked-in consumers that can do little to change their behaviours anyway. This contributes to their social acceptability and makes them popular with politicians.

Phase-out policies are also attractive from an industrial policy perspective. Changes in technology require that an entire supply chain is set up around the new technology, from production to servicing to end-of-life management and recycling. Such changes can be subject to coordination failures because a critical mass is needed to make entry in production, servicing and end-of-life management profitable. Phase-out policies boost demand for green technologies and create predictability for market participants, who can more easily coordinate on the needed investments to serve the emerging market. The EU decision in October 2022 to phase out internal combustion engine cars is a case in point. EU legislators had been discussing measures to reduce emissions from road transport since the adoption of the Green Deal in December 2019 and some car manufacturers had

7 Intuitively, early retirement becomes economical when operating costs are so high that the net value of the service of the equipment is smaller than if it was replaced with a new one, even after accounting for the capital cost. At the value of the carbon tax that makes the owner of an equipment with one remaining year left indifferent between early retirement (and investment) and keeping the existing equipment, owners of newer vintages are also indifferent between these two options. If early retirement becomes profitable for the first owner, it also becomes profitable for owners of all newer vintages.

started to make moves in support of electric vehicles. At the announcement of the phase-out decision in October 2022, EU Commissioner Frans Timmermans tweeted "EU car industry is ready, consumers are eager to embrace zero-emission mobility"[8] while Jan Huitema, the European Parliament's rapporteur and author of the car emissions report, stated that the new rule created "clarity for the car industry and stimulate[d] innovation and investments for car manufacturers. (…)".[9]

CONCLUDING COMMENTS

When it comes to climate action, there is no 'one size fits all'. Policies need to be tailored to the specificities of the sectors and markets at hand to ensure they are effective, efficient, socially acceptable and administratively feasible. Phase-out policies are – rightly so – part of the toolbox of policymakers.

Phase-out policies are especially attractive options when dealing with long-lived fossil-based equipment in markets where at least one of the following conditions holds: equity concerns are salient, usage is inelastic (captive consumption), the person deciding on the investment is either short-sighted or does not bear the operating costs of the equipment (split incentives), the alternative technology is at its infancy and a new supply chain needs to be set up to support it. Under these conditions, phase-out policies can be more effective than a simple carbon price while accounting for equity considerations. Long-lived consumer goods, such as boilers and electric vehicles, are therefore sensible sectors for phase-outs. These are sectors that, in the EU, have until recently escaped the introduction of a carbon price exactly for these equity concerns.[10]

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10 In December 2022, EU legislators have agreed, as part of a broad reform of the Emissions Trading Scheme, to create a separate trading scheme for the building and road transport sectors. Prices would be effectively capped at 45 EUR per ton, which is much below estimates of the social cost of carbon and prevailing prices on the main emissions trading scheme, presumably to protect consumers.

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CHAPTER 6

Sobriety

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INTRODUCTION

The Kaya decomposition provides a convenient and simple framework for thinking about our options to reduce CO_2 emissions. There are four of these, obviously neither independent nor causally linked: lowering the size of the population, the growth of GDP per capita, the energy intensity of GDP or the carbon intensity of energy. Economists are reluctant to embark in the first direction and recommend lowering the population. The second option is contentious as well. The question is whether we just have to endure a temporary slowdown during the transition phase, or whether degrowth is the only possible outcome in the long run. As for the fourth option, the purpose of the energy transition, amply analysed in the literature, is precisely to achieve the decarbonisation of energy. Regarding the third option, there are several ways of slowing down the energy intensity of GDP: on the supply side, changing production methods towards a circular economy, recycling, adopting energy-saving technologies, and producing goods that are more energy-efficient through innovation; on the demand side, changing behaviours.

Up to now, the progress that has been made at the global level in the fight against global warming is mostly due to a decrease in the energy intensity of GDP, through an increase of energy efficiency due to technological improvements and, for a small part, to decarbonisation of electricity production. But this progress has been too limited and too slow, as is the implementation of ambitious climate policies. Therefore, the emphasis has recently switched to reducing demand. What is meant here has to be clarified. Is it necessary to reduce global demand or only demand for greenhouse gas (GHG)-emitting goods and services? The second option, requiring a change in the composition of demand, is less demanding. However, it is not so easy to achieve, as we are entrenched in our consumption patterns and our ways of life, shaped by abundant and cheap fossil energy since the Industrial Revolution. Moreover, even if changing the composition of demand can be achieved, it may not be enough.

The debate about the level of sustainable consumption is not new. Arrow et al. (2004), for example, discuss the social welfare functions through which it is possible to evaluate what is sustainable and what is 'too much'. This debate has to take place, on the one hand,

within the recognition of the planetary boundaries (Röckstrom et al. 2009), capturing essential biophysical processes that sustain life on earth, and, on the other hand, having in mind that the right metric is welfare, not consumption.

I am not going to explore these issues in all their dimensions. I rather adopt the lens of climate policy and try to define what reducing demand means, on the household side. Reducing demand can be achieved by price policies or it can be voluntary. I define here 'sobriety' as the voluntary reduction of demand. I focus first on defining voluntary behavioural changes and their determinants at the individual level. Recognising that sobriety cannot just be reduced to the individual level, I then consider its societal dimension.

CHANGES IN PREFERENCES AT THE INDIVIDUAL LEVEL

Behavioural changes

The International Energy Agency (IEA) defines behavioural changes as "changes in ongoing or repeated behaviour on the part of consumers which impact energy service demand or the energy intensity of an energy related activity" (IEA 2021). It thus adopts the view of a change in the composition of demand. The report identifies three main types of behavioural change: (1) reducing excessive or wasteful energy use; (2) switching transport mode; (3) gains in materials efficiency (for example, through higher rates of recycling or improved design and construction of buildings and vehicles). This latter channel makes immediately clear that the frontier between behavioural change, technical innovation, infrastructure development and social organisation is often not easy to draw. The IEA (2021) estimates that those behavioural changes have the potential to reduce energy-related activity by around 10–15% by 2050.

The authors of Chapter 5 of the Intergovernmental Panel on Climate Change (IPCC)'s sixth assessment report (Creutzig et al. 2022) evaluate the potential of reduction in demand for reducing global GHG emissions in the end-use sectors at 40–70% by 2050 compared to reference scenarios. But the reduction in demand the authors consider goes beyond mere behavioural changes. It classifies the demand-side options into three categories, dubbed 'avoid', 'shift' and 'improve'. 'Avoid' is the more radical option. It involves giving up some very high carbon-emitting consumptions, such as long-haul flights and cars. 'Shift' involves adopting less carbon-intensive modes of consumption, such as cycling or a plant-based diet. 'Improve' corresponds roughly to changing household equipment (adopting green innovations like heat pumps or electric vehicles), which the IEA (2021) does not consider as a behavioural change.

A more specific study is the one by Dugast and Soyeux (2020), who document the impact that 'small gestures' can have on an individual's carbon footprint in France (in the case where all people in France adopt these gestures). They offer two versions of their estimates: the 'average French' version and the 'heroic French' version. In the first,

small gestures (switching to a vegetarian diet, cycling for short trips, no longer flying, buying fewer new clothes, lowering the temperature at home, buying second-hand household appliances and technology, etc.) are relatively marginal and do not require great efforts, whereas in the second, as its name suggests, the gestures are restrictive and the associated changes in lifestyle are significant. Generalised heroic behaviour reduces the carbon footprint by 26%. As for average behaviour, the authors estimate that it allows for a 5–10% lowering of the footprint, depending on how it is defined – what is considered 'heroic' or normal varies greatly from one person to another!

Modelling

To illustrate how a change in the composition of demand through changes in preferences and a price policy can be represented in a modelling framework, let us take as an example a modelling of the representative household's behaviour inspired by Henriet et al. (2014).

The household has access to three types of goods: non-durable goods, energy and durable goods (a house, car, refrigerator, computer, etc.). Durable goods accumulate over time thanks to investment.

Services provided by durable goods Z_t are a constant elasticity of substitution (CES) aggregate of the stock of durables D_{t-1} at the beginning of the period and efficient energy consumption $A_t^e E_t$:

$$Z_t = \left(\nu D_{t-1}^{\frac{\epsilon-1}{\epsilon}} + (1-\nu)(A_t^e E_t)^{\frac{\epsilon-1}{\epsilon}} \right)^{\frac{\epsilon}{\epsilon-1}} \tag{1}$$

where A^e represents energy efficiency, ϵ the elasticity of substitution between durables and efficient energy, and $1 - \nu$ the share of efficient energy in the provision of durable goods services.

The consumption index C_t at period t is a CES aggregate of the consumptions of non-durable goods N_t and services provided by durable goods Z_t in that period:

$$C_t = \left(\gamma N_t^{\frac{\omega-1}{\omega}} + (1-\gamma) Z_t^{\frac{\omega-1}{\omega}} \right)^{\frac{\omega}{\omega-1}} \tag{2}$$

where ω is the elasticity of substitution between non-durables and the services of durables, and $1 - \gamma$ the share of durable goods services in overall consumption.

Energy E is a CES aggregate of fossil energy Ef and decarbonised energy Ed:

$$E_t = \left(E_{f,t}^{\frac{\zeta-1}{\zeta}} + E_{d,t}^{\frac{\zeta-1}{\zeta}} \right)^{\frac{\zeta}{\zeta-1}} \tag{3}$$

where ζ is the elasticity of substitution between the two energy sources.

The representative household seeks to maximise the discounted sum of its utilities under its intertemporal budget constraint.

This simple framework is convenient for disentangling the mechanisms through which CO_2 emissions, proportional to fossil energy consumption, can decrease.

First, they can decrease thanks to improvements in energy efficiency – the effect of the energy-saving technical progress A^e in equation (1) – that allow the same amount of services from durable goods to be obtained with less energy over time.

Second, they can be prompted by climate policy – a carbon price (tax or cap and trade) or implicit carbon pricing (bans, regulations, standards) – or external price shocks like the recent shocks to the gas price and the wholesale electricity price on the European markets. Those policies or external shocks incentivise the substitution of decarbonised energy to fossil energy in equation (3), which is the aim of the energy transition, and change the relative prices of the three goods. Ultimately, they change the household's instantaneous budget constraint.

Third, emissions can decrease thanks to changes in preferences, voluntary behavioural changes towards sobriety. In the model, they can be represented by increases of the v and/or γ parameters in equations (1) and (2), which shift iso-utility curves. A higher v means that to reach a given level of services from its durable goods, the household prefers to use less energy. A higher γ means, that everything else equal, the household enjoys the services provided by durables less. In the housing and transport sectors, examples of the former include the reduction of indoor temperatures, the adoption of energy-saving practices and the reduction of speed on highways; examples of the latter include a reduction in the size of dwellings and a shift to less powerful cars or to cycling.

Finally, another type of behavioural change consists in increasing the lifespan of durables such as cars or computers. This can be represented by a decrease in the depreciation rate of the durables stock.

A drawback of this type of CES modelling is that it represents homothetic preferences, with which the Engel curves are linear in income. The empirical literature shows, however, that this is not the case for energy. Caron and Fally (2022) estimate a model with non-homothetic preferences à la Comin et al. (2021) and find that direct household energy consumption increases less than proportionally to income in developed countries and is more income-elastic in developing countries. This effect is not quantitatively negligible and therefore should be taken into account.

Equipped with this simple framework (or an equivalent one), the consequences of the adoption by a household of 'sober' behaviour can be evaluated and compared to the consequences of a price policy. However, this representation cannot take into account households' behavioural biases and irrational behaviour, the cultural and social dimensions of their preferences, or the fact that changing behaviour requires that supply evolves together with demand (more on this below).

TRIGGERING BEHAVIOURAL CHANGES

Behavioural changes may be triggered by better information (through education, information campaigns, labels, NGOs, etc.), by nudges, by imitation of (online) influencers, by switches in the mood of your reference group, by the renewal of generations or by a price policy itself. On this issue, economics has a lot to learn from other social sciences such as psychology, sociology and anthropology.

Consumer information

Let us look first at the issue of consumer information. Labels are increasingly used to raise consumer awareness on the carbon footprint of their consumption. Apps on mobile phones provide easy ways to bridge the 'intention to action gap'. The success of apps that provide information on the dietary quality of food products seems to show that access to better information can indeed change consumer behaviour. But people's diet has a direct impact on their health, while their carbon footprint is more abstract, so the efficacy may be smaller. With regards to energy efficiency labels, Brounen and Kok (2010) show that in the Netherlands, dwellings that receive a good energy efficiency rating sell for 10% more than others. The results of a field experiment presented in Aydin et al. (2018) show that the provision of information about a household's electricity consumption reduces that consumption by around 20% on average. Houde (2018) shows that there is great heterogeneity in consumer response to energy efficiency labels on refrigerators: this information is useful for some consumers, while for others it can crowd out efforts to process more precise but complex energy information. In a field experiment in Texas, Burckhardt et al. (2019) find very little response to information provision and appeals to energy conservation during summer peak load days. Alcott and Knittel (2019) present experimental evidence that consumers are poorly informed about fuel economy when they buy new cars, but that providing them with information has no effect on the average fuel economy of vehicles purchased. The literature on the evaluation of this type of policy remains relatively rare and is not yet conclusive. However, the quality of the information provided is crucial for trust, and the danger of greenwashing –here taking the form of deceptive or misleading green claims – is repeatedly put forward.

Nudges

Motivated by insights from psychology and following the influential contribution by Thaler and Sunstein (2008), there is a growing literature investigating how non-pecuniary incentives ('nudges') can be used to reduce households' energy consumption by acting on behavioural biases. The evidence is mixed and, when an effect is found, its permanence is often questioned. Moreover, each intervention is very specific (see the survey by Carlsson et al. 2021). Among the most recent papers, Löschel et al. (2022) investigate whether such interventions can be scaled up. They develop an energy savings app for mobile phones, promoted by marketing campaigns and financial incentives. The app randomises a goal-

setting nudge prompting users to set themselves energy consumption targets. The effect is negligible, probably because of self-selection of the users. Interestingly, List et al. (2022) develop a framework that allows them to estimate and compare welfare effects of both nudges and taxes in the markets for cigarettes, influenza vaccinations and household energy. They find that while nudges are effective in changing behaviour in all three markets, taxes are clearly more efficient in the energy market. Their explanation for these results is that nudges dominate taxes when the standard deviation of the behavioural bias exceeds the magnitude of the average externality.

Interactions with climate policy

An important question is whether agreeing to make small gestures is an indicator of willingness to accept more fundamental changes and substantial climate policy measures, or whether it leads people to consider that they have done enough for the climate.

Using surveys conducted in Japan, Werfel (2017) finds that virtuous behaviour by households in terms of energy savings, when perceived as effective, reduces their support for an increase in the carbon tax. Hagmann et al. (2019) show experimentally that a policy based on nudges (in this case, a nudge aimed at households intended to make them sign up to green energy contracts) decreases the population's support for carbon pricing because it gives hope that the problem of global warming can be solved without too much cost or effort.

We can also wonder whether, in the opposite direction, taxes such as the carbon tax, which constitute an extrinsic motivation to reduce CO_2 emissions, crowd out the intrinsic motivation which pushes us to perform climate-friendly 'small gestures'. Goeschl and Perino (2012) find that this is indeed the case. They further show that emissions standards do not have the same intrinsic motivation crowding-out effect.

Mattauch et al. (2022) examine the impact of climate policy-induced changes in consumers' preferences. One of the questions they raise is whether carbon taxes and regulations crowd in or crowd out voluntary action, which is again the more general question of intrinsic versus extrinsic motivation. The answer is that it depends on the context. In both cases, policy instruments should be adjusted to take into account the endogeneity of preferences. Two specific policies unambiguously trigger changes towards more climate-friendly preferences: providing urban transport infrastructure changes mobility preferences towards public transport or bike, while public health policy shapes dietary preferences towards more healthy and environmentally friendly products.

Habits and cohorts

Habits acquired in youth seem to shape behaviour in adulthood. Severen and van Benthem (2022) show that individuals who learned to drive during the 1979 oil crisis used a car less and public transport more for their commute to work in the 2000s. They thus seem to have kept the habits they picked up when gasoline was expensive, during

their early years as a driver. This is a scarring effect that can be observed more generally: early life exposure to a lack of energy (or anything else, for that matter) makes people consume it less in their adulthood. As habits are an important obstacle to behavioural changes, disrupting habits may be a powerful way to trigger the change.

Another interesting question is whether the mere renewal of generations is going to trigger the adoption of more sober behaviours. Indeed, behaviours change over time with households' age but also with the generation they belong to. In this spirit, Chancel (2014) studies cohort effects in energy consumption. He does not find convincing evidence that younger generations have more environmentally friendly preferences, but stresses the methodological difficulties of estimating age- period cohort models and the need for further research.

THE SOCIETAL DIMENSION

The authors of Chapter 5 of the IPCC's sixth assessment report stress repeatedly that the demand-side mitigation they envisage can only happen through societal, technological and institutional change (Creutzig et al. 2022). Indeed, sobriety cannot depend solely on everyone's willingness to make 'small gestures'. Sobriety should instead target the social, regulatory and infrastructural conditions that support GHG-intensive ways of life. It should aim to modify both infrastructures and social norms.

Infrastructure

Appealing to sobriety is mostly useless if the means to be sober are not provided simultaneously. Building appropriate infrastructure is essential. This infrastructure ranges from cycle lanes and high-speeds railways in the transport sector to denser cities in the housing sector. Providing the means to reduce energy consumption also applies to price policies: enabling and facilitating substitutions from energy-intensive to climate-friendly goods is essential to ensure the effectiveness of the policy. The provision of climate-friendly infrastructure leads to structural behavioural changes: new ways of working (working from home) and new ways of inhabiting space (in denser cities, closer to work, in smaller dwellings).

Social norms

Changing social norms is essential as well. Changes in values and culture can spur long-lasting changes in behaviour, as shown by the examples of smoking and recycling (Nyborg et al. 2016). A social norm does not change just like that, however. The literature stresses the role and the determinants of cultural transmission (Bezin 2015, 2019). Public policy and exogenous shocks can trigger rapid changes in norms, as the examples of smoking in restaurants or the persistence of teleworking after the Covid-19 crisis have shown. Social learning and the influence of peers also play an important role. For instance, Bollinger and Gillingham (2012) and Gillingham and Bollinger (2021) show the role of peer effects in the case of residential solar photovoltaic adoption, while Bollinger et al. (2020) do the same for residential water conservation. Today, social media influencers do not in general promote climate-friendly products, brands or behaviours, but a time when they do may come! In the meantime, it seems clear that a change in social values towards sobriety is very unlikely to happen on a large scale in societies that value consumption highly and where people are showered with 'contradictory injunctions', like appeals to sobriety together with ads for SUVs.

Effort sharing

Should everyone adopt more sober behaviour? Clearly not – poor households who cannot satisfy their basic needs cannot be asked to become more sober. When the IPCC stresses the importance of reduction in demand (Creutzig et al. 2022), its main message is that consumption should no longer be based on quantity, but only on what is needed. Those who have 'too much' should consume less, while those who have 'not enough' should consume more. This raises the very difficult question of what is decent, what is enough. It also means that inequalities have to be reduced, both within and between countries.

The natural question that then arises is whether it would it be enough to target climate policies to the 'super-rich' only, to make them achieve the necessary emission reductions. According to Chapter 6 of the 2022 World Inequality Lab report (Chancel et al. 2022), the top 10% emitters at the world level emit 47.6% of total carbon emissions, and the top 1% emit 16.8% of the total. Or, to put it differently, one hundredth of the world's population emits about 50% more than the bottom half of the population. Controlling the emissions of the world's super-rich is essential from the point of view of mitigation, even though it will not be enough: given the magnitude of the emission reductions that must be achieved to stay within the carbon budget corresponding to a 2°C target, almost everyone in the rich countries will have to contribute. It is probably even more important symbolically, because conspicuous consumption by the wealthiest is hardly compatible with injunctions to induce sobriety.

CONCLUSION

To wrap this short review up, let me offer a few personal thoughts.

Asking households to voluntarily change their consumption behaviours and become sober cannot be a substitute for ambitious price policies to achieve the necessary demand reduction. On the contrary, they are complements, even though in some circumstances price policies can crowd out voluntary behaviour and vice versa. Both have to take place in a social context of a reduction in inequality. A carbon tax whose revenues are redistributed in order to make it progressive, a society valuing sobriety, investments in infrastructure providing the means to change behaviour, along with regulations targeting conspicuous carbon-intensive consumption, would be an effective climate policy mix.

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CHAPTER 7

Managing energy demand with information-based policies in times of crises

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The overlapping crises of the 1970s shaped our current energy systems and policies. The Iranian oil embargos impeded putting energy security at the centre of energy policies. At the same time, increasing awareness of local environmental problems, such as the acid rain problem and water pollution, led to a raft of laws and regulations targeting the power sector. Fifty years later, energy systems are at a junction and, again, facing multiple crises. Although we have made enormous progress in cleaning our energy systems, the consensus is clear: society's dependence on fossil fuels still generates (too) high levels of local and global pollution. The war in Ukraine has also revealed that we should not take energy security for granted. More than ever, local energy supply disruptions have negative global economic consequences.

Addressing the current crises will require systemic transformations, technological disruptions and behavioural changes. To achieve those, several lessons can be learned from the policy responses to the seventies. First and foremost, getting the right price signals in the energy system is a necessary condition. However, in an era of energy-induced high inflation, further increasing energy prices by taxing energy externalities is simply too politically toxic to be considered. Like in the seventies, it is a combination of information-based policies, mandates, standards, and subsidies that policymakers now favour.

Information-based policies are the easiest and fastest to deploy. They are also crucial to gain political capital. In the face of the discontentment among voters due to high energy prices, shortages, and rationing, governments ought to implement policies that are salient to their citizens. Information policies certainly achieve this purpose. But what exactly are information-based policies? Are they justified based on specific market failures? Are they effective in the short or long term? Ultimately, should they be part of the portfolio of policies required to achieve a successful energy transition?

WHAT ARE INFORMATION-BASED POLICIES IN THE ENERGY CONTEXT?

The overarching goal of information-based policies is to manage energy demand better. They take different forms and distinguish themselves by the speed at which governments can deploy them in response to crises. Public appeals and education campaigns are the fastest policies to be deployed. In recent months, those are precisely the policies that have emerged. Governments across Europe have launched public websites combined with aggressive marketing campaigns to educate about and appeal to energy conservation.

In the medium term, we expect governments to favour emergency funding of long-established energy programmes. Energy audit programmes, a popular information-based policy encouraging energy efficiency investments, should be a prime target for these additional funds. Most developed economies already have ambitious energy efficiency targets as part of their climate change mitigation strategies. The heightened concern about energy security is an additional impediment to scaling up energy audits.

In the long run (i.e. in a matter of a few years), different information-based policies may emerge. First, there are labelling and information disclosure programmes for energy-using durables. For instance, the energy labels that are now ubiquitous on most appliances and consumer electronics were inherited from the seventies. More recently, the disclosure of energy performance was also mandated in the European real estate market. However, this is not systematically the case in other regions, and the current crises could accelerate the adoption of such a policy. Another type of information-based policy is based on feedback interventions, which often require technologies to collect and disseminate energy information. Feedback interventions aim to provide tailored information to energy consumers with the hope that it fosters energy conservation or investments in energy efficiency. It can also be part of a broader deployment of smart-grid technologies that enable the automation of energy demand.

WHAT MARKET FAILURES MOTIVATE INFORMATION-BASED POLICIES?

Governments will deploy an eclectic set of information-based policies in response to the current crises. One crucial question is whether there are specific market failures that motivate such governmental interventions. Put another way, as there is political momentum to implement and reform energy policies, should governments target existing market failures with information-based policies?

Information asymmetries between energy consumers, technology and service providers are the first rationale for information-based policies. For energy-using durables, ranging from cars to houses, energy usage is a complex attribute that consumers can only estimate with government-mandated labelling, information disclosure programmes and energy audits conducted by experts. Furthermore, energy prices are shrouded by archaic and complex billing procedures that create a temporal disconnect between the timing of consumption decisions and payment. In some European countries, this problem is

very salient. German and Swiss households, for instance, are only billed once every six months for the energy they consume. In sum, deep information asymmetries about the quantity and the price of energy make it simply impossible for consumers to optimise at the margin.

The role of information-based policies should be to fill this information gap. However, this is not as simple. A second market failure is superposed to information asymmetries. Behavioural failures, a misnomer used by economists to describe biases, heuristics, and other behavioural phenomena not in line with *Homo economicus*, are also important in the energy context. Hausman (1979) famously referred to consumers' 'lack of telescopic ability' as a potential explanation for the slow adoption of energy-efficient air conditioners. Since then, numerous empirical studies have documented manifestations of behavioural failures such as inattention, biased beliefs, present bias, and warm-glow, to name a few, as important drivers of energy decisions. Beyond providing hard information, the role of information-based policies is also to correct these behavioural failures, or at least to account for them in the design of policies.

ARE INFORMATION-BASED POLICIES EFFECTIVE?

In the face of the overlapping energy and climate crises, multiple criteria determine what *policy effectiveness* means for society. Reduction in energy use and associated emissions is one metric that is particularly relevant for energy security and avoiding climate tipping points. However, economists will be quick to argue that more than simply focusing on such reductions is required. We should determine a policy's cost-effectiveness and how it compares to a specific benchmark, such as the social cost of carbon. Ideally, we would like to go one step further and conduct a complete welfare analysis and quantify the welfare effects of information-based policies while accounting for the different market failures at play. Only some empirical studies go all the way to this last step. Cost-effectiveness calculations of information-based policies are more common, but not the norm. The temporal dimension is also important in determining policy effectiveness. The persistence of the impacts of information-based policies is often a concern. The short-term versus the long-term impact should then be carefully assessed.

Some types of information-based policies have been well studied, but for others, little is known. Table 1 provides a selected list of relevant empirical studies that can guide us in deploying and designing policies in response to the current crises. The table classifies each study along three dimensions: the speed of deployment (short, medium and long term), the criteria to evaluate the effectiveness (reduction in quantities, cost-effectiveness, and welfare metrics), and the temporal dimension of the policy evaluation (short and long term).

TABLE 1 OVERVIEW OF EMPIRICAL STUDIES ON INFORMATION-BASED POLICIES IN THE ENERGY CONTEXT

Policy	Speed of deployment	References	Criteria to evaluate cost-effectiveness	Temporal dimension	Important result
Public appeals	1-3 months	Reiss and White (2008)	Energy use	Short-run (6 months)	Public appeals for energy conservation during the California energy crisis led to a 7% reduction.
		Ito, Ida, and Tanaka (2018)	Energy use; welfare changes	Short-run (6 months)	Experimentally induced public appeals for peak energy conservation led to a 8% reduction, which fades off over repeated appeals.
Education campaigns	3-6 months	NA			
Energy audit	6-12 months	Schleich and Fleiter (2019)	Adoption rate	Long-run	Audits for small businesses increase adoption of energy-efficient technologies by 10-20 points.
		Allcott and Greenstone (2017)	Welfare changes	Medium-run	No evidence of large information gaps on the consumer side.
Energy labels on consumer technologies	12-36 months	Houde (2018)	Welfare changes	Long-run	Coarse labelling schemes have uncertain welfare effects.
		Blasch, Filippini, and Kumar (2019)	Adoption rate	Short-run	Energy and financial literacy are important mediators in the response to energy labels.
		Andor, Gerster and Sommer (2020)	Adoption rate and WTP	Long-run	Consumers value energy information beyond its economic value.
Feedback interventions	12-36 months	Khanna et al. (2021)	Energy use	Short/Long run	Meta-analysis that focuses on different information-based policies.
		Allcott and Kessler (2019)	Welfare change	Short-run	Feedback interventions induce a negative personal cost on targeted consumers.
Mandatory information disclosure	24-48 months	Myers et al. (2022)	Prices and adoption rate	Short-run	Mandatory disclosure of energy performance impacts house prices and investments in energy efficiency
		Frondel et al. (2020)	Prices	Short-run	Mandatory disclosure of energy performance impacts house prices

This selected list of papers is far from being exhaustive. Only one meta-analysis is cited. Khanna et al. (2021) review different behavioural interventions to reduce energy use, and many consist of information-based policies. There are several other, but more dated, meta-analyses on this topic (e.g. Abrahamse and Steg 2013, Delmas et al. 2013, Karlin et al. 2015, Labandeira et al. 2020). These meta-analyses show that feedback interventions are the most studied type of information-based policy in the energy context. The consensus is that such interventions can lead to small reductions in energy use of less than 5%, and there is much heterogeneity in the design of feedback and evaluation methods. As a result, the impacts vary substantially across studies.

Moreover, the cost-effectiveness and welfare effects of feedback interventions are rarely discussed. Allcott and Kessler's (2019) study is one important exception that goes as far as evaluating the full welfare effects. The authors show that such an intervention creates non-negligible personal costs for consumers. Although the feedback intervention they studied improves social welfare, focusing on the reduction of energy use alone greatly overstates the welfare effect of such policies.

Energy labels are the second most studied information-based policy (e.g. Newell and Siikamaki 2014) What is surprising, however, is that although they have occupied a central place in energy policy for the last 50 years, we are still determining how much energy such a scheme can save on average. Even less is known about their welfare effects. Houde (2018) is one of the few studies that attempt to quantify the welfare effect of such a scheme and shows that the welfare impact of energy labels is ambiguous. Because the label tends to use coarse information, this can lead to the unexpecting crowding-out of energy-efficient investments and, thus, possible welfare losses. Many studies show that energy labels impact behaviour but do not perfectly correct behavioural failures. Detailed and technical energy and financial information can be confusing to consumers (Blasch et al. 2019). Moreover, willingness to pay for energy efficiency goes beyond pure monetary savings (Houde 2018, Andor et al. 2020) due to warm-glow, biased beliefs and other behavioural phenomena.

For other types of information-based policies, we are still in the infancy of accumulating credible empirical evidence. For instance, mandatory disclosure of energy performance in the housing market, a policy that could have multi-billion dollar impacts, has been studied with credible causal frameworks only recently. Two such studies show that the policy impacts equilibrium outcomes, such as offered prices, but the overall reduction in energy use and the broader welfare effects are still to be determined. Energy audits are another policy for which we lack guidance about overall effectiveness, even though governments have widely favoured them for several decades. In some contexts, they lead to the adoption of more energy-efficient technologies (Schleich and Fleiter 2019). However, their role in correcting information failures has been questioned (Allcott and Greenstone 2017).

Finally, we know very little about public appeals and education campaigns, the first policies that are usually deployed in response to energy security concerns. To date, two studies about public appeals suggest that they can work in the short term. Education programmes are yet to be studied by economists.

ARE INFORMATION-BASED POLICIES REQUIRED TO ACHIEVE A SUCCESSFUL ENERGY TRANSITION?

The lack of comprehensive and robust empirical evidence about the effectiveness of information-based policies in the energy context should not dampen our enthusiasm about them. Based on existing market failures in energy markets, policy instruments that leverage information are clearly justified. It is, however, time to think outside the box and use the window of opportunity offered by the energy and climate crises to enable data-driven deployment of new information-based policies. There are three areas that are prime for innovative approaches that could help in the energy transition.

First, we should combine the deployment of sensors and connected devices with minimum performance standards and mandatory disclosure of energy information. In particular, automating the collection and tracking of energy usage for appliances, electronics and buildings and using that information to enforce minimum energy performance standards and labelling schemes is an obvious thing to do. Energy standards and label programmes were designed at a time when the real-time tracking of energy use was simply not possible. As a result, monitoring and enforcing these policy instruments have always been a weak point, which has contributed to a gap between expected and realised energy performance. Deploying information-tracking devices will help close this gap.

Second, the salience of energy and climate issues is at its highest in times of high energy prices and potential shortages. Now is thus the ideal time to enact targeted information and education to achieve long-term behavioural changes. Governments should experiment with such programmes and determine what works and what does not. One-size-fits-all marketing campaigns, as we have seen so far, are unlikely to be effective, especially if the crises are recurrent.

Third, price signals need to be better communicated and explained to consumers, and information-based policies have a crucial role here. Again, sensors and tracking technologies may have an essential role to display energy prices in a more salient and temporally relevant way.

All in all, the complete decarbonisation of our energy systems does not rely solely on energy labels, feedback interventions, public appeals, and education programmes. But these are strong complements to mandates and pricing schemes, which are the policy levers required for the broad systematic changes society must enact to achieve the energy transition.

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PART II
BOOSTING GREEN ENERGY SUPPLY BY DECARBONISING ELECTRICITY

CHAPTER 8

Promoting solar energy: Accounting for barriers to the transition

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There are a limited number of ways to reduce greenhouse gas (GHG) emissions at a country level. First, it can be driven by a reduction in economic activity. This solution has long been overlooked by economists, but it has recently regained interest in Europe with the concept of energy sobriety brought to the forefront by the Ukrainian war and the subsequent issues with gas provision. A second way consists in decoupling economic activity from emissions, which can only be achieved through increased energy efficiency or energy decarbonisation, once leakage is ruled out. Diversification or increasing marginal costs suggest that a mix of the solutions should probably be used. For instance, a combination of retrofitting buildings and decarbonising energy for construction is probably better in terms of cost efficiency than going for either very energy-efficient buildings using dirty energy or uninsulated buildings with decarbonised energy. Hence, the production of electricity has to be decarbonised in the near future (IPCC 2018). Nuclear, which is in the EU green taxonomy, and carbon capture and storage are under consideration. However, new nuclear with current technology may become expensive[1] and fusion is still far from a usable technology, while carbon capture and storage is still expensive and limited due to the restricted capacity for CO_2 storage (Anthonsen and Christensen 2021). One good option currently for decarbonising electricity generation is the use of renewable electricity infrastructures such as wind farms or solar PV.

Solar energy generation in particular has recently gained a lot of attention due to the sharp reduction in cost. As noted by the International Energy Agency (IEA 2020), solar PV is now one of the cheapest technologies in most countries, having become cheaper than new coal or gas-fired power plants. However, production of electricity by solar accounted for only 3% of global electricity production and around 10% of renewable electricity production at the end of 2020.[2] The low penetration of solar electricity generation despite its low cost suggests the existence of barriers to the greater diffusion of solar PV. Indeed, at least two obstacles have been identified. First, electricity from solar PV is intermittent. As a result, it is non-dispatchable and not continuously available. In some ways, the electricity generated is not of the same 'quality' as electricity provided by gas plants, for

1 See, for example, Lazard & Co's computation of the levelised cost of energy (LCOE) at www.lazard.com/media/451419/lazards-levelized-cost-of-energy-version-140.pdf
2 Source: https://www.iea.org/data-and-statistics/data-tools/renewables-data-explorer

instance. Second, solar generation infrastructure (i.e. the panels) requires critical raw materials (CRMs). Note that these two characteristics are in general shared with other renewable sources of electricity, such as wind.

The context of the Ukrainian war has made these two barriers even more acute when it comes to public policies. One might have expected that disruption to gas supply would speed up the development of renewable electricity sources like solar. However, short-run concerns over immediate dispatchable electricity provision, together with disruption to supply chains for materials, have led to policies at the European level to limit the increase in the consumer price of gas. In November 2022, the European Commission proposed an instrument that consists of a safety price ceiling of €275 on month-ahead Title Transfer Facility (TTF) derivatives.[3] As stated by Kadri Simson, Commissioner for Energy, such a measure may address "episodes of excessively high [gas] prices. [...]. The mechanism is carefully designed to be effective, while not jeopardising our security of supply, the functioning of EU energy markets and financial stability."[4] However, it is to be hoped that it will also not jeopardise the replacement of gas with renewables like solar in the longer run.

Accounting for these barriers leads to a more comprehensive cost of PV generation that is higher than the standard LCOE usually computed (e.g. Hernandez et al. 2021). In addition, it has consequences for the optimal energy transition in terms of the time path for building infrastructure, electricity consumption, and also fossil fuel phase-out. In this chapter, I examine these consequences and derive some policy recommendations for an energy transition that takes into account both solar intermittency and CRM requirements in order to properly promote solar energy.

A SIMPLE REPRESENTATION OF THE TRANSITION IN THE ELECTRICITY SECTOR

In the context of a 'carbon budget' approach, there is a long tradition of macro-dynamic partial equilibrium models a` la Hotelling that consider renewable energy as a 'backstop technology' (for early papers, see Hoel and Kverndokk 1996, Tahvonen 1997 and Chakravorty et al. 2006). In these models, renewable energy represents an abundant flow that is available with certainty but more expensive than fossil energy. The energy transition occurs because the price of the fossil fuel rises over time through a 'Hotelling effect', with the switch to the clean renewable energy occurring when this price reaches the cost of the backstop. This standard representation overlooks the fact that the relevant cost of the renewables is the cost of the investment in capacity rather than the variable operating cost, which is close to zero. Extending the approach to account for investment

3 The mechanism would be triggered automatically when both of the following conditions are met: (i) the front-month TTF derivate settlement price exceeds €275 for two weeks; and (ii) TTF prices are €58 higher than the LNG reference price for ten consecutive trading days within two weeks.

4 "Commission proposes a new EU instrument to limit excessive gas price spikes", press release, 22 November 2022.

in capacity and adjustment costs (Tsur and Zemel 2011, Amigues et al. 2015, Coulomb et al. 2018) provides a suitable framework to analyse the consequences of intermittency or CRM requirements.

Specifically, electricity may be produced with fossil fuel-fired power plants and from renewable sources, and the climate constraint imposes the need to make the transition from the former to the latter. Electricity of solar origin is assumed to be abundant and carbon-free. Its production is constrained by installed capacity, which is assumed to be small initially. Costly investment allows solar capacity to be increased, but there are no variable production costs. Fossil fuel sources are assumed to be abundant as well,[5] but they are carbon-emitting. The issue with fossil fuel extraction and consumption is not scarcity but the impact on the climate. In addition, we neglect extraction costs and assume that a large fossil capacity exists at the beginning of the planning horizon, so investment in fossil fuel-fired power plants can safely be abstracted from. Climate policy takes the form of a carbon budget that should not be exceeded in order to have a good chance of keeping the temperature increase to within 2°C. This carbon budget is consumed as fossils are burned.

Pommeret and Schubert (2022) and Pommeret et al. (2022) determine the optimal fossil phase-out, electricity mix and path of investment in solar capacity during the energy transition, while accounting for two salient characteristics in the transition towards a decarbonised electricity sector: solar generation intermittency and the use of raw materials for solar panels. Acceptability to consumers and myopia by regulators will also be introduced, as in Pommeret et al. (2022).

ACCOUNTING FOR INTERMITTENCY

Some static partial equilibrium models focus on the design of the electricity mix when intermittency is taken into account (Ambec and Crampes 2012, 2019, Helm and Mier 2019). The concept of a 'system LCOE' has also been introduced in the literature to measure the cost of a system that includes back-ups to manage intermittency. Hirth et al. (2016) argue that such a measure should be used to compare the profitability of systems based on renewables with that of systems using other sources. Another way to tackle the issue is to compute a distribution for the LCOE, as proposed by Darling et al. (2011), to account for the uncertainty associated with renewables. Finally, in Durmaz and Pommeret (2020), my co-author and I propose a levelised cost of consumed electricity (LCOCE) for a household that optimises its electricity consumption as well as grid feed-ins and electricity stored given varying electricity tariffs, weather conditions (solar irradiance) and use of smart grids. We show that accounting for intermittency reduces the cost of solar consumption for a dwelling in the UK, while it increases it for a high-rise

5 Fossil reserves are so large that in the context of climate change, their scarcity can safely be ignored (e.g. McGlade et al. 2015).

building apartment in Hong Kong. This outcome highlights the importance of computing extended costs that are location-dependent, which implies not only different weather conditions, but also different types of dwellings, consumption habits and electricity tariffs.

To focus on the transition, simulation exercises have been conducted for France based at least on one meteorological year (RTE 2021, France Strat´egie 2019). They show that flexibility costs are significantly higher in scenarios with a high share of renewable energy, driven by the need for decarbonised thermal energy and, to a lesser extent, batteries.

In Pommeret and Schubert (2022), my co-author and I handle intermittency in a very simple way by extending the model presented in the previous section. First, day and night electricity are considered two different goods because the consumer may value them differently as they are not available at the same time, and also because they are not produced with the same technology: day electricity may be produced using fossil fuels and solar, whereas night electricity cannot be produced by solar (except if stored). In addition, part of the intermittency is unpredictable: during the day, solar radiation can only be partially harnessed if there are clouds. Finally, only battery-like short-term storage is considered, which allows electricity to be stored imperfectly from day to night at no monetary cost but with a physical loss.[6]

Starting with low solar capacity, the prevailing sequence when there is only predictable intermittency is as follows. It is optimal to first use fossil fuels during the night and day, then to use fossil fuels during the night only, and finally to go for no fossil fuels at all when the carbon budget is exhausted. Due to losses, storage only begins when fossil fuels have been abandoned during the day and the solar capacity is large enough. In addition, numerical resolution of the model calibrated for Spain shows that a more stringent climate policy or technological improvements (i.e. more efficient solar panels or storage) speed up the transition but have no permanent effects, that is, the steady state remains the same. In contrast, steady-state solar capacity and electricity consumption are higher in case of a negative shock to investment costs.

Under unpredictable intermittency,[7] analytical results can only be obtained with an isoelastic utility function and a quadratic investment cost. If clouds significantly reduce solar generation, the sequence is different because the use of fossil fuels during the day is optimally abandoned at a later stage to ensure that, in the case of little or no sun, day electricity consumption can be satisfied. To compensate for the smaller quantity of fossil fuel-based electricity left available for night, a portion of day electricity production by solar panels is stored despite the loss. However, if the cloud problem is not too bad, the optimal solution does not significantly differ from that without unpredictable intermittency in

6 We only allow for intra-day storage. This restricts its usefulness to tackle intermittency since storage cannot be used as insurance against clouds the next day.

7 Though accounting for the fact that the weather will be uncertain, the dynamics of storage, solar panel accumulation and electricity consumptions are chosen once and for all at the beginning of the programme.

the sense that it is characterised by the same sequence of phases. Numerically solving the model shows that this latter case prevails in Spain, where unpredictable intermittency does not have a large welfare cost (agents would only need to be compensated 1.5% of their consumption each period). This relatively innocuous impact is consistent with the empirical findings of Gowrisankaran et al. (2016) for large-scale solar energy in the southeast of Arizona, where unpredictable intermittency represents less than 5% of the social cost of generating one fifth of electricity with solar.

Some results contribute to the current debate on the back-ups that are necessary when intermittent renewable energy develops. First, once the electricity sector is decarbonised, we obtain that unpredictable intermittency requires a larger capacity for solar electricity generation (i.e. in some sense, overcapacity). Second, numerical resolution for Spain shows that less thermal capacity needs to be maintained, though for a longer time.

ACCOUNTING FOR CRITICAL RAW MATERIALS

A 2021 report from the IEA, *The Role of Critical Minerals in Clean Energy Transitions*, stresses that an energy system powered by clean energy technologies needs significantly more minerals – notably copper, silicon and silver – for solar PV, as well as lithium for the batteries needed for backup. Even if there is currently no shortage of mineral resources, recent price rises for copper and lithium highlight how supply could struggle to keep pace with the world's climate ambitions. In the same report, the IEA suggests, as part of its plan for action, that policymakers must reduce the risk of price volatility and supply disruption, scale up recycling, and promote technology innovation at all points along the chain value.

In France, a plan for programming mineral resources for the low-carbon transition[8] considered four major families of-low carbon technologies, including solar PV (and stationary storage), and compared, for the technologies that could potentially be mature within ten years, the mineral resources they use. The findings suggest that silver (which is mobilised significantly in PV crystalline technologies) and cobalt (for batteries) are both crucial for the energy transition and characterised by geological scarcity and/or geopolitical risk. However, the 2020 French framework law for long-term energy policy does not explicitly account for CRMs embodied in the equipment and infrastructure for renewable electricity generation and storage, although recycling is mentioned (Ministère de l'Écologie 2020: 185).

Considering CRMs in the energy transition first introduces an additional exhaustibility constraint on top of the carbon budget. In some sense, there has been a transfer of the issue of scarcity in the environmental economics literature over time. The issue first appeared with exhaustible fossil fuels in the 1970s, which constrained growth. This was

8 Details at www.ecologie.gouv.fr/productivite-des-ressources#%23scroll-nav__3 (in French).

followed in the 2000s and 2010s by the climate change issue, modelled as a carbon budget – hence, carbon exhaustibility – which puts a stronger constraint on the economy than fossil fuel exhaustion in the sense that burning all available fossil fuels would make it impossible to meet the carbon budget (McGlade and Ekins 2015). The constraint on fossil fuels became obsolete in some sense, and the one on carbon emissions may not prevent growth thanks to renewable energy. In the 2020s, however, we now face an exhaustible resources issue that constrains the development of infrastructure for renewables, and hence growth.

Second, consideration of CRMs has non-trivial and policy-relevant implications for the energy transition, in particular once the possibility of recycling is accounted for. For instance, as argued in Fabre et al. (2020), it is crucial to consider the asymmetry between minerals that can be recycled and fossil fuel resources that cannot. This asymmetry implies that investment in infrastructure to generate renewable electricity should be brought forward, in order to boost the flow of secondary resources to be recycled. The implications of the relative material intensity of renewable energy production for climate policy are studied in Chazel et al. (2020). The authors adapt the simplified integrated assessment model of Golosov et al. (2014) and apply it to the case of copper by assuming that complete recycling is feasible and optimal in the long run, such that the entire cumulative production of primary minerals can ultimately be recovered and recycled. They find that the mineral constraint significantly hinders the development of renewables in the long run, with 50% less renewable energy production at the 50–60-year horizon.

In Pommeret et al. (2022), my co-authors and I extend the model presented above to consider the case where the distinguishing feature of solar infrastructure is its intensity in mineral inputs, as in Fabre et al. (2020), but we assume the existence of a backstop technology allowing a sustainable consumption level to be maintained such that neither the exhaustibility of fossil fuels nor climate change constitutes a physical limit to consumption growth. In addition, we characterise the optimal dynamic choice of the rate at which the depreciated share of green capital is recycled. Finally, we assume that the carbon budget is met before CRMs are exhausted.[9]

We find that more abundant minerals contributes to increasing energy consumption mostly in the future, while a less-stringent carbon budget tends to increase consumption relatively more early on. Moreover, recycling has implications for several features of the energy transition, including the timing of the adoption of the backstop solution and momentum in investment in green capital right before this time. We show that it is optimal to use minerals intensively to build up a large green capital stock just before switching to the backstop input.

9 Another succession of phases can be studied using the same methodology.

In addition, we introduce some close-to-real-world climate policy in a decentralised setting, consisting of, first, a fixed carbon tax whose proceeds fund a feed-in premium for electricity produced from renewable sources, consistent with policies implemented widely across the world to stimulate the fossil phase-out and the production of electricity from renewable sources of energy. Second, we consider a myopic regulator who sets, once and for all, these policy instruments without taking into account the scarcity of minerals. Consistent with the intuition, if the regulator does not take into account the need for non-renewable mineral resources to build up the infrastructure for the energy transition, the carbon budget will not be satisfied, and the date of fossil fuel phase-out is later than planned. Moreover, such a constrained policy requires a relatively high initial carbon tax for the tax revenues to finance the subsidies. This points to the difficulty of simultaneously pursuing the objectives of climate mitigation and policy acceptability.

CONCLUSION

Accounting for barriers such as solar intermittency, scarcity of the CRMs needed for solar panels, regulator myopia and consumer acceptability significantly affects the dynamics of the fossil fuel phase-out and renewables development. In fact, it could even jeopardise the transition itself. The 2018 '*gilets jaunes*' movement in France showed that acceptability is a must for the transition to happen. More recently, the gas crisis has shed new light on the importance of the intermittency issue. The fact that backup for intermittent renewables is currently limited somewhat to gas is used as an argument to abandon the development of solar as a means to end reliance on gas imported from Russia.

Together with our results, this calls for accounting for these existing barriers when designing public policy, which could be done immediately. Next, removing these barriers should be on the short-term agenda. This would require technological progress, but also industrial policies to support it.

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CHAPTER 9

Decarbonisation and regulation of the electricity sector in Europe

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The amount of carbon dioxide emitted in the production of 1 kWh of electricity has fallen by 54% in the EU since 1990. However, the electricity sector remains the main emitter of CO_2 (29%), along with transport. In order to achieve the 2050 climate neutrality objectives set out in the 2021 European Climate Law, the 'Fit for 55' package plans an accelerated reduction in the cap of the European carbon market (the EU Emissions Trading System, or EU ETS) and an important increase in the share of renewable energies in gross final energy consumption. Electricity is directly concerned by these two objectives.

The decarbonisation of this sector is all the more important as electrifying transport, heating and industry increases demand for electricity but reduces the carbon footprint. Moreover, following the energy crisis caused by the invasion of Ukraine by Russia, it was decided to further accelerate the transition to clean energy. Thus, the REPowerEU Plan aims to stimulate investment in renewable energies and to make Europe independent of Russian fossil fuels.

The dynamics to achieve the objectives appear extremely ambitious and raise complex questions about financing, the impacts on the different economic agents – producers and consumers – and, above all, ensuring security of supply in all its dimensions. The considerations about a reform of the European electricity market that are beginning in this context will be faced with acute trade-offs to reconcile affordability, security and sustainability. However, these can be alleviated if environmental regulations and the market design of the sector are well coordinated. In this chapter, I consider first the way two forms of electricity market regulation – liberalisation and the introduction of renewables – have interacted in the past, then questions raised by the energy crisis, and finally the role of the wholesale power market.

HIGHLY SEPARATED REGULATIONS SO FAR

The liberalisation of the electricity market and the introduction of renewables in the generation mix both took off at the end of the 1990s. The reduction of emissions from the electricity sector had been recognised as a priority since the Rio Convention in 1992, so that in France, for example, the implementation of a first plan for wind power began in 1996. The new regulatory design for the electricity sector stems from the same period.

However, the two processes were seen as falling under separate or even conflicting agendas, with environmentalists fearing that the liberalisation of the market would lead to increased energy demand.

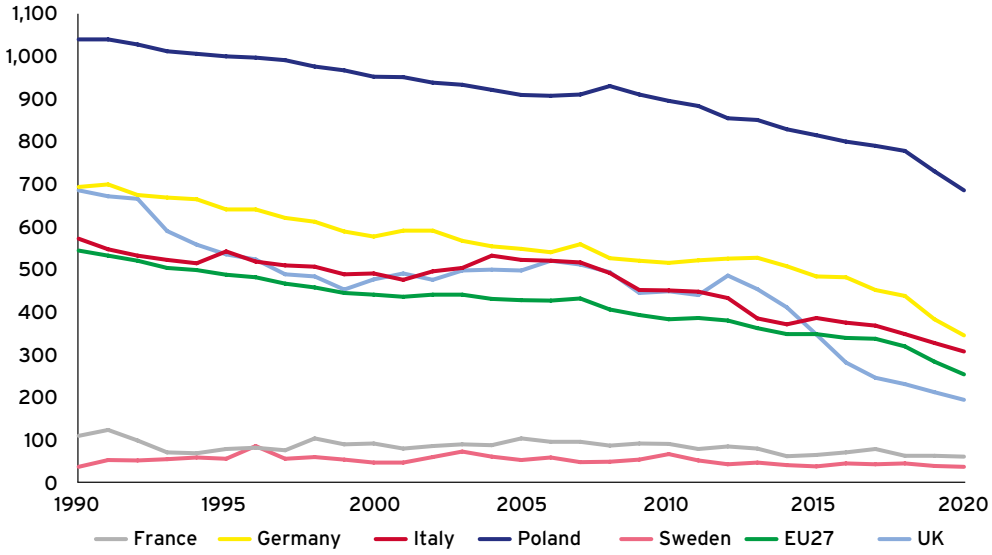
Indeed, the goals set within renewable energy regulations have been decided mainly on the basis of technical assessments of accessible potentials, not by means of economic evaluations of what should be the optimal mix of technologies, taking into account the balance between their costs and their climate benefits. In addition, the use of feed-in tariffs has often been favoured, disconnecting the remuneration of these investments from the value of the electricity produced. The development of electric renewables was thus essentially conceived independently of the functioning of the electricity market.

Admittedly, both types of regulations have since been improved and brought closer together. On the environmental side, the establishment of the European carbon market (the EU ETS), with the electricity sector as its main player, was the most striking innovation. However, its price remained weak until 2020, at below €25/tCO2. On the side of electricity regulation, the development of capacity mechanisms has supplemented short-term wholesale markets to provide generation adequacy at peak hours. In addition, since 2015 the use of auctions, associated with conditional premiums in the framework of contracts for differences (CfDs) compensating for the deviations between effective market prices and strike prices guaranteed by the contract, has become standard for the introduction of all new large-scale renewable capacities. The implementation of renewables policy is thus more in line with the functioning of the electricity market (Newbery 2016). However, the fundamental principle of a command-and-control approach has persisted. Above all, both regulations remain as controversial as ever, despite these improvements.

Debates around renewables policies have focused on their direct and indirect costs. While the cost reduction of these technologies has been massive, the impact of their deployment on public finances and on imports is never negligible (Gollier and Tirole 2015). In addition, their net performance depends on the type of equipment that is phased-out – coal, gas or nuclear (already decarbonised). Figure 1 shows the heterogeneity of situations in Europe in this respect.

Transmission system operators also highlight the costs resulting from the intermittency of these energy sources. These costs increase sharply according to their penetration rate (Crassous and Roques 2014) because connecting decentralised energies requires additional network investments as well as backups or storage devices to ensure security of supply. Moreover, the day-to-day management of power plants induces additional ramping costs to manage faster increases or decreases of load.

FIGURE 1 CO_2 EMISSIONS FOR THE PRODUCTION OF 1 KWH IN EUROPE (g CO_2/kWH)



Source: Ministère de la Transition écologique (2022).

Initially, the controversies concerning market design centred on the organisation of the wholesale market and its short-term functioning between two polar designs: mandatory pool organising a centralised auction mechanism, and bilateral contracts supplemented by different reserve markets. This choice is complex, as many arguments must be taken into account: *technical*, concerning dispatching and network balancing; *economic*, in particular the risk of excessive market power; and *institutional*, to make the market work at European level. Consequently, debates cannot be settled definitively. However, it is generally admitted that, if not optimal, the existing market design works in technical terms, the demand being satisfied at each instant and using power stations in merit order.

The major problem from the perspective of the full decarbonisation of the sector is that this merit order only reflects the private costs that producers bear, which differ considerably from the social costs that should be taken into account (Samadi 2017). Without internalising the costs of climate change at the correct level – and more generally, all external, environmental, intermittency and learning curve costs – and ensuring that discount rates and risk premiums do not bias equipment choices, cost minimisation achieved by the wholesale markets is only partial and potentially illusory. The problem is not theoretical: in the absence of a sufficient carbon price, we experienced a return to coal in Europe during the 2010s, contrary to what would have been desirable for decarbonisation. Incidentally, this reminds us that while well-designed subsidies for each tonne of carbon avoided could constitute a substitute for carbon pricing for implementing renewables, the latter remains essential to guide the evolution of the power generation mix.

Moreover, in general, the efficiency of spot markets is not sufficient, since this sector exhibits important specificities: it provides non-storable services, the demand for which is random and varies at every moment, using very (and increasingly) capital-intensive equipment. All market players are therefore faced with significant risks at all horizons, from the volatility of their short-term costs and revenues to the uncertainty over the returns on investments whose maturity is exceptionally long. It was thus pointed out from the outset that the wholesale market would not be enough to deliver the desired long-term outcome (Bouttes and Trochet 2004). The 2022 crisis leads us to revisit these questions, which had initially been postponed in a context of overcapacity, moderate fossil prices and a less acute climatic emergency.

SECURITY OF SUPPLY ISSUES ON THE FOREFRONT AGAIN

First, the current energy crisis has raised awareness that dispatchable equipment will remain essential for the functioning of the sector in the medium term, in the absence of suitable electricity storage devices. Hence, REPowerEU recognises the need for alternative supplies of gas.

Moreover, the possibility of power cuts and the surge in prices have revealed to the public that secure and affordable access to electricity is much less ensured than imagined. In this respect, many European countries are going to be faced with major needs of renewing their power systems which, if delayed, could lead to major tensions. In the French context, two reports from the country's transmission system operator, drawn up just before the crisis, illustrate the issue.

RTE's 2021 report on medium-term perspectives (RTE 2022a) highlights low margins during several years, due both to nuclear maintenance operations and accumulated delays on all new capacities. In addition, it is pointed out that the improvement of security of supply depends crucially on increased demand-side management and new interconnections, and on the use of the capacity mechanism to keep sufficient dispatchable power.

Above all, RTE's report on carbon neutral pathways to 2050 (RTE 2022b) underlines that energy efficiency is key to reaching climate targets and that carbon neutrality cannot be achieved without significant renewables development. But the feasibility of scenarios relying on renewables is questioned given the pace of deployment required, backup needs and the risks of generating excessive pressures on the artificialisation of land or tensions around mineral resources. The power grids must also be upgraded rapidly to make this transition possible and, to manage fluctuations, it will be necessary to develop hydropower storage as well as install batteries to support solar power.

As the scenarios become very expensive when moving towards 100% renewables, building new nuclear reactors is considered relevant from an economic point of view. In any case, the complete cost of the French electricity system would increase significantly, by between 33% and 75% depending on the scenario.

The good news is that the UK, which faced significant power investment needs earlier, has renewed its toolkit to meet these challenges, combining:

- auctions to guide the evolution of the power fleet in the desirable direction while preserving competition;
- CfDs to limit excessive risk premiums required on long-term projects; and
- a carbon floor price, to make carbon policies credible and thus secure the remuneration of greener projects (econometric studies suggest that the spectacular drop in British unit emissions costs highlighted in Figure 1 is attributable to this instrument, see Leroutier 2022).

WHAT ROLE FOR THE WHOLESALE MARKET IN THIS NEW CONTEXT?

The wholesale market is fiercely controversial today. Indeed, it is the setting of prices at the level of the variable costs of the marginal power equipment that determined the pass-through from gas prices to electricity prices in 2022. The most radical proposal is for a decoupling of final prices from wholesale prices. However, wholesale prices reflect the opportunity cost of electricity at each moment. It is absolutely undesirable to hide this while demand management is recognised as a priority. In addition to providing the relevant signal to guide producers and consumers in the short term, it is also valuable for investment choices and their funding. For example, producers must compare the additional costs associated with switching to more capital-intensive plants and the additional infra-marginal rents that they can expect, which reflect the net value of the electricity provided.

However, wholesale markets are efficient only in 'normal times'. In the tightest situations, instantaneous price adjustment is neither possible nor acceptable, because it would lead to extreme price levels, reflecting the limits of short-term demand response abilities. Consequently, the infra-marginal rents are structurally insufficient to finance capacities ('missing money', see Joskow 2008). Moreover, the fact that the wholesale market provides incentives for correcting any imbalances in the generation fleet does not guarantee convergence towards the optimal long-term fleet, at horizons marked by huge economic, technological and regulatory uncertainties.

Finally, the needs of producers and consumers to hedge price volatility impacts on their revenues or bills must be met. Otherwise, the benefits of market unification can be evanescent or even negative (Newbery and Stiglitz 1984). That is why price caps (or 'tariff shields') for the most vulnerable households or firms have proven to be unavoidable in 2022. But the corresponding mechanisms, which have been implemented

in an emergency, are contradictory to efficient demand management. Insurance schemes established ex ante would be better. Futures and contracts between the various players of the market can be mobilised for this purpose.

In particular, retail pricing must be designed to reflect the combination of different services, of energy supply but also network and capacities, as well as the price of risk embedded in the contracts. This latter dimension implies that, compared to volatile spot prices, paying less in some situations is compensated by a higher price in others and that the price of this risk transfer is paid.

Not only should such contractual arrangements not be ruled out in principle on the grounds that they could constitute barriers to entry, but it is also important to ensure that essential hedging instruments are in place. However, their design must limit this risk, and preserve the marginal price signal. This latter problem does not arise for renewables CfDs because their variable cost is zero. In general, this requires that the compensations are established on the basis of predefined subscribed volumes.

France was a pioneer in the application of a marginalist approach to electricity, according to the principles developed by Marcel Boiteux. However, the building of retail prices included a specific transformation step for the definition of pricing periods. Above all, their basis was not the structure of observed instantaneous marginal costs but rather that which would have prevailed with an optimised fleet structure (a long-term marginalist approach), which was considered more relevant for guiding consumers' choices of their electrical equipment. Thus, the planning of the power mix was a preliminary and structural step, which the existing wholesale market does not produce. Proposals for so-called hybrid markets draw on similar analysis, with the new complexity resulting from intermittency (Joskow 2019).

CONCLUSION

The energy crisis has not revealed a fundamental misdesign of the wholesale electricity markets in Europe but rather the lack of hedging instruments against their volatility and the need to guide long-term investment decisions. However, the economic efficiency of these markets requires an effective carbon price as close as possible to its social cost.

Given the structural nature of the decarbonisation objective for the electricity sector, the alignment of the objectives of the two branches of regulation – environmental and market design – has become essential and the externalities between the two must be recognised. The definition of a common reference value for the social cost of carbon is a prerequisite, because such a complex system cannot be driven without this compass.

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CHAPTER 10

Challenges for retail electricity

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To reach the goal of net zero emissions by 2050, the production of electricity should nearly triple, with three-quarters of the output coming from renewables (IEA 2022). We expect electricity to be used in all our daily applications, even though most of it will be produced from uncontrollable sources (mainly photovoltaic and wind). Given the limited storage capacity of electric power, consumers will have to adapt to the natural variations of renewable sources, and energy retailers will have a key role to play in this. They shall provide consumers with affordable and secure electric power, which necessitates some changes in their business model, from the mere marketing of a commodity to the provision of essential energy services.

In Section 1 of this chapter, I recall the current organisation of the electricity industry based on vertical unbundling. Section 2 explains why electricity is the ideal candidate to meet our growing need for clean energy. In Section 3, I characterise the various degrees of dependence of retail tariffs on spot prices. In Section 4, I explain that the promotion of real-time pricing rather than flat prices has undesirable regressive effects. Section 5 is devoted to the need for stable commitments to share the surplus and risks in the provision of electric energy to a poorly price-responsive demand. In Section 6, I recall that perfect competition in retail facing heterogeneous consumers entails negative redistribution, with high-income consumers paying less per kWh than poor households. In section 7, I sketch some improvements that would secure the provision of electricity without losing social efficiency. I conclude in Section 8.

1 FROM PRODUCTION TO RETAIL

In countries where the electricity industry was liberalised at the end of the 20th century, the natural monopolies of transmission and distribution are separated from production and sales, two activities that can be organised through market mechanisms. This vertical unbundling eases the entry of new operators, who can access the grid without paying undue fees to the incumbent. A collateral advantage is that entrants are not obliged to be both producers and sellers to final clients. Companies with technical expertise may enter only the upstream segment of the industry and sell their output either by contract to large consumers and retailers or on a spot market. Symmetrically, those with marketing expertise may enter downstream only, and buy energy either through bilateral agreements or on the spot before selling to final customers. In France, as of 30 June 2022,

some 50 companies offer retail electricity, not necessarily to all types of consumers (CRE 2022). The incumbents are still providing 27% of total consumption at regulated tariffs. They have signed commercial contracts for a 29% market share and newcomers have won the remaining 44%.

To address the 2021–2022 energy crisis in Europe, many economists and policymakers have promoted structural reforms of the wholesale electricity market. They have blamed the wholesale market for skyrocketing prices (not so long ago, the crime was to post negative prices), subordinating electricity to natural gas fickleness, and providing non-thermal producers with unearned windfall profits (e.g. von der Leyen 2022). In fact, energy wholesale markets are just doing the job they were designed for, that is, balancing supply and demand in real time and sending quantitative signals on scarcity or abundance (aka prices). The real problem is downwards in the value chain, namely, in the retail market (Poudineh 2019). Indeed, except for large industrial and business customers, consumers are unable to react to prices that vary from one hour to the next, whereas they need electric power throughout the day and night.

Until recently, in all countries with a liberalised power industry, policymakers considered that an efficient retail market was a place with many entrants proposing a variety of contracts, with consumers switching from a supplier to another one to take advantage of better commercial offers (e.g. European Commission 2021). This view can be relevant under regular circumstances. But exogenous shocks like the 2021 Texan winter[1] and the 2022 Russian aggression against Ukraine[2] have acted as eye-openers to the need to revise this way of thinking.

2 THE PROS AND CONS OF ELECTRICITY

All energy sources are intermediary goods that necessitate dedicated equipment to provide services such as heating, cooking, transporting, lightening, entertaining, and so on. Consequently, energy consumers are physically dependent on their transformation equipment. For a given service, switching from one source to another one can be very costly (for example, for heating), if not impossible (for example, for entertaining). Electricity has two disadvantages compared with the other forms of energy: it is a secondary energy that necessitates the potentially polluting transformation of a primary energy, and it is not storable at large scale. But it has two advantages that explain its success: it is multi-task, and it is clean at the consumption location. It follows that electricity is ubiquitous in developed countries, and conditional on being produced from non-polluting primary energy sources, it is now viewed as the energy of the future. If it was once a commodity competing against other energies, it is now an essential good. As a

1 https://www.tse-fr.eu/winter-texas
2 https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=uriserv:OJ.CI.2022.131.01.0001.01.ENG

result, the way it is made available to final users must be scrutinised not only through the lens of competition policy, but also taking into account social concerns and behavioural failings, without forgetting the rules of financial regulation.

3 PERMANENT VERSUS SPORADIC EXPOSURE TO SPOT PRICES

In the liberalisation process of the electricity industry, it has been considered that all consumers, including households, could play an important role (Joskow and Wolfram 2012). This was one of the European Commission's mantras with its "Empowering electricity consumers" campaign (Crampes and Waddams, 2017). In some countries, notably Spain, dynamic pricing – that is, billing consumers at the spot market price – has been instituted as the default pricing contract. Those who want a more stable contract have to opt out. In reality, because of a strong 'default effect' consumers do not switch, even though opting out simply involves a phone call or a click towards a website (Fowlie et al. 2021).

Alternatives to real-time pricing (RTP) are not limited to a flat rate re-evaluated once a year. There exist softer forms of dependency on spot prices than strict proportionality (e.g. Astier and Léautier 2021, Andrey and Haurie 2013). With time of use (TOU), the contract specifies ex ante a handful of time periods where prices per kWh will be lower or higher than the regular one. This family of tariffs can only reflect variations in net supply that are predictable well in advance. Under critical peak pricing (CPP), a default constant price is set for all hours except a limited number of hours per year, chosen ex post, during which the price is set at a much higher level; this level can be fixed ex ante or depend on the state of nature. With peak-time rebates (PTR), customers receive a financial reward if they decrease their consumption below a counterfactual baseline. This works as if consumers were reselling electricity. In a load-shedding contract, power companies reduce electricity consumption by switching off supply to voluntary customers in case of systemic risk, and the consumer who signed this contract is compensated. This differs from PTR in that switching off/on is not decided by the consumer – it is a decision of the distribution company, the energy supplier or a third-party equipped with remote control. It is one form of priority service – a contract where the quality of the good is represented by the probability of being served.

We see that retailers can propose to consumers a menu of contracts and each consumer can select the one that better fits her/his needs. However, behavioural economics show that there are many biases in this decision process, and there is a high chance the consumers will make a wrong decision (EIA 2014).

4 REGRESSIVE EFFECTS OF REAL TIME PRICING

Given that electricity cannot be stored, full exposure of rational users to wholesale prices is the most efficient way to tackle scarcity. However, even though consumers adjust their consumption pattern to spot prices, the outcome can be socially undesirable. Indeed, in a system where the energy part of the retail price does not vary over time, this component is an average computed to balance the accounts of the operators. Therefore, it is higher than the wholesale price during off-peak hours, and lower at peak hours. Thus, compared to the cost of the system reflected by the wholesale price, when the retail price is time-invariant, households that consume large quantities during off-peak hours subsidise those that consume large quantities during peak hours. Imposing real-time pricing as the default system reverses this redistribution. By using Spanish data, Cahana et al. (2022) show that RTP is regressive, i.e. it increases the bill of low-income consumers and decreases that of high-income consumers. Regressivity is statistically established by identifying the relationship between daily consumption patterns and income, using data on the regional distribution of income by zip code and econometrics to allocate each household to a particular income distribution. Air conditioning and electric heating are the main explanation for this undesirable regressivity. Indeed, there are strong differences in spot prices between summer and winter, but this opens no opportunity for consumption shifts from one season to the other. By contrast, price variations are weaker across a day, where one can for instance shift the start of the washing machine by a few hours or even a day. Then there are opportunities of gains from adapting to price signals, but they are tiny. Now, note that air conditioning is mainly used by high-income households and of course in the summer, when spot prices are low. For many low-income households, electricity is the source of heating during the winter, when high demand pushes up wholesale prices. Thus, with the generalised switch from an annual flat price to real-time pricing, low-income earners lose and high-income earners gain. From a pure fairness point of view, retailers should not encourage poor households to enter into contracts indexed on wholesale prices.

5 THE NEED FOR STABLE ARRANGEMENTS

In an industry where (i) the product is not storable, (ii) production and consumption necessitate specific equipment, and (iii) demand and supply are highly variable in a non-correlated way, social efficiency calls for contracts with clauses fixing surplus and risk sharing, and a duration sufficient to encourage investments. Retail electricity is a business that does not require costly equipment. However, being the middleman between the producer and the consumer, the retailer must be able to withstand random shocks from both sides. The danger of this position has been demonstrated by the recent rise in the price of natural gas and the ensuing rise in the electricity spot price. During

2022, some 30 energy suppliers (electricity and/or gas) went bankrupt in the UK, and the regulator (Ofgem) had to organise the reassignment of their 2 million customers to other companies.

The UK safety net protects consumers, but it does not stop retailers from going bust. In France, thanks to a mechanism named 'Regulated Access to Incumbent Nuclear Electricity' (*Accès Régulé à l'Electricité Nucléaire Historique*, or ARENH), both consumers and retailers are partially protected against spot perturbations. ARENH is a regulated mechanism aimed at promoting competition in retail electricity by creating a level playing field for suppliers, who can purchase a capped quantity of nuclear energy from EDF, the incumbent company, at a price fixed by the government (currently 42€/MWh). They are only constrained in their individual demand (each can ask no more than its market share in retail) and the total demand of ARENH energy (there is a 100 TWh yearly cap, increased to 120 TWh for 2022); additionally, they are not allowed to sell abroad. This means that retailers receive for free a call option on nuclear energy, and they do not hesitate to exercise it. They play opportunistically with the mechanism,[3] buying up to the cap when the spot price is higher than the ARENH price and zero in the opposite case. Their exposure to spot risks is limited to the difference between their commitment with clients and the quantity they obtain through the ARENH mechanism. If they sign sale contracts indexed on spot prices, they are fully insured against wholesale risks. In contrast, they bear the price risk if their clients hold fixed-price contracts. The French regulator suggests that retailers should be obliged "*... by means of a prudential strategy, to secure a proportion of their fixed price offers with products covering the same maturities on the wholesale markets*" (CRE 2021).[4]

Consumers can choose to sign a fixed-price contract with a retailer to be protected against price risk and rely on some form of public safety net to prevent supply interruptions. Large consumers can also bypass retailers and sign power purchase agreements with electricity generators. These bilateral contracts have a duration of 10 to 15 years. They are mainly viewed as a solution to the producer's need for secure funds, in particular for operators who want to invest in renewable energies. They also allow large consumers to hedge against market prices, leaving them with a residual risk on quantities, inherent to the intermittency of renewable sources.

3 https://www.tse-fr.eu/regulated-access-incumbent-nuclear-electricity
4 On the necessity of risk hedging, see also Pollitt et al. (2022: Part B), European Commission (2022) and Wolak and Hardman (2021).

6 PRICE DISCRIMINATION

Fairness is not the first concern of retailers. As private firms, they are motivated by profits, which means locking customers in to contracts with high prices. Competition could prevent that, but depending on their age, location or education, not all consumers are able to make an objective judgement on commercial offers. How much freedom can sellers be given in their pricing policy?

In 2009, Ofgem imposed a non-discrimination clause on large retailers in the UK energy market. The Standard Licence Condition 25A was introduced to prevent suppliers from charging their incumbent customers higher prices than their out-of-area customers. Three years later, Ofgem decided not to renew the ban, apparently because prohibiting spatial price discrimination had eventually led to competition weakening. Whether price discrimination is good or bad for efficiency is very dependent on demand characteristics (Crampes and Laffont 2016). Unfortunately, it is indisputably bad for equity because it is done to the detriment of poor households.

Kahn-Lang (2022) uses zip code information on household revenues to show that in Baltimore in the US state of Maryland, consumers pay different prices for electricity in the same market, with low-income households and marginalised communities paying systematically higher electricity prices than their higher-income counterparts. Why does competition in a homogeneous product like electricity lead to regressive pricing? The main reason is behavioural. The least wealthy households do not monitor the evolution of their bill due to lack of time and/or education. They are insufficiently attentive to the opportunities offered by the market. Sellers often propose a contract with a low introductory price and do not mention tacit renewal clauses with upward price adjustments. After a few months, signatories might switch to a new, more profitable contract, but they do so with delay because they pay no attention to market conditions. The Baltimore study highlights the consequence of this procrastination (Heidhues et al. 2021): there is a positive relationship between the price charged and the age of the contract.

Why do the wealthiest households escape this increase? The explanation is both cultural and demographic. Wealthy households find out about sales conditions and eventually change supplier online. Their contracts are better adjusted to the opportunities offered by the market, and they escape the insistence of door-to-door salesmen. Moreover, because of the higher population density in poorer neighbourhoods, it is cheaper to go door-to-door there than in richer neighbourhoods. These distributional impacts might worsen in the future with the broader adoption of smart technologies by high-income groups.

7 OF BOLTS AND NUDGES

Spot prices are not sufficiently informational to guide consumers, except very large ones that have an incentive to keep control on their energy bill (for example, factories, hospitals and supermarkets). How could the wellbeing of small consumers be improved? An extreme view is that they will never have time or motivation to observe wholesale prices and adapt their withdrawal of electricity based on this observation. The main reason is that electricity is not a final good, just an intermediary good that we use for cooking, heating and so on. Since most small consumers have no idea about the number of kWh necessary for cooking food or drying clothes, they should not be considered as rational agents. Retailers or independent firms should act as energy architects and provide global services, not just kilowatt hours. It is like a 'hotel room' model: when a traveller rents a room in an hotel, the object of the transaction is 'one night', without having to negotiate about the number of electric bulbs, gallons of hot water, sheets, blankets, and so on. What the consumer is expecting from the service provider is an indoor comfortable temperature, some fresh beers, hours of TV programmes and so on. Delegated load-shedding programmes belong to this family of solutions (Crampes and Léautier 2015).

The main drawback of delegation mechanisms is that consumers lose some freedom of daily choice. A less drastic solution is to enable the consumer with some pieces of hardware or software. There is an increasing range of e-appliances, WiFi enabled plugs and in-house routers with which the consumer can programme and/or remotely control the on/off command of indoor equipment (Bollinger and Hartmann 2018, Wolak and Hardman 2022). Furthermore, for households that can afford it, battery storage, rooftop solar and electric vehicles provide both incentives and opportunities for enhanced energy management by consumers.

Instead of control hardware, behavioural economics suggest that nudges can be helpful (Ruokamo et al. 2022). Informational nudges make the consequences of electricity consumption decisions more visible by households and help them in energy saving. Nudges can be delivered through colour-changing light bulbs when the contract is of the CPP or PTR type. Warning messages can be delivered through SMS. Suppliers can also send individualised home energy reports to show how consumption compares to that of neighbours, and targeted recommendations on how to save energy.

8 CONCLUSION

The retail market, and more particularly the market for residential consumers, is the weakest link in the liberalised electricity industry, as retailers trade with poorly informed agents who are unable to adapt their consumption to rapid price fluctuations. The recent price increases on wholesale markets will have an adverse effect on consumer engagement

in real-time pricing. Most consumers will feel more comfortable with flat prices and regulated electricity tariffs. It is likely that the European authorities will reconsider their policy of encouraging real-time electricity pricing (Art. 11 of Directive (EU) 2019/944).

As electricity has become an essential good in developed countries, the mission of retailers must be reinvented. In the traditional model of transferring energy from producers to consumers and money in the opposite direction, the physical part is actually done by distributors, and they also control smart meters. The main role of the retailer should be to transform erratic spot prices into final prices with little fluctuation and to assist its customers in satisfying their energy needs. To make this activity efficient, energy suppliers and ITC firms must identify behavioural hurdles and innovate beyond the meter. On the regulation side, standard competition policy is not sufficient. Layers of financial regulation must be added, such as prudential requirements and stress testing to evaluate the resilience of each seller and the capacity of the group to recover after systemic shocks without public subsidies (Ofgem 2022).

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CHAPTER 11

Assessing the scientific impact of sustainable development, climate change and biodiversity projects in the Horizon 2020 programme

Phoebe Koundouri, Haris Papageorgiou and Conrad Landis[1]

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1 INTRODUCTION

Sustainable development, climate change and biodiversity constitute a major component of the European Union's Horizon 2020 programme, with climate action and sustainable development listed as the key objectives of the programme. The regulation of Horizon 2020 requires the tracking and the reporting of its expenditure, and at least 35% of the programme's total budget is expected to address climate action, while at least 60% is expected to involve sustainable development (no target was set for biodiversity).

The so-called 'Rio markers', which were developed by the OECD, have been adapted by the Directorate-General for Climate Action (DG CLIMA) and the Directorate-General for Environment (DG ENV) and adopted as the tracking methodology to support this cross-cutting issue. The flagging mechanism is applied at both the topic and project level. There are three possible values (or scores) for the Rio markers, indicating whether the Rio Convention themes are not targeted (0), a significant objective (1) or a principal objective (2) of the action. The values are attributed according to the extent to which the themes are explicitly addressed at the level of problem analysis (context), objectives and results, and activities. The values attributed are used to determine the fixed percentages of the overall budget for the Horizon 2020 project that are considered appropriate for each theme. The EU has decided to use 0%, 40% and 100%, respectively.

1 This chapter presents results included in Naujokaityte et al. (2023). The chapter is a synopsis of a paper titled "An evaluation of Sustainable Development, Climate Change and Biodiversity as a cross cutting issue in H2020 program" (Koundouri et al. 2023).

Progress in addressing this cross-cutting issue is monitored through three key performance indicators:

- KIP1: The percentage of the EU financial contribution that is allocated to climate change
- KIP2: The percentage of the EU financial contribution that is allocated to sustainable development
- KPI3: The percentage of EU financial contribution that is allocated to biodiversity

In this chapter, we revisit the state of play, the tracking and the monitoring process with the aim of providing insights into the efficiency of the processes along the policy cycle. We propose and partially unfold a new flagging, review and monitoring approach that addresses the needs and the inefficient processes for facilitating the assessment of sustainable development, climate change and biodiversity as a cross-cutting issue. Finally, we report on the effectiveness of the policy intentions regarding this cross-cutting issue and present findings on the remarkable performance of sustainable development, climate change and biodiversity projects in terms of scientific impact.

2 METHODOLOGY

To evaluate the cross-cutting issue of sustainable development, climate change and biodiversity (or SDCCBD) in Horizon 2020, we explore the state of play, the relevance, the efficiency and the effectiveness of SDCCBD. Our methodology encompasses desk research and a literature review, four interviews with European Commission officials and beneficiaries, as well as data-driven analysis of SDCCBD based on Horizon 2020 outputs (i.e. publications) and other Commission administrative and monitoring data provided.[2]

3 EMPIRICAL RESULTS

State of play

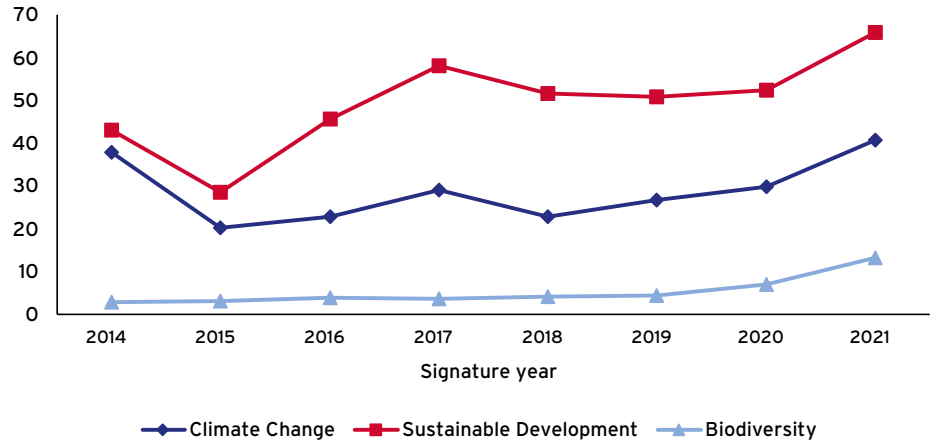
This section explores the state of play of the integration of sustainable development, climate change and biodiversity across the Horizon 2020 programme, the pillars, the programme parts and the types of action. The evolution over the duration of Horizon 2020 is also evaluated. Figure 1 presents the KPIs over the programme by year, based on flags at the project level. The reported year refers to the date the projects were signed ('signature year'); projects flagged as 'rejected'[3] are excluded from the calculations. The figure shows a steady increase in the average shares of the overall Horizon 2020 budget allocated to sustainable development, climate change and biodiversity over the evolution

2 EU Open Data Portal (https://data.europa.eu/en) and eCorda data (https://corda.eea.europa.eu/SitePages/About.aspx). The eCorda dataset provides the Rio marker flags for the projects related to SDCCB.

3 eCorda "Status" field, flags data as "Closed", "Terminated", "Signed", "Under Preparation", "Suspended" OR "Rejected".

the programme from 43.8%, 27.3% and 3.3%, respectively, in the pre-interim period (2014-2017) to 55.2%, 29.9% and 7.1%, respectively, in the post-interim period (2018-2021). Moreover, there is a clear positive trend in performance in the three KPIs between 2019 and 2021, which was reinforced by the European Green Deal and the introduction of the EU Taxonomy.

FIGURE 1 SDCCBD KPIs BY YEAR: ALL SDCCB-FLAGGED HORIZON 2020 PROJECTS (% OF TOTAL BUDGET/EU FINANCIAL CONTRIBUTION)



Source: EU Open Data Portal and eCorda data (https://corda.eea.europa.eu/SitePages/About.aspx).

Relevance of sustainable development, climate change and biodiversity

The proposal for Horizon 2020 came before the formal adoption of the Sustainable Development Goals (SDGs) (in 2015), which were thus not part of the narrative. After their adoption, the SDGs were used as a reference point but not a direct link. Horizon 2020 was drafted in the aftermath of the euro crisis, and its major motivation was to create jobs and boost growth. Sustainable development was framed later, during the evolution of focus areas (such as the circular economy). In recent years, the integration of sustainable development, climate change and biodiversity in research and innovation (R&I) was shaped by extreme events such as the 2017 wildfires in Portugal, which led to discussions of the role of the environment really gaining momentum. Moreover, there was a recognition in the Interim report (European Commission 2017, European Parliament 2021) that the climate objectives will not be met due to the lack of ex-ante planning and that monitoring was patchy.

Since the adoption of the 2030 Agenda (United Nations 2015, 2020), policies have evolved considerably or been adapted to better address the relevant issues in the EU and beyond. Building on the Paris Agreement and the SDGs as frameworks for action, the EU introduced the European Green Deal on 1 December 2019 with the goal of achieving climate neutrality by 2050. The key objectives of sustainable development, climate change and biodiversity as a cross-cutting issue in Horizon 2020 continue to be highly relevant

to all programme areas, given the challenges posed by implementing the objectives of the Agenda 2030 with its 17 SDGs, the Paris Agreement (COP21), and the European Green Deal.

Efficiency of sustainable development, climate change and biodiversity

Cross-cutting issues are mainstreamed widely within Horizon 2020 in terms of financial efforts and the number of actions covered, and SDCCBD was also mainstreamed through all Horizon 2020 funding processes. Sustainable development is the most mainstreamed cross-cutting issue, followed by climate change (Koundouri et al. 2023).

Based on the Rio marker categories (principal objective/secondary objective/not targeted), weighting factors of 100%/40%/0% (generally referred to as 'policy markers') are used to quantify expenditure on climate action, sustainable development and biodiversity, respectively. The resulting figures are not cumulative.

In terms of identifying and monitoring the SDCCBD cross-cutting issue, the Rio marker flagging system, as well as the focus on expenditures, is problematic. A key difficulty in implementing this cross-cutting issue with targets set comes from the bottom-up components of Horizon 2020. The content of bottom-up actions is, by nature, unpredictable. The Commission has no means to steer the orientation of the projects that are funded, despite them representing a very substantial part of the budget. Furthermore, the data collected measure only the EU expenditure in support of sustainable development, climate action and biodiversity, not the results and the actual impacts of these investments. In other words, the OECD Rio markers are based on 'intention' rather than actual impact. As a result, a fully automated, scalable flagging, review and monitoring approach has been presented by the study team (Koundouri et al. 2023) and is partially unfolded here. The tracking of outputs will be based on data mining/science techniques that map the Horizon 2020 projects and their outputs (i.e. publications) to the SDGs. This process would enable a fine-grained quantitative analysis providing evidence on SDG contributions based on the project outputs. It would also allow for a more systematic and thorough treatment of bottom-up actions or ad hoc reporting. The impact of Horizon 2020's SDG contributions can be measured through Field-Weighted Citation Index (FWCI) scores. In this section, we showcase our approach based on the publication of Horizon 2020 projects, but it could also be expanded to include any type of output, such as deliverables, intermediate reports, and so on.

The SDGs were fully adopted in 2015, that is, after the H2020 proposal was drafted, so they were only used as a reference point rather than a direct link.[4] Moreover, the H2020 programme was drafted in the aftermath of euro crisis in 2012, and was mainly focusing

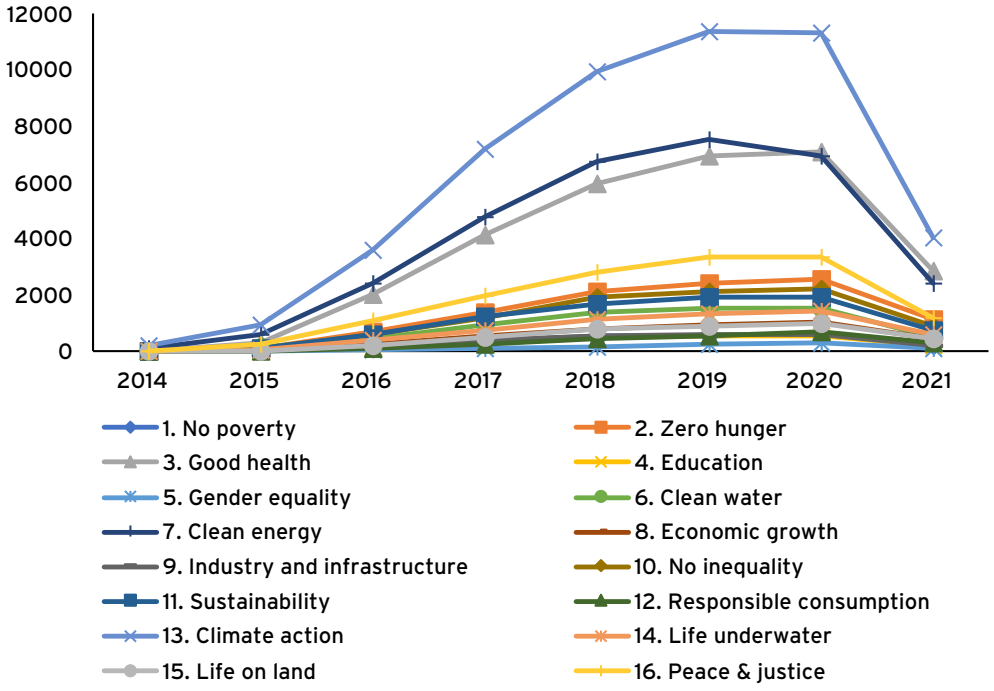
4 In contrast to the Horizon Europe programme.

on enhancing European growth. Links to sustainable development, climate change and biodiversity gained momentum later, with the introduction of focus areas (the circular economy, reusable space).

In order to further capture the impact as well as derive useful conclusions on the efficiency/consistency of the Rio marker flags ('flagged projects'), we employ data mining techniques to compare the performance in the KPIs versus alternative definitions of the KPIs by mapping the publications of Horizon 2020 programme to the SDGs ('SDG tagged projects') using our SDG classification system.

It is important to note that there is a significant lag between the project signature date and the production of scientific publications and the latter better reflects the evolution during the life cycle of the project, so we will adopt it as a reporting scheme throughout this chapter. Impact can be tracked by looking at the number of tagged projects mapped to specific SDGs by publication date (reported in Figure 2).

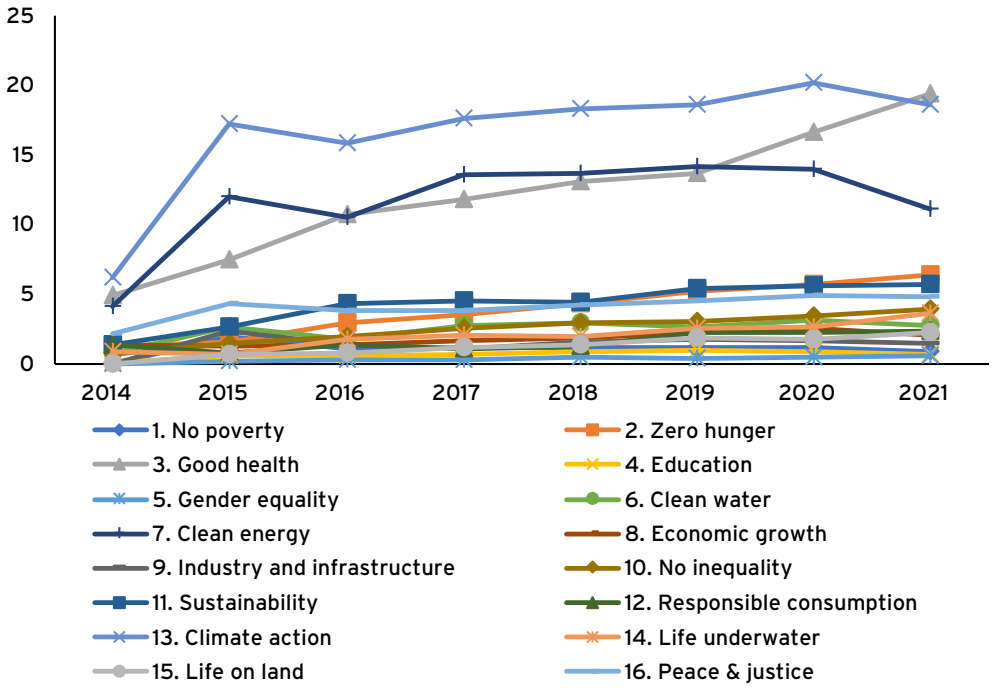
FIGURE 2 SDCCB-RELATED HORIZON 2020 PUBLICATIONS, BY SDG



Based on the 16,191 projects with publications over the period 2014 to 2021, we report detailed comparisons of the inconsistencies of the Rio marker flagged projects and the SDG tagged projects. Most importantly, there are significantly more false negatives (i.e. projects which are flagged with a zero Rio marker despite a share of their publications being mapped to SDGs) than false positives (i.e. projects with a positive Rio marker flag but without any publications mapped to an SDG).

In order to further explore the impact of the cross-cutting issue, we define an alternative scheme to the Rio markers. For each project, we calculate the share of publications related to a specific SDG versus the total number of publications. Using this scheme, an alternative version of the KPIs is defined as the percentage of EU contributions per SDG reported at the publication date (Figure 3), revealing a significant share of all EU contribution to all SDGs. Moreover, the share significantly increases during the 2018-2021 period, relative to 2014-2017.

FIGURE 3 SDCCB SDG-FLAGGED KPIs: PERCENTAGE OF EU CONTRIBUTION BY SDG



Effectiveness of sustainable development, climate change and biodiversity

Interviews with European Commission officials and Horizon 2020 beneficiaries reveal that in the approach adopted to sustainable development, climate change and biodiversity, there is a gap between monitoring expenditure and evaluating actual impact, which is exacerbated by the considerable time lag between actions and true impact on the ground. A complete monitoring system should not limit itself to monitoring expenditure but should also include monitoring of (short-term) impacts.

Moreover, a gap was identified in terms of the lack of diversity in the consortia of projects. In order for Horizon 2020 to deliver impact on the ground, the consortia need to reflect the diversity of stakeholders that will be called upon to implement the proposed solutions.

TABLE 1 AVERAGE FWCI SCORES FOR SDG AND NON-SDG PUBLICATIONS PER THEMATIC PILLAR

	Cross Theme (EU.0.)	Excellent Science (EU.1.)	Industrial Leadership (EU.2.)	Societal Challenges (EU.3.)	Spreading Excellence and Widening Participation (EU.4.)	Science with and for Society (EU.5.)	Euratom Research and Training Programme (Euratom)
SDG_1		2.45	1.12	2.07	2.33	0.96	0.77
SDG_2	4.14	2.77	1.74	2.64	2.96	1.16	1.09
SDG_3	1.52	3.14	1.88	3.58	1.87	1.70	1.14
SDG_4		1.69	1.08	2.56	2.17	1.19	1.12
SDG_5		2.43	2.10	2.23	3.70	0.57	
SDG_6	1.43	2.89	1.37	2.05	1.13	1.38	1.04
SDG_7	1.24	2.50	1.39	2.10	1.27	0.48	1.29
SDG_8	1.51	2.78	2.14	3.95	1.35	1.53	0.80
SDG_9	4.54	2.13	1.25	1.88	2.70	1.16	4.16
SDG_10	3.49	2.71	1.46	2.81	2.63	1.12	0.92
SDG_11	0.64	2.35	0.85	2.16	0.94	1.01	1.06
SDG_12	6.61	3.21	2.34	2.48	2.81	2.06	1.59
SDG_13	2.14	2.60	1.51	2.71	1.35	1.07	1.25
SDG_14	1.77	2.49	1.64	2.18	1.16	1.48	1.15
SDG_15	10.15	3.81	3.34	3.84	1.89	1.18	0.80
SDG_16	0.65	2.36	0.82	1.74	1.42	1.60	0.80
NON_SDG	1.11	2.60	0.90	1.68	1.55	0.98	1.15

Source: Own calculations

In order to track the impact of the cross-cutting issue, we focus on the output of scientific research conducted during projects and look at the FWCI of Horizon 2020 publications. Interestingly, across most of the thematic pillars,[5] the publications for most of the SDGs have a high average FWCI (i.e. they are cited more than expected) and consistently outperform the non-SDG publications (Table 1). Moreover, comparing the 2014-2017 and 2018-2021 periods, the pattern is persistent across most of the SDGs (Table 2).

TABLE 2 AVERAGE FWCI SCORES FOR SDG AND NON-SDG PUBLICATIONS PER YEAR

	2014	2015	2016	2017	2018	2019	2020	2021
SDG_1		1.40	1.75	2.83	1.93	2.01	2.05	1.72
SDG_2	2.22	1.71	3.47	3.28	3.42	2.82	2.29	2.04
SDG_3	1.04	2.56	3.36	3.39	3.17	3.01	3.61	3.61
SDG_4	2.02	1.71	1.50	1.45	1.94	1.50	1.24	2.10
SDG_5		1.07	5.11	3.78	2.32	2.82	1.70	1.13
SDG_6	1.34	1.34	3.45	2.15	2.40	2.47	2.31	1.94
SDG_7	1.31	1.83	2.59	2.21	2.33	2.10	2.12	1.85
SDG_8	0.31	3.39	2.68	2.13	2.88	3.04	3.19	1.83
SDG_9		1.01	1.18	1.21	1.93	1.58	2.02	2.94
SDG_10	0.82	2.58	3.10	3.77	2.89	2.53	2.04	1.57
SDG_11	1.09	2.00	1.50	1.55	1.80	1.89	2.39	1.73
SDG_12	2.10	2.05	2.05	2.73	3.25	3.54	3.02	2.42
SDG_13	1.46	1.88	2.53	2.45	2.53	2.39	2.48	2.08
SDG_14	1.28	1.83	2.15	2.20	2.67	2.51	2.48	1.84
SDG_15		4.17	3.59	3.03	4.33	4.02	3.57	2.39
SDG_16	0.21	2.13	2.88	2.31	1.98	1.86	1.72	1.20
NON_SDG	1.36	1.89	2.10	1.84	2.16	2.10	2.07	1.54

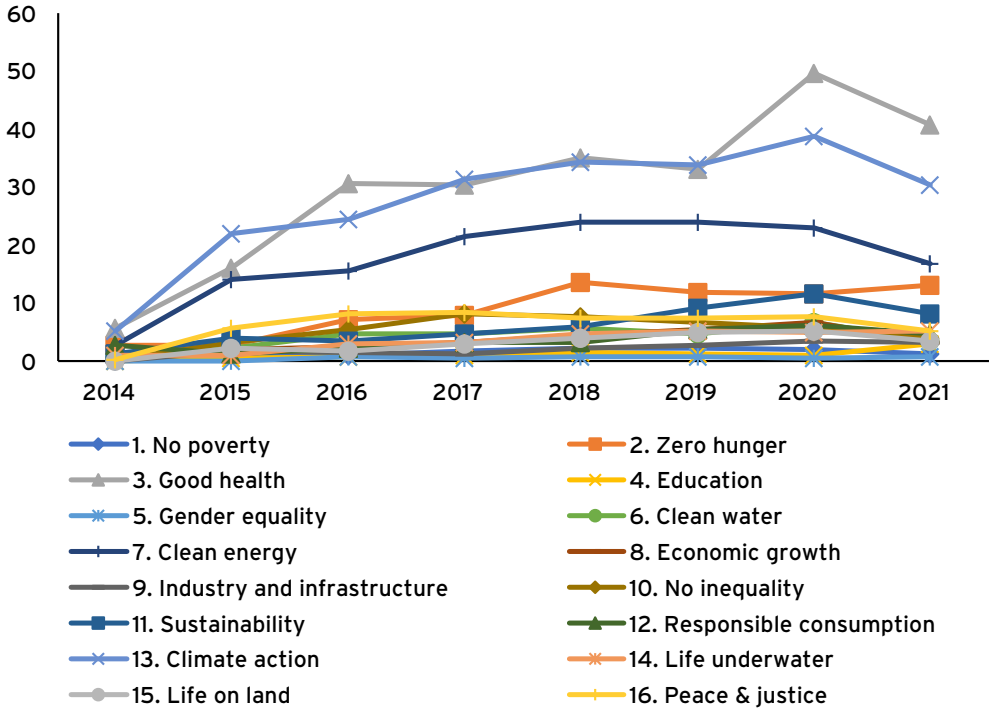
Source: Own calculations

In addition, we employed the FWCI to update our SDG tagged KPI calculations. FWCI measures the ratio of the actual number of citations received by an output to date and the 'expected' number for an output with similar characteristics. In this regard, the FWCI-weighted KPIs capture the impact of the financial contribution to the production of scientific research in SDGs. In order to measure the impact of outliers, we calculate the FWCI-weighted KPIs, by using the average FWCI of all publications for a specific year, project and SDG.

5 eCorda provides a classification of H2020 projects by thematic Pillars and Types of Actions.

Figure 4 presents the FCWI-weighted KPIs for all SDGs and reveals a significant increase over the Horizon 2020 timespan, especially for the SDGs relating to climate change, hunger, clean energy, and health.

FIGURE 4 SDCCB SDG-FLAGGED KPIs: PERCENTAGE FWCI-WEIGHTED EU CONTRIBUTION, BY SDG



Source: Own calculations

CONCLUSION

Sustainable development, climate change and biodiversity constitute a major component of the Horizon 2020, with climate action and sustainable development listed as the key objectives of the programme. There are, however, significant issues with the monitoring of this cross-cutting issue, as there is a gap between *intention*, as expressed by expenditure, and true *impact*, as expressed by the outcome of the Horizon 2020 projects.

Several areas for improvement have been identified, such as mainstreaming the sustainable development, climate change and biodiversity inputs in the Horizon 2020 implementation and monitoring system to improve efficiency and effectiveness.

This underlines the need for targets to be more connected to the level of implementation of specific SDGs. Moreover, 'biodiversity' is too narrow to account for the whole spectrum of ecosystem services and needs to be expanded to account for impact on the ground. There is also a need in future to focus on proving that the legislated policies are implementable and showcasing ways to implement and financially support initiatives.

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PART III
THE MACROECONOMICS OF THE GREEN TRANSITION

CHAPTER 12

Is green growth achievable?

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Climate change mitigation objectives, and in particular commitments to reach net-zero emissions, need a much faster and significant reduction in emissions at the aggregate level than what has been achieved so far. In the EU, the intermediate goal of a 55% reduction in net emissions by 2030 versus 1990 requires a doubling of the annual rate of emission cuts over the 2020–2030 period versus the 2005–2019 period. Is this feasible without 'degrowing'?

TWO INTERPRETATIONS OF 'GREEN GROWTH'

The required decoupling of greenhouse gas (GHG) emissions from economic growth has led several international organisations to promote the concept of 'green growth'. The OECD defines it as "economic growth that ensures that natural assets continue to provide the resources and environmental services on which our well-being relies" (OECD 2014). This differs from the concept of 'degrowth', which is based on the idea that the net-zero transition is only possible by reducing production. There are two interpretations of green growth depending on the form it may take and its macroeconomic consequences (Jacobs 2013).

The first interpretation argues that the net-zero transition would have positive economic impacts as from the short term: investments to ensure the transition would stimulate demand, and both activity and employment along with it. This theory is based on the usual Keynesian arguments, under the additional assumption that a 'green' investment will have more economic benefits than a 'brown' investment in the short term. A green investment (such as in the energy efficiency renovation of buildings) would be more labour-intensive, and its economic impact would be more locally concentrated. However, the empirical evidence on green fiscal stimulation is limited (Agrawala et al. 2020). This theory also encompasses techno-optimist arguments according to which the transition will be supported by breakthrough carbon-free innovations that could be the source of

1 This chapter reflects the opinions of the authors and does not express the views of the institutions.

significant productivity gains. Critics of this theory point to the high degree of uncertainty surrounding the emergence of these technologies and their ability to generate spillover effects on the rest of the economy.

The second interpretation of green growth, which is becoming a consensus view among experts, posits that the net-zero transition would result in benefits in the long term – relative to the negative impacts of inaction on climate change – but would be costly in the short term. Thus, fossil fuel phase-out – which is a prerequisite to reduce GHG emissions quickly and significantly – could be akin to a negative supply shock (Pisani-Ferry 2021). Moreover, the additional investment needed to achieve the transition would come at the expense of consumption and other short-term investments. In any case, the cumulative costs for economic activity would remain below the costs of inaction on climate change: the cost of inaction could exceed 15% of global GDP by 2050 for a temperature increase of 2–3°C (Carantino et al. 2021).

THE MAIN POLICY INSTRUMENTS TO SUPPORT DECARBONISATION

A wide range of policies can be deployed to make economic agents decarbonise their activities: carbon pricing, eliminating fossil fuel subsidies, sector-specific regulations, financial regulations, public subsidies, public investment, improved access to information. They all involve direct costs, efficiency costs and opportunity costs, albeit in various proportions and with different burden sharing between public and private sectors. Carbon pricing is generally considered the backbone of the transition since it minimises efficiency costs while yielding resources to compensate households and/or firms. Although adopting pricing schemes is becoming more widespread, only 23% of global emissions were subject to carbon pricing in 2022, and less than 4% were priced at more than $40/tCO2eq (World Bank 2022).

According to the European Commission (2021), the additional (public and private) investment needed over the 2021–2030 period compared to the previous decade to achieve the EU's new climate objectives by 2030 – in the energy generation, industry, transportation and construction sectors – would be equivalent to about 2 to 3 percentage points of GDP per year at EU level, i.e. an increase of over 55% from 2011–2020 levels. These investment needs for the climate transition mostly relate to 'gross' amounts to be committed for emissions reductions. They relate neither to the net additional investment that may be observed at a macroeconomic level (since some financing can be shifted from 'brown' investments to 'green' investments), nor to the final cost for economic agents who, for example, may recoup all or part of these investments through energy savings thanks to the energy efficiency renovation of buildings.

SUPPLY AND DEMAND SHOCKS

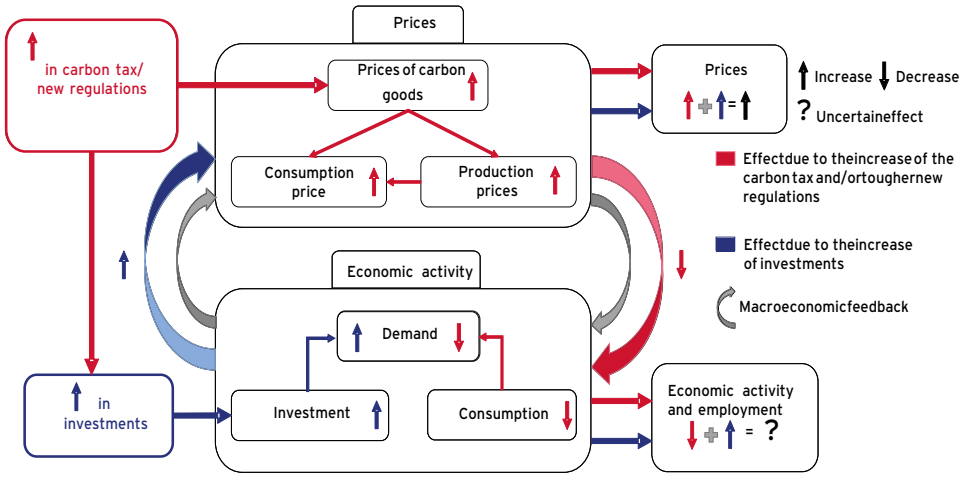
From a macroeconomic perspective, the transition to net-zero emissions will have two main effects: a rise in the relative price of carbon emissions, and an increase in decarbonisation investments.

Increasing the costs of carbon emissions through carbon pricing and new regulations is akin to a negative supply shock. It raises the cost of production in the sectors affected, and therefore producer and consumer prices (see Figure 1, orange part). Although regulation is not an explicit carbon price, it does make it more difficult to implement a high-emission production process. It also involves a cost due to the substitution with low-carbon or decarbonised alternatives. A rise in production costs would have a direct negative impact on activity, as well as an indirect impact resulting from price hikes that would hamper consumption. Several empirical studies have found that an increase in the carbon price could have a moderate or even non-significant macroeconomic impact (Konradt and Weder di Mauro 2021), but these were conducted when carbon prices were low (until the end of the 2010s), possibly limiting their future validity. In fact, predicting the impact of inflated costs on the economy is extremely difficult since it will crucially depend on technologic change and on the ability to substitute green capital to brown capital and to fossil energies.

The emergence of new carbon-free technologies, their diffusion and their macroeconomic impact remains largely uncertain. The majority of empirical studies back the weak version of Porter's hypothesis: environmental policies do stimulate innovation, but they also embed short-term costs resulting from the restriction of inputs in production processes (Calel and Dechezleprêtre 2014). Yet, the results of these studies largely depend on the scope of analysis (firm-, industry- or economy-wide level), the characteristics of a given company (size, financing constraint), the type of pollution covered by the policy and the design of the environmental policies (explicit carbon prices, standards or regulations).

Additional investments in the green transition are akin to a positive demand shock. This shock stimulates economic activity in the short term by generating additional demand for firms and thus increasing employment. However, this increase in demand drives prices up temporarily as long as supply cannot immediately meet all of the demand surplus (see Figure 1, blue part). Financing requirements for these investments may also drive interest rates upwards, which may cause a crowding-out effect. Finally, higher public investment may require cuts in current spending in order to meet debt-sustainability requirements. Although the Keynesian multiplier is generally found to be larger for public investment than for public consumption or untargeted transfers, the net effect of the transition through public spending could end up relatively limited.

FIGURE 1 TRANSMISSION CHANNELS OF (i) A RISE IN CARBON TAX AND NEW REGULATIONS, AND (ii) AN INCREASE IN INVESTMENTS IN THE NET-ZERO TRANSITION, EXCLUDING THE IMPACT OF CLIMATE CHANGE



Note: The diagram shows shocks on the left and impacts on prices, activity and jobs on the right. The upper section covers price mechanisms, while the lower section shows real mechanisms. The arrows between these two sections indicate macroeconomic feedback. For example, if prices rise, demand falls.

Source: Girard et al. (2022).

The type of mitigation policies will contribute to shaping both the supply shock and the demand shock. The revenue generated by carbon pricing (a cost) could be recycled into subsidies to households and/or firms (an income). Absent carbon pricing revenues, public subsidies will have to be financed through higher taxes or through higher debt, with possible crowding-out effect. This public finance channel is all the more likely that governments will also have to face the damages of climate change itself and the cost of adaptation policies.

MACROECONOMIC IMPACT OF THE TRANSITION TO ZERO-CARBON

While both higher production costs and higher investments are most likely inflationary, the ex post nominal impact of these two shocks will crucially depend on monetary policy and on households' expectations about their future incomes, and on possible exogenous shifts towards more frugal ways of life. Moreover, the real impact of net-zero transition is ambiguous. One could consider the impact on household purchasing power as an illustrative example. On the one hand, rising production costs should hamper activity and income growth. On the other hand, additional investments to decarbonise the economy would stimulate activity and household income through both lower unemployment and increased wages. Other mechanisms must also be taken into consideration to measure the overall macroeconomic impact on purchasing power. Indeed, a drop in the energy consumption of households caused by investments and improved energy efficiency could support other consumption purposes thanks to income and substitution effects.

Frictions and adjustment costs, particularly in relation to job and capital reallocations (e.g. the rigidity of employment, the cost of skill acquisition, premature write-down of assets in carbon-intensive sectors – referred to as 'stranded assets') will also determine the overall macroeconomic impact of net-zero transition in the short term.

Moreover, the macroeconomic impact of the net-zero transition will depend on the level of cooperation between countries. If a coordinated net-zero transition were carried out, prices would increase in similar proportions across all countries depending on their productive structure, as a result of the mechanisms described above. Coordination would limit the losses of competitiveness and market shares for the companies facing ambitious climate policies. The global dimension also includes the risks of supply bottlenecks for critical raw materials for green technologies and the rollout of renewables, as well as risks related to fragmented supply chains.

Overall, the majority of existing estimates report that negative effects tend to exceed the positive ones, leading to a limited negative net impact at the global level (NGFS 2022). They also highlight the responsibility of policymakers in designing the adequate combination of policies. As already mentioned, the way the revenues from carbon pricing will be used will be crucial. Additionally, structural reforms could smooth the reallocation of production factors and limit the adjustment costs. For instance, this would mean facilitating the acquisition of the skills required for the transition, such as in the field of the energy renovation of buildings. Last but not least, the predictability of the policies will be key to drive expectations and trigger an orderly transition.

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CHAPTER 13

Equitable climate mitigation strategies in a world of high energy prices

Ian Parry
International Monetary Fund

Global carbon dioxide (CO_2) and other greenhouse gas emissions must be reduced by 25–50% below 2019 levels by 2030 to get on track with containing global warming to 1.5–2°C (Black et al. 2022a). To be globally effective, strategies will need to include stronger action in all countries, including high-emitting emerging market economies, while at the national level, governments will need to increase the relative price of fossil fuels, including coal. Critical to moving forward will be addressing equity concerns at both global and national level – the differentiated responsibilities of developing countries in climate mitigation, and the burdens of higher energy prices on households, particularly the poor. This chapter outlines equitable strategies at global and national level and then considers how surging energy prices affect these strategies.

MEETING THE GLOBAL CHALLENGE

Even if countries fully achieved current mitigation pledges in Nationally Determined Contributions (NDCs) submitted under the Paris Agreement, this would only reduce global CO_2 emissions 11% below 2030 baseline levels. As a group, high-income countries would cut their emissions 35%, but middle- and low-income countries would only cut their emissions 8% and 9% percent, respectively (the latter countries account for 48% and 18% percent of baseline global emissions in 2030, respectively).[1] A global regime with enhanced mitigation action is critical but it should respect the Paris Agreement's equity principle, generally understood to imply that speed of emissions reductions should rise with per capita incomes, complemented with climate finance for lower-income countries.

While the Paris Agreement has catalysed the development of climate mitigation strategies at the national level, most likely it is insufficient by itself to achieve the reductions in global emissions needed by 2030. For one thing, it is difficult for countries to negotiate greater mitigation ambition given there are too many parties (the EU plus 166 countries) negotiating over too many parameters (one pledge per party). For another, is it difficult for countries to aggressively scale up mitigation policy when acting unilaterally, due to concerns about competitiveness and uncertainty over mitigation policy in trading

1 All figures are from Black et al. (2022a).

partners. An additional international mechanism is likely needed to complement and reinforce the Paris Agreement, containing a concrete plan to deliver the necessary reductions in global emissions.

One possibility is an international carbon price floor arrangement, which would have two key elements (Parry et al. 2021). First is a focus on a limited number of large emitters to facilitate negotiation while still covering the bulk of global emissions – for example, baseline emissions in China, the EU, India, and the US alone are nearly two thirds of the global total in 2030. The second element is a focus on a minimum carbon price that each participant should implement. Carbon pricing is an efficient and easily understood parameter, and joint action among large emitters to scale up pricing would be an effective way to address concerns about competitiveness and policy uncertainty.

The arrangement would need pragmatic design, however. First, to address the differentiated responsibilities of developing countries, price floor requirements could be differentiated according to country groups defined by level of development, and the arrangement could include a robust and transparent mechanism for transferring financial and technological support for low-income countries. Second, the arrangement would need to accommodate countries where, for political or other reasons, carbon pricing is not a central element of the mitigation strategy, so long as they achieve, though other instruments, the equivalent reduction in emissions that would have been achieved had they met the price floor requirement.[2]

For illustration, if advanced and high- and low-income emerging market economies were subject to price floors of $75, $50, and $25 per tonne in 2030, and countries met whichever is the more stringent of the price floor and their NDC, this would be sufficient to align global CO2 emissions with staying below 2°C, even with only six participants in the arrangement (Canada, China, India, the EU, the UK, and the US) (Parry et al. 2021).

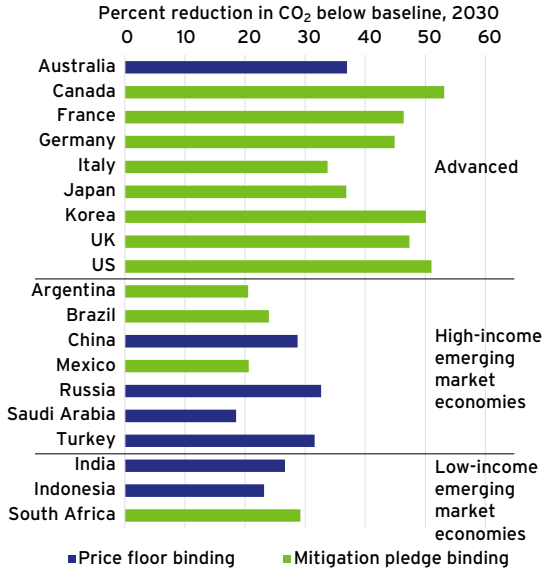
Indeed, if this regime applied to G20 countries, the burden of emissions reductions and mitigation costs would be equitably distributed (Figure 1). Advanced countries would be cutting their emissions about 35–50% below baseline levels in 2030, while high- and low-income emerging market economies would be cutting their emissions 20–30%. NDCs would be the binding constraint for most advanced countries and the price floor for most emerging market economies. And mitigation burdens, as measured by welfare or efficiency costs (loosely speaking, the annualised costs of using cleaner but costlier technologies), would be around 0.5–1.0% of GDP in advanced countries and 0.5% or less in most emerging market economies, prior to any climate finance (South Africa is an exception given its stringent NDC and high carbon intensity). Indeed, accounting

2 Operational methodologies are available for mapping carbon pricing and other commonly used instruments into their emissions reductions (e.g. Black et al. 2022b). The arrangement may need financial and trade penalties to promote participation (e.g. Gollier and Tirole 2015).

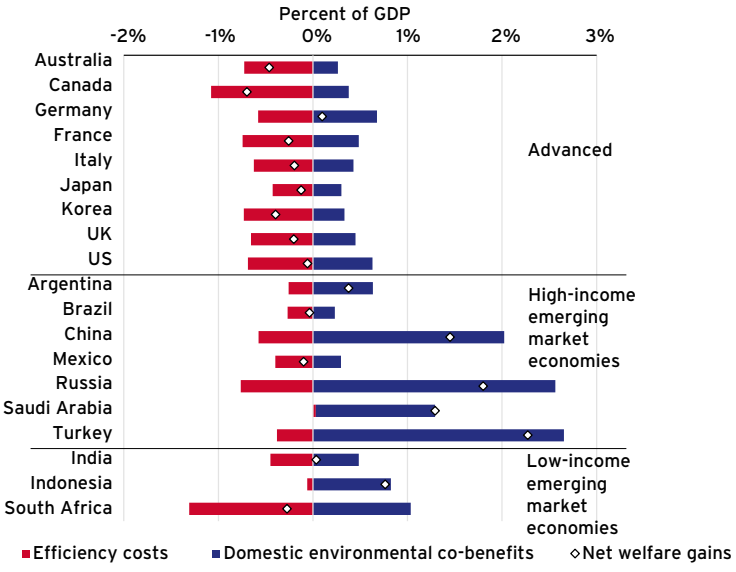
for domestic environmental co-benefits (particularly reductions in deaths from local air pollution) implies that key emerging market economies (like China, Turkey, and Indonesia) are better off on net, before even counting global climate benefits.

FIGURE 1 IMPACTS OF REINFORCING NDCs WITH $75/50/25/TONNE PRICE FLOOR, G20 COUNTRIES, 2030

a) Emissions



b) Welfare/efficiency



Notes: Welfare/efficiency costs reflect losses in consumer and producer surplus in fuel markets accounting for prior fuel tax distortions and correspond to integrals under marginal abatement cost schedules. Domestic environmental co-benefits include reductions in local air pollution deaths and traffic congestion/accident externalities.

Source: Updated from Parry et al. (2021).

An alternative to the price floor regime would be for large emitters to negotiate country-level emissions targets that, in aggregate, are aligned with global temperature goals. However, this implies a greater number of parameters to negotiate (one target per participant), countries may have stronger incentives to push for a weaker target (as this affects only them, not other countries in their development group), and the approach leaves uncertainty over specific policy actions in different countries.

Another alternative regime could involve building up a global carbon market through linking emissions trading systems (ETSs), though the regime would need to address similar deign issues. First, the carbon market would need to be part of a broader agreement that included large emitters that are not implementing ETSs. Second, it would need to address international equity issues, perhaps though trading ratios where a permit from a low-income country is worth, say, three permits from an advanced country. And third, it would need to contain a concrete trajectory of emissions caps that ensured global emissions are aligned with global temperature goals.

THE NATIONAL CHALLENGE

At the national level, to meet (NDC or enhanced) emissions commitments, countries will need comprehensive strategies that are both effective and acceptable.

The centrepiece should be carbon pricing – charges on the carbon content of fossil fuels or their emissions – in the form of carbon taxes or ETSs, phased in progressively over time. Carbon pricing provides across-the-board incentives to reduce energy use and shift towards cleaner energy sources. There are limits to the acceptability of carbon pricing, however, because of the burden it imposes on households and firms as carbon tax revenues, or allowance rents in ETSs, are passed forward in higher energy prices. Countries may also have supplementary emissions targets at the sectoral level.

Carbon pricing may therefore need reinforcing by measures at the sectoral level that are less efficient, but likely have great acceptability given their generally much smaller impact on energy prices. Traditionally, these measures have taken the form of regulations – for example, on the emission rates of vehicles or renewable shares in power generation – or subsidies for clean technologies, though feebates are a potentially more flexible and cost-effective approach.[3] Many countries have integrated feebates into vehicle tax systems, which promotes the transition to cleaner vehicles but, unlike higher fuel taxes, does not encourage people to drive less. The same instrument could be applied to reduce emissions intensity in other sectors. Pricing, or proxy pricing, of emissions sources beyond the energy sector is also important, for example to promote forest carbon storage or reductions in methane leaks from extractive activities.

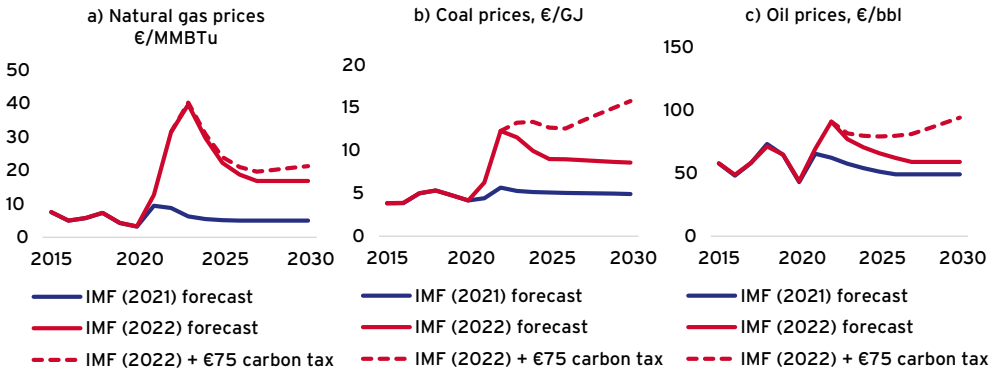
3 Feebates are the fiscal analogue of emission rate regulations and provide a sliding scale of fees on products or activities with above-average emissions intensity and a sliding scale of rebates for products or activities with below-average emissions intensity (e.g. Parry 2021).

Another key element of the mitigation strategy is to ensure just energy transitions with robust assistance targeted at low-income households and other vulnerable groups – for example, through stronger social safety nets, medical and educational services targeting the poor, and assistance programmes for displaced workers and regions. Recycling carbon pricing revenues in productive ways that benefit households in general – for example, lowering taxes on work effort or funding investments for the Sustainable Development Goals – can boost the economy while helping to ensure the overall reform package meets distributional objectives. And competitiveness concerns need to be addressed through, for example, border carbon adjustments or relief measures for energy-intensive, trade-exposed firms.

IMPLICATIONS OF SURGING ENERGY PRICES

Global natural gas, coal, and oil prices increased about 850%, 190%, and 110%, respectively, between mid-2020 and late-2022 (Figure 2), in part due to the recovery in global energy demand, previously weak fossil fuel investment, and disruptions following the Russian invasion of Ukraine.

FIGURE 2 TRENDS IN INTERNATIONAL FUEL PRICES



Source: Black et al. (2022a)

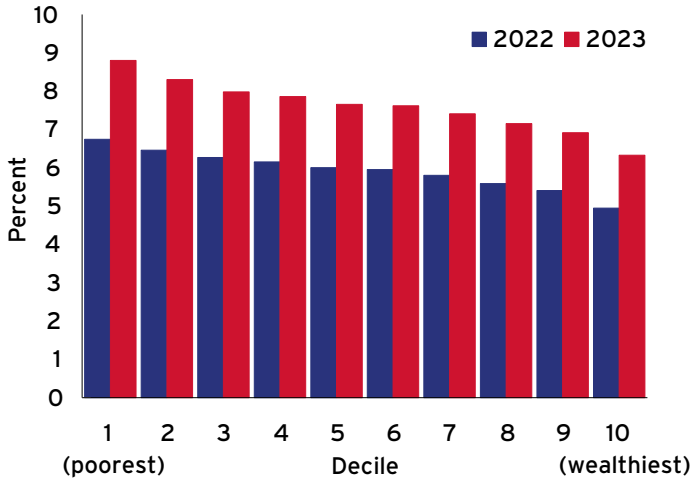
The immediate implication of the energy price shocks is that they are a reason to accelerate – not delay – the low-carbon energy transition, not just to address the climate crisis but also to shield economies from recurrent price and supply disruptions in fossil fuel markets.

Another implication is that higher energy prices have significantly lowered projections of baseline global CO_2 emissions.[4] The effect has, however, been cushioned because the sharp increase in the price of natural gas relative to coal has caused some switching from gas to coal and, while future prices are highly uncertain, projections suggest the surge will be partially reversed as markets adjust over time (Figure 2).

Indeed, declining prices provide an opportunity to gradually increase carbon prices, while allowing the price of gas to decline below current levels. For illustration, phasing in a $75 carbon price on top of projected prices would imply 2030 gas prices that are 32% *below* mid-2022 levels, though oil and coal prices would be 3% and 28% higher, respectively (Figure 2).

A pressing priority for many countries has been to provide robust assistance to help households with higher energy bills. Averaged across European countries, the energy price shock implied burdens on average European households of 6% of their consumption in 2022 and (a projected) 8% burden for 2023, with burdens disproportionately larger for lower-income households (Figure 3).

FIGURE 3 INCREASES IN HOUSEHOLDS' COST OF LIVING RELATIVE TO JANUARY 2021, EUROPEAN AVERAGE



Source: Arregui et al. (2022).

Governments have responded with a variety of temporary compensation measures, including reduced taxes on energy products, caps on electricity and gas prices, and one-off financial supports.[5] Ideally, however, household assistance would be targeted to lower-income households (to limit fiscal costs on the government) and unrelated to energy

4 For example, from 40 to 35 billion tonnes in 2030 in Black et al. (2022a), reflecting both the impacts of higher fuel prices and lower GDP on fossil fuel demand.
5 See Arregui et al. (2022) for more details.

consumption (to preserve incentives for energy conservation) – for example, measures could strengthen existing social safety nets or provide means-tested lump-sum rebates in energy bills. These measures should become permanent as carbon pricing keeps energy prices high.

Indeed, a predictable and rising carbon price is still critical for levelling the playing field between fossil and clean technologies. If high baseline energy prices presently preclude direct carbon pricing, there is a greater role for supporting instruments that establish this price signal indirectly. For example, a feebate or tradable emission rate standard for the power sector that penalises emissions-intensive generation while rewarding low-carbon generation effectively raises the relative cost of coal generation without a significant impact on electricity prices. Similar instruments can promote electrification and other abatement technologies in the industrial sector without a significant loss of international competitiveness for the average industrial firm.

ENHANCED MITIGATION AMBITION AND POLICY REMAIN URGENT

In short, surging energy prices have not affected the urgent need to close large global climate mitigation ambition and policy gaps. Even if current mitigation pledges were fully achieved, global emissions reductions in 2030 would be less than half the amount needed to be on track for limiting warming below 2°C. An additional arrangement among large emitters is needed, with concrete policy actions that would deliver the needed reductions in global emissions. The costs for emerging market economies need not be large, and often are justified by domestic environmental co-benefits, before even counting the benefits from containing climate change or flows of climate finance.

Domestically, getting the price of fossil fuels relative to clean energy sources right (that is, aligned with mitigation targets) will be critical, and for the near term this may need to be done with policy packages that avoid a further increase in residential electricity and gas prices (albeit at the loss of some efficiency compared with carbon pricing). Policymakers will need to design these packages carefully, for example to avoid large divergencies in implicit carbon prices across sectors and instruments, while maintaining robust and targeted assistance mechanisms for vulnerable groups.

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CHAPTER 14

The green energy transition, part 1: Background and hurdles

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1 INTRODUCTION

The last three years have been characterised by a sequence of shocks unprecedented in their speed of transmission, depth and global reach. The Covid-19 pandemic in early 2020 and ensuing lockdowns brought 'bottlenecks', diffused shortages and strained global value chains. Russia's attack on Ukraine in February 2022 and ensuing sanctions precipitated an energy crisis which rocked fossil fuel markets as well as markets for 'critical climate minerals' and various commodities (Kuik et al 2022, Adolfsen et al. 2022, Nerlinger and Utz 2022, ECB 2022, Banbura and Bobeica 2022). The impacts on economic activity and prices, especially energy and food prices, were substantial.

Initially concerns about energy security prevailed over environmental consideration, i.e. the strive to reduce carbon emissions. Collective climate actions have been subdued in recent years and are inadequate to reach the 2015 Paris climate goals. Meanwhile, climate-related physical risks, both acute and chronic, as well as diverse transition risks are rising globally. The pandemic and the conflict may also have enduring consequences on the green energy transition, which is the focus of this chapter. Energy is critical for most human activities. About 70% of today's global greenhouse gas (GHG) emissions, which are primarily responsible for global warming, are emitted by the energy sector. Thus, success in the green energy transition is central to reaching the 2015 Paris goals.

This chapter explores several features of the green energy transition vis-à-vis unfolding climate dynamics. It is organised as follows. Section 2 reviews some projected climate dynamics. Section 3 lays out the main features of the transition. Section 4 highlights diverse gaps that are coming to the fore. Section 5 argues that an epochal shift in energy systems is required. Section 6 presents some final remarks.

1 I am grateful for comments from Andrej Ceglar, Fabio Tamburrini, Gabriel Fagan, Carol-Sue Lehmann, Jan Willem van den End, Jakob Feveile Adolfsen, Ariana Gilbert-Mongelli, and Carl Bruce. I am responsible for any errors and omissions and the views might not represent those of the ECB.

2 CLIMATE DYNAMICS

A daunting climate trend is worsening. There is a scientific consensus that the earth's climate is warming due to rising concentrations of GHGs.[2] The latest report of the Intergovernmental Panel on Climate Change (IPCC 2022) predicts that we will reach 1.5°C global warming already in the next decade. [3] This means that we are facing decades of high impact-climate events ahead of us, which will escalate with every additional increment of global warming (IPCC 2022).

Adverse tipping points, thresholds and cascades are piling up uncertainties. The accelerating warming trend might be exacerbated by so-called adverse tipping points, irreversible cascades and non-linearities, making the future difficult to predict. To ease the subsequent discussion, I group these under the banner of climate-related and ecological tipping points (CETPs). Increasing temperatures raise the risk of crossing such climate thresholds and pushing the climate system into irreversible changes, amplifying global warming itself (IPCC 2022, Lenton et al. 2020). Presently, the thresholds likely to be crossed earlier than previously thought include the collapse of Greenland's and West Antarctic's ice sheets, the collapse of ocean circulation in the polar region of the North Atlantic, the dying off of the coral reef in the Southern Hemisphere, the thawing of permafrost in the Northern Hemisphere (leading to GHGs being released), and the loss of sea ice in the Barents Sea (Stern 2022). Vanishing ice sheets reduces the reflection of solar heat.[4] In various parts of this chapter, we discuss other types of tipping points as well as developments that might instead be favourable for the green transition.

With lags, climate trends also respond to climate policies, the development of renewable resources and new technologies. Climate projections are subject to numerous uncertainties. As additional physical evidence is collected and climate models improve, long-term climate projections are constantly updated by climatologists. Such projections are conditional on the magnitude of net GHG emissions, and are lowered by mitigation policies, innovation, and technological progress (the transition towards renewable energy, technology of carbon capture and storage), its diffusion and industrialisation. Climate estimates are by their nature best efforts, *ceteris paribus*, utilising available scientific data.[5] Given the daunting climate trends, a global policy response was embodied in the 2015 Paris Agreement (COP21), which enshrined the goal

2 GHGs include, carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), and fluorinated gases. Each has its specific sources. We refer to them as GHGs or just CO_2 as the latter is the main GHG.

3 According to the IPCC (2022), *"[i]t is unequivocal that human influence has warmed the atmosphere, ocean and land. Widespread and rapid changes in the atmosphere, ocean, cryosphere and biosphere have occurred"* (see also Waldinger 2022). The science behind the climate change impacts is clear: every increment in global warming will escalate the climate impacts on natural ecosystems, society and our economy.

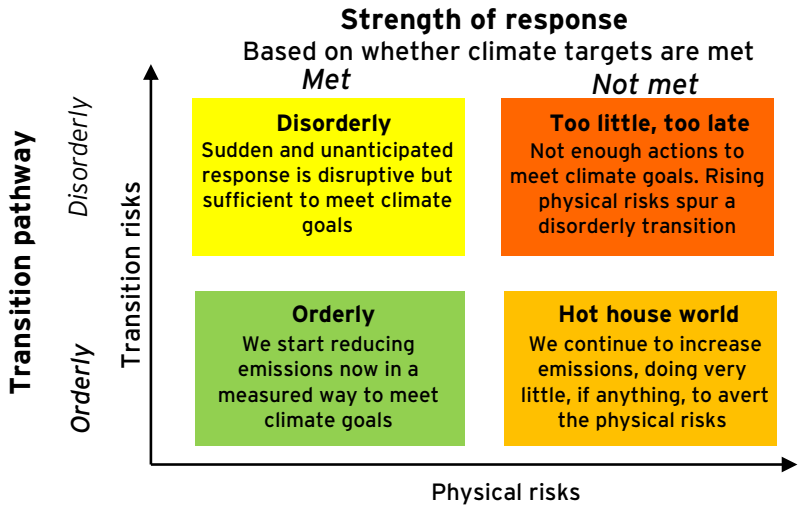
4 Scientific evidence already points to rising sea levels and coastal flooding; increasing frequency and intensity of hurricanes, droughts, and fires; food and water scarcity in some regions; losses in biodiversity; and heat stress, air pollution and disease transmission (IPCC 2022). On irreversible cascades, see also Chapter 3 in IPCC (2022).

5 The carbon budget provides a benchmark for tracking climate goals and the green energy transition. The IPCC (2022) illustrates that to achieve the COP21 goals, we must not generate beyond specific volumes of GHGs. While the carbon budget is global, countries have agreed on nationally determined contributions (NDC) with detailed domestic decarbonization paths in the Paris Climate agreement.

of 193 countries to keep global warming well below 2°C above pre-industrial levels by 2100, but preferably below 1.5°C. However, progress by governments in reducing domestic carbon emissions, embedded in National Determined Contributions (NDC), has thus far been slow and uneven.[6]

A virtuous scenario might be slipping away. Experts are concerned that as cumulated GHGs continue rising, at a pace inconsistent with the targets in the Paris Agreement, physical risks will become increasingly powerful and unpredictable. Correspondingly, the challenge of slowing down GHG emissions will become increasingly formidable. Moreover, as gaps between indispensable and actual climate actions widen, they might require hasty and sub-optimal large shifts in climate policies that entail additional risks and considerably higher costs (as argued below). This impasse is well captured by the macro-scenarios elaborated by the Network for Greening the Financial System (NGFS) that weigh the timeliness and thrust of adaptation as well as mitigation efforts.[7] At the cost of oversimplifying, it helps to think in terms of two extreme developments: a predictable *'orderly'* scenario in which rapidly adapting to the climate challenge and mitigating its pace by a swift transition to a low-carbon economy reduces future climate risks and bears several benefits; and at the opposite extreme a '*too little, too late*' scenario marked by a disorderly transition, with insufficient climate actions resulting in increasing physical risks (Figure 1).

FIGURE 1 TRANSITION PATHWAYS TO ADDRESS PHYSICAL AND TRANSITION RISKS



Source: Adapted from NGFS (2021).

6 See https://climateactiontracker.org/, www.climatewatchdata.org/net-zero-tracker, and https://globalenergymonitor.org/
7 The features of all scenarios are in NGFS (2020, 2021), see also https://www.ngfs.net/en. Current climate-economic models do not anticipate accurately the possible unfolding of tail climate-related risks.

Summing up

Currently projected climate dynamics are alarming. Robust mitigation policies, such as the green energy transition, have the potential to slow down these dynamics but with a lag if they are not applied rapidly and extensively. Yet, most of the available evidence concurs that progress in slowing climate change by starting the decarbonisation process in earnest has thus far been modest. The above scenarios – 'orderly' versus 'too little, too late' – have different environmental, social, economic and financial implications. The green energy transition might have features that could impact such bleak dynamics.

3 FEATURES OF THE GREEN ENERGY TRANSITION

The focus of this chapter is on the green energy transition and its impacts. This choice is motivated by various considerations. Energy is critical for most human activities and its central to the decarbonisation effort. About 70% of today's global GHG emissions – which are primarily responsible for global warming – are emitted by the energy sector (e.g. for electricity generation, transport, heating, and industrial uses). Thus, to support the goals in the 2015 Paris Agreement, the energy sector needs to decarbonise – to turn 'green'.[8] Thus, rapid progress in the green energy transition is central to reaching the Paris COP 21 climate goals.

The green energy transition has features that set it apart from other climate actions. Green energy systems are scalable and somewhat more flexible and diffused than some existing fossil fuel-based power-generating systems.[9] A green energy generation mix of various renewables can be replicated and adapted to the needs and circumstances of various regions, countries and across sectors (i.e. there can be positive spillovers). Green practices and sustainable solutions can be emulated and adapted. Green energy sources have already reached a high degree of maturity, are cost competitive and exhibit continuing progress.[10]

There is a nascent discussion about favourable socioeconomics tipping points. While most of the discussion concerns the previously mentioned adverse climate-related and ecological tipping points (CETPs), there is also a nascent discussion about favourable socioeconomic tipping points (SETPs). These pertain to the future of society and inform important climate policy choices (Figure 2). They could be tipping points leading to cascading decarbonisation effects, such as a reduction in the price of solar panels and other renewables that could lead to a rapid surge in uptake, parity in prices of electric and internal combustion mobility (LCOEs) or replacing meat proteins with plant-based proteins, to name just few. van Ginkel et al. (2020) observe how climate change-induced

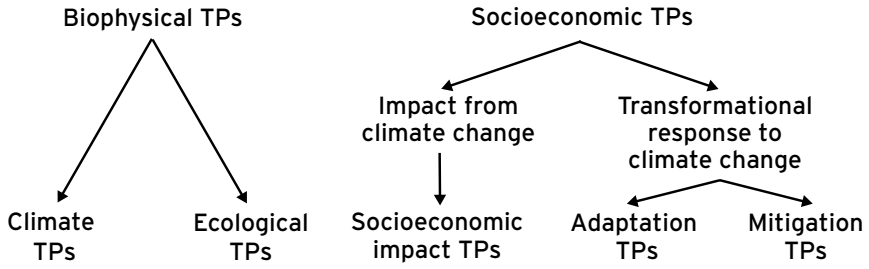
8 Other measures also are indispensable, such as reducing emissions from farming, sheltering carbon sinks, and supporting forestry and land management.

9 Including exploration, drilling, extraction and refining, transportation, and so on.

10 Renewable might not yet have the convenience, ubiquity and flexibility of current fossil fuels that have been tried, tested and honed for many generations (Mongelli 2009), yet progress is rapid.

socioeconomic tipping points foresee possible abrupt changes to a socioeconomic system to new, fundamentally different states spurred by climate change that will also need to be recognised and managed.[11]

FIGURE 2 CLIMATE AND ECOLOGICAL TIPPING POINTS VERSUS SOCIOECONOMIC TIPPING POINTS



Source: van Ginkel et al. (2020).

The green energy transition also has a set of requirements. Various authors and institutions agree that faster development of renewables and the green energy transition hinges on diverse preconditions. One of these is a clear, stable and transparent regulatory and legislative framework. Essential features of this include a broad fiscal framework, ranging from predictable carbon pricing to investing in green infrastructure and support for research and development (R&D); adequate public and private financial support, ranging from the use of proceeds from carbon pricing, to widely accepted environmental, social and governance (ESG) standards to guide companies and socially conscious investors, all the way to a 'green Capital Market Union' (CMU); continuing scientific advancements and technological innovations; and addressing several gaps which impede progress at its foundations.

Summing up

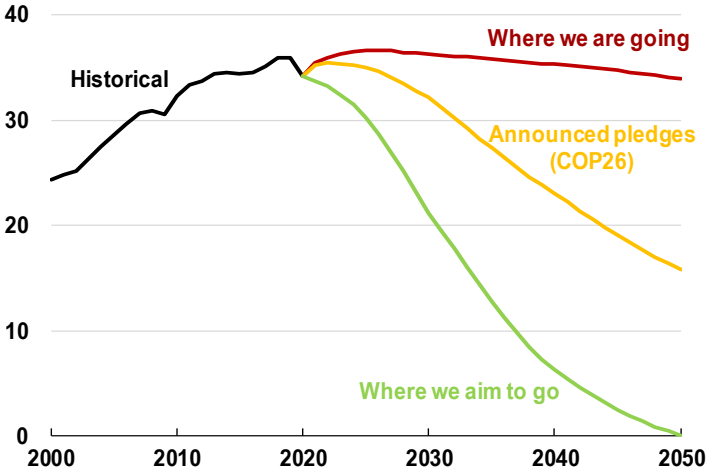
Rapid progress in the green energy transition is central to reaching the climate goals in the 2015 Paris Agreement. Its various requirements are discussed in the next sections. Every aspect of the green energy transition – at whatever speed – will have important environmental, social, economic and financial impacts. The transition will unfold against the background of overall (thus far) subdued climate policies that must be sustained by favourable socioeconomic tipping points. What slows down such tipping points? The answer is various gaps, which are discussed next.

11 Thus, this new literature must comprehend the interactions between biophysical and socioeconomic tipping points. Tipping points in 'earth systems' will require unprecedented adaptation mechanisms. These are now starting to be fully integrated in the climate policy agenda.

4 SEVERAL GAPS AND ASYMMETRIES ARE COMING TO THE FORE (A 'COGNITIVE DEFICIT'?)

There is a need for setting shorter-term climate targets. As the end of this century, or even mid-century, is a distant date (for policymakers and the public), shorter-term goals have been set. For example, the EU's Fit for 55 package set the goal to reduce GHGs emissions by 55% in 2030 relative to 1990 levels – on the way to net zero by 2050 (Caselli et al. 2021). By the end of 2020, EU emissions had already been reduced by about 30% relative to 1990 levels; thus, a further 25% reduction of emissions is sought. However, the IPCC warns that projected emissions in 2030 will exceed those required to reach the Paris Agreement target by over 40% (Figure 3). After the initial reduction in emissions, progress seems to be stalling.

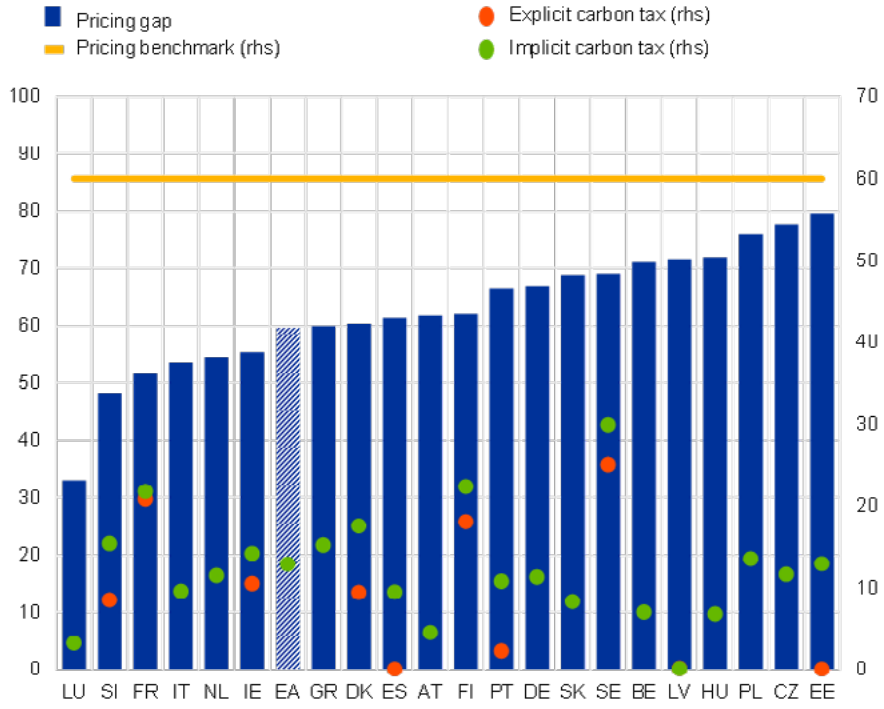
FIGURE 3 CLIMATE CHALLENGE NOT BEING TACKLED



Source: OECD (2022).

Several gaps are coming to the fore. Various gaps are affecting the speed and thrust of the progress in bringing net carbon emissions to zero and achieving the green energy transition. There is an '*ambition gap*' in setting climate commitments, but also an '*implementation gap*' (IPCC 2022, UNEP CCC 2021) (see Figure 4). As an example of the latter, Black et al. (2022a, 2022b) argue that "measures equivalent to a global carbon price exceeding $75 per tonne by 2030 are needed to stay below 2oC, whereas the current global average carbon price is only $5 per tonne" (see also OECD 2022 and IMF 2022). However, these are not the only gaps stalling the climate transition.

FIGURE 4 CARBON PRICING GAP IN 2018 (% OF BENCHMARK 60 EUR/TCO2)



Note: The carbon pricing gap measures the shortfall of pricing carbon emissions in the whole economy in line with the benchmark value of €60/tCO_2.

Source: OECD (2022).

Could there also be an awareness gap and a cognitive deficit? Perhaps there is still limited general recognition by the public at large of the climate dynamics in motion, and the risks they entail.[12] The public might be caught between different strands of the debate. The scientific community has been studying and documenting the impacts of climate change for decades, which has helped increase understanding and awareness of the issue, but mostly among more educated people (Hondroyiannis et al. 2022). Media coverage seems at times more sensationalist and focused on natural disasters than educational in raising awareness about the underlying causes, various policy challenges and the need to make difficult choices. Several forms of climate activism – including peaceful protests such as Fridays for Future, climate activist campaigns, and grassroots movements – have helped bring attention to the issue of daunting climate dynamics and put pressure on policymakers to act. Some extreme forms of climate activism might instead be backfiring. All in all, raising general awareness and climate education remain important steps to muster support for climate mitigations.[13]

12 Expectation management is also required. As GHGs cumulate and stay in the atmosphere for a long time, even strong mitigation policies to decarbonise might slow down new additions but might not prevent the adverse effects of already existing GHG stocks (inertias).

13 Admittedly, raising awareness also means broader uptake of 'indigenous knowledge' when it comes to living in synergy with nature, being especially important for adaptation to climate change.

There is also an acceptance gap vis-à-vis an orderly green transition. The acceptance of climate change mitigation policies can be low for various reasons. One is an awareness gap – not fully understanding the causes and impacts of climate change makes it difficult to then support mitigation policies. Another reason is political polarisation – climate change has become a politicised issue and different political ideologies often put forward different views on the causes and appropriate actions to take. Climate policies might be perceived as unequitable (e.g. the *gilets jaunes*) and are politically difficult due to concerns about loss of competitiveness and of jobs. Thus, perceived costs are high (more below). There is also a significant amount of misinformation and scepticism about climate change, which can make it difficult for individuals to distinguish between credible and unreliable information. Misinformation or information biases might be supported by specific economic interests.

A mountain to climb or the 'elephant in the room'? All in all, there is no simple or quick way to generate wide acceptance of climate policies. It might require efforts to educate the public while engaging in dialogues with all stakeholders, who may have different perspectives and legitimate concerns as well as diverse expectations. Better informing on the benefits of mitigating climate policies – e.g. cleaner energy, sustainable jobs, better synchrony with nature (which is important for our health), mitigation of extreme events – would have also psychologically beneficial consequences, perhaps leading to a brighter 'collective' mindset. It also will require policymakers to design, explain and implement mitigation policies in a way that considers the concerns and interests of different stakeholders.

A horizon gap is looming. The 'tragedy of the horizon' emerges because of the wide gap between the perceived timing of the potential ruinous impacts of climate change – i.e. in the very distant future – and the typical horizon for planning by businesses, politicians and public authorities. In the words of former Bank of England Governor Mark Carney, "*[o]nce climate change becomes a defining issue for financial stability, it may already be too late*".[14] The more recent empirical evidence cited above corroborates the view that the horizon is in fact shortening and both acute and chronic physical risks stemming from climate change are rising.

Asymmetric perceived costs and benefits. The above considerations about various gaps might bear on the perception of the trade-offs between the costs and benefits of undertaking decisive climate adaptation and mitigation policies.

- The costs might largely be perceived as clear and present and may be quite heterogeneous, including loss of competitiveness, job leakage and transfer of activities, slowing economy activity, rising prices and freeriding by other countries. The costs might even seem unwarranted by climate change sceptics.

14 See his speech of 29 September 2015 on "The Tragedy of the Horizon".

- The benefits might instead be seen as too far in the future and uncertain, more so perhaps than in the case of traditional investment decisions, despite increasing evidence that any short-term costs will be dwarfed by the long-term benefits of slowing and reversing climate change, such as general health improvements thanks to cleaner air that reduces mortality rates and morbidity from local air pollution, output, financial stability and biodiversity (Adrian et al. 2022, IMF WEO 2020, IPCC 2022).

Summing up

Several gaps and cognitive deficits are now coming to the fore. These represent stumbling blocks of various origins that require different solutions. There are trade-offs. The current daunting climate change dynamics and rising climate-related physical risks might impact awareness about climate change (not least because more people will experience these phenomena), raise acceptance of the need for climate actions and underscore the net benefits. The above scenarios – 'orderly' versus 'too little, too late' – have different implications for the costs-versus-benefits balance, as in the latter gyrations in risk aversion as well as social discount rates might be possible.[15]

5 AN EPOCHAL SHIFT IN ENERGY SYSTEMS IS REQUIRED.

The current energy system lies at the centre of climate objectives. Over 70% of current net GHG emissions originate from the energy sector (from electricity generation, transportation, heating, industry, and other uses). The green energy transition refers to a steady increase in the share of renewable sources of energy while reducing the share of fossil fuels (oil, coal, and natural gas). [16] The latter are presently the largest source of carbon emissions. Such a transition encompasses foremost a steady transformation of energy systems towards a rising mix of renewable sources, including solar for generating photovoltaic electricity, wind for eolic electricity generation, hydrogen, geothermal, hydropower, tidal, wave and biomass. Solar and wind energy are currently the most promising and scalable avenues to tilt the energy mix. The technology is advancing rapidly and the costs per megawatt are declining steadily. Hydrogen holds great potential, but needs further technological and infrastructure developments. Geothermal and hydropower already provide significant contributions and might not be able to increase much further, but they can be used in a complementary manner when dispatchable electricity is required. Other renewables might also contribute to the objectives of the green energy transition.[17]

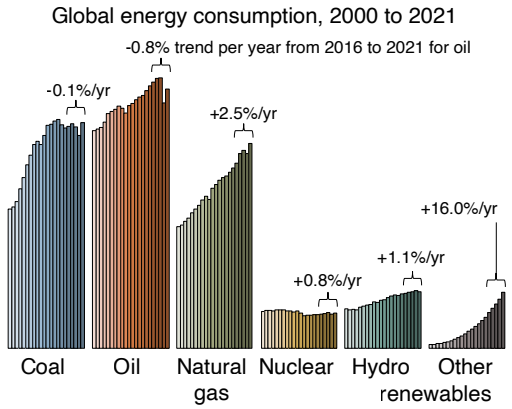
15 See also Mongelli et al. (2022). Moreover, disruptive financial events may generate a systemic crisis. See for example, the *'green swan'* catastrophic events mentioned in Bolton et al. (2020) and Bolton and Kacperczyk (2021).

16 'Renewable' is often used interchangeably with 'sustainable' and/or 'zero-' or 'low-carbon'. Technically, existing nuclear energy – as opposed to small modular reactors (SMRs) – is also low-carbon, but it presents various other issues and is not discussed in this chapter.

17 There is a drive to include nuclear energy from small modular reactors in the mix of renewables; this might be relevant for rapid reduction of GHG emissions while transitioning to full green energy mix (NEA 2022).

Where are we starting from? What is the current energy mix? To gauge the scale of the challenge facing us, it helps to get a picture of how energy is presently generated. The 'global carbon budget (Global Carbon Project 2022) reveals that coal, oil and natural gas remain the primary global energy sources even though renewables have begun to increase rapidly (Figure 5).

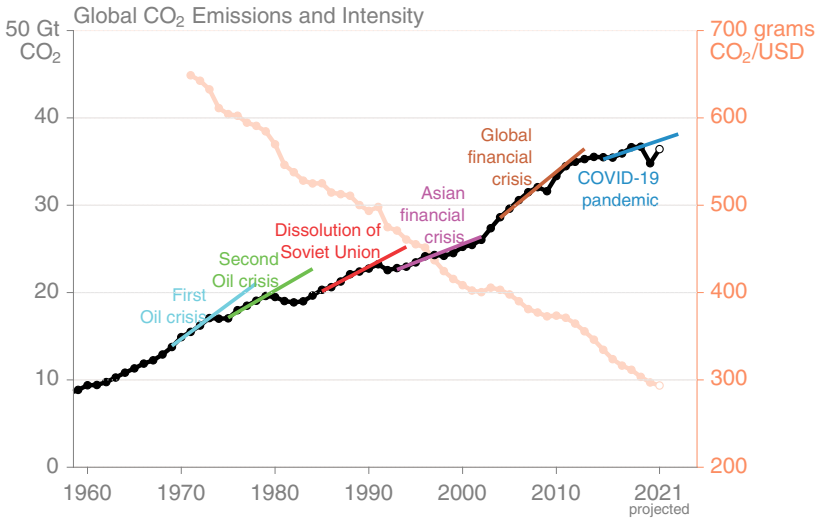
FIGURE 5 CURRENT ENERGY MIX, 2000-2021



Source: Global Carbon Project (2022) and Wikipedia (https://en.wikipedia.org/wiki/Energy_transition and https://en.wikipedia.org/wiki/Climate_Change_Performance_Index).

Is the level of aggregate emissions changing? Net additional fossil CO_2 emissions began to slow down after the 2008–2009 global financial crisis, decelerated during the 2010–2012 euro area crisis, sank at the start of the 2020 pandemic, but rebounded thereafter (Figure 6).

FIGURE 6 GLOBAL CO2 EMISSIONS AND ENERGY INTENSITY, 1960-2022



Source: Used with permission of the Global Carbon Project under the Creative Commons Attribution 4.0 International license.

In other words, there has still been no start to the needed downward trend in GHG emissions. At the same time, it is encouraging that the global energy intensity has declined consistently since the 1970s.[18] The overall energy intensity of an economy is shaped by three factors: growth of the economy, energy intensity per se and the GHGs content of the energy required.

Summing up

Climate trends are daunting and there has still been no detectable reversal in GHG emissions from the slowly changing mix of current energy sources to suggest the start of a green shift. Thus, the scale of the decarbonisation challenge remains immense and as times passes and the global carbon budget is depleted, we may be getting further away from the Paris 2015 objectives.

6 SOME FINAL REMARKS

The green energy transition requires structural shifts in all features of energy systems – including supply, distribution, energy usage and consumption – but also in industrial systems, housing and land usage. The scale of the challenge is immense, yet in terms of contributing to reaching the goals in the Paris Agreement, it has barely started (although some progress is already noticeable).

Given various adverse climate-related and ecological tipping points (CETPs), we are facing known unknowns but also several unknown unknowns. One of the impediments today to starting vigorous climate policies and the green energy transition seems to be awareness and 'cognition': there might still not be an adequate constituency to support upscaling climate policies and the green energy transition.

This stumbling block might change more rapidly than others, as argued in the nascent discussion about favourable socioeconomic tipping points (SETPs). There could be tipping points leading to cascading decarbonisation effects, such as reductions in the prices of solar panels as well as other renewables (that could lead to a rapid surge in uptake), parity in prices of electric and internal combustion mobility (LCOEs), or replacing meat proteins with plant-based proteins.

Yet, success in the green energy transition ultimately hinges on concerted actions by governments, which have several policy instruments at their disposal to mitigate climate change (such as carbon pricing). The thrust, coordination and credibility of climate policies will also have profound effects, which are discussed in a complementary chapter in this eBook. Similarly, the green energy transition will require adequate financing, which presents a novel set of challenges that are also discussed in a separate chapter of this eBook.

18 See also Andrew (2022) and Hannah et al. (2020).

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CHAPTER 15

The green energy transition, part 2: Drivers, effects of carbon pricing, new externalities and policy challenges

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1 INTRODUCTION

There is a scientific consensus that the Earth's climate is warming due to rising concentrations of greenhouse gases (GHGs). The latest report of the Intergovernmental Panel on Climate Change (IPCC 2022) predicts that we will reach 1.5°C global warming already in the next decade. Climate change is increasingly affecting our societies and economies. Adapting to it, and mitigating its consequences, requires a rapid transition to a low-carbon economy. The primary responsibility for this shift rests with governments. They are legitimised and have a broad spectrum of policy instruments at their disposal, such as setting the necessary price of carbon emissions, defining a regulatory framework to reduce emissions and undertaking needed sustainable investments.

A global policy response is embodied in the 2015 Paris Agreement (COP21), which enshrined the goal of 193 countries to keep global warming well below 2°C above pre-industrial levels, but preferably below 1.5°C, by 2100 . However, progress by governments in reducing domestic carbon emissions, embedded in National Determined Contributions (NDC), has thus far been slow and uneven.[2]

Moreover, government action alone is not enough to address the complexity and scale of the sustainable transformation required to achieve climate goals. There is a growing consensus that a comprehensive policy package would be more effective in tackling the market failures at the roots of the climate challenge. This requires a mix of fiscal, regulatory and structural measures as detailed in Pisu et al. (2022), as well as financial policy instruments (ECB 2021, Weder di Mauro 2021).

This chapter is organised as follows. Section 2 reviews the principal climate policy instruments available to governments. Section 3 discusses the connections between carbon taxes and carbon pricing. Section 4 inquires whether carbon pricing is effective.

1 I am grateful for comments from Andrej Ceglar, Fabio Tamburrini, Gabriel Fagan, Carol-Sue Lehmann, Jan Willem van den End, Jakob Feveile Adolfsen, Ariana Gilbert-Mongelli, and Carl Bruce. I am responsible for any errors and omissions and the views might not represent those of the ECB.

2 See https://climateactiontracker.org/ and www.climatewatchdata.org/net-zero-tracker.

Section 5 finds that the energy transition is also driven by market forces. Section 6 lays out a set of externalities and challenges that are commensurate to the scale and thrust of the epochal shifts in energy systems. Section 7 briefly lists some macro-impacts from the green energy transition. Section 8 presents some final remarks.

2 WHAT IS DRIVING THE GREEN ENERGY TRANSITION?

Internalising externalities with a Pigouvian tax. Market failures have long been identified as the root cause of the anthropogenic component of climate change. The price of fossil fuels does not account for the cost of depleting a free resource, namely, the clean environment (which is becoming scarce). In the words of a Nobel Prize winner, "*[t]he problem is that those who produce the emissions do not pay for that privilege, and those who are harmed are not compensated*" (Nordhaus 2013). To tackle environmental risks and the climate challenge, governments could levy a Pigouvian tax commensurate to the damage generated by the emission of GHGs. Diverse challenges must be addressed. For example, what might be an adequate range for such a tax? Guidance can be provided by computations of the social cost of carbon (SCC), which is not easy to ascertain and is currently not the most commonly used instrument.[3]

Governments have several policy instruments at their disposal to mitigate climate change. National governments have a broad spectrum of policy levers at their disposal over and beyond Pigouvian carbon taxes (Boneva et al. 2022). Such climate policy instruments, which are not mutually exclusive but complementary, can be price based or non-price based (see OECD 2022 for a detailed description). Some instruments can even be motivated by other policy needs, such as raising revenues, but are highly climate relevant (see Table 1).

Climate instruments must adapt to local and regional circumstances. While explicit carbon pricing is still seen as the foremost climate instrument, views have come around to embracing a wholistic approach as the most effective, i.e. deploying all instruments as needed. For example, carbon pricing is contained in most US states, while subsidies are used to influence the shift of relative prices between high- and low-carbon-intensive production processes and services.

3 The SCC estimates the economic costs of emitting one additional tonne of carbon dioxide into the atmosphere. SCC frameworks have both supporters and detractors. Furthermore, SCC estimates might vary depending on some critical assumptions such as the social discount rate, population growth, and TFP productivity. These estimates provide a valuable framework for linking diverse facets of the assessment of carbon pricing (for example, IAM-DICE models; see Wang et al. 2019, Kaufman et al. 2020 and Lutz et al. 2021).

TABLE 1 CLIMATE CHANGE MITIGATION POLICY INSTRUMENTS

Instruments	Price-based		Non-price-based
	Explicit carbon pricing	Other price-based	
Climate policy instruments[a]	Carbon taxes Emissions trading systems (ETS) Cap and trade	Emissions-based vehicle taxes (e.g. Euro 6) Feed-in tariffs Feebates Tradable GHG emissions	Corporate tax incentives GHG emissions intensity standards Technology mandates or prohibitions Climate R&D Bonuses for energy conservation
Non-climate policy instruments[b]		Fuel excise taxes Fossil fuel subsidies Electricity excise taxes Electricity subsidies Other subsidies[c]	Air pollution standards Chemical regulations (e.g. fertilizers)

Note: a Main policy motivation is to reduce GHG emissions. bMotivated by other policy needs, such as raising revenues, but highly climate relevant. c For examples, subsidies to some industries, agriculture and/or household (e.g., lump-sums). Instruments not mentioned in the table, include biodiversity policies and nature-based solutions (e.g., carbon sinks), which can have mitigation benefits as well.

Source: Adapted and extended from OECD (2022).

3 CARBON PRICING AND ITS AIMS

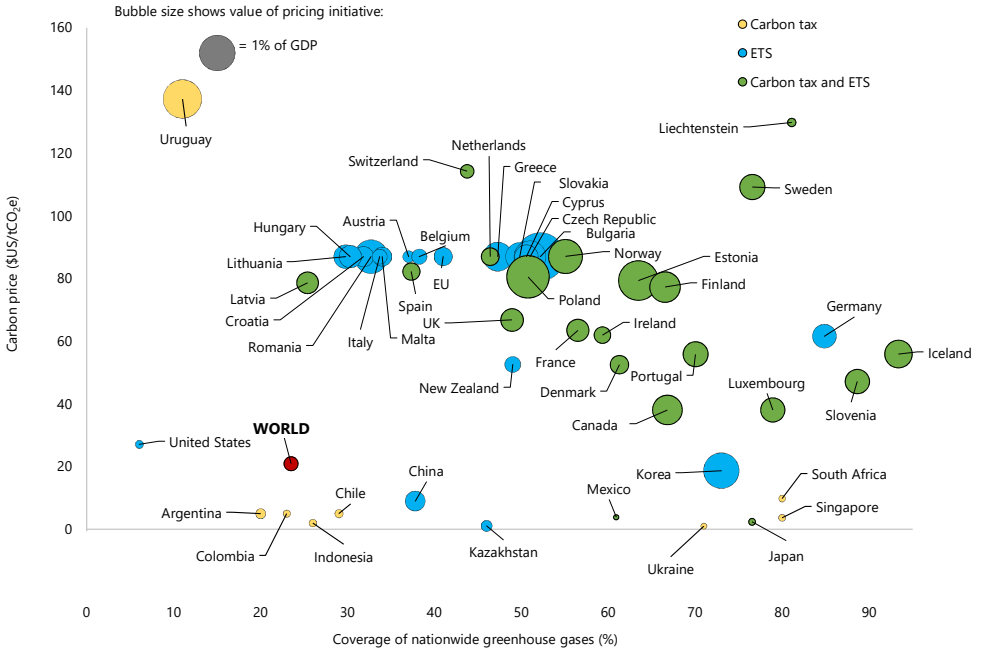
'Carbon pricing' is a broader concept than levying a Pigouvian carbon tax. Carbon pricing is a fundamental element for the decarbonisation process and the transition towards green energy. Different approaches to calculating it have been formulated by various countries and institutions. In a recent set of reports, the OECD puts forward the concept of *effective carbon rates* (ECRs), which summarise the way countries price carbon through a combination of fuel excise taxes, carbon taxes and emissions trading systems (ETSs) (OECD 2021).[4] For the World Bank, carbon pricing is an instrument that captures even more external costs stemming from the emission of GHGs such as, amongst others, carbon taxes, internal carbon pricing, carbon crediting mechanisms, ETSs and results-based climate finance (RBCF).[5] Thus, different approaches to estimating both current carbon prices as well as required carbon prices exist.[6] Figure 1 illustrates the wide variation in both coverage and levels of carbon prices across the world.

4 As a reference, the OECD has adopted a benchmark of €60 per tonne of CO_2 as a forward looking 2030 low-end and mid-range 2020 benchmark (OECD 2021), but postulates €120 per tonne of CO_2 by 2030. The IMF has adopted a slightly higher benchmark ($75 per tonne of CO_2).

5 https://carbonpricingdashboard.worldbank.org/what-carbon-pricing

6 https://cepr.org/voxeu/columns/carbon-taxes-may-be-boon-world-even-short-run

FIGURE 1 COVERAGE AND LEVELS OF CARBON PRICES, 2020



Note: Carbon prices are a weighted average between schemes (carbon taxes, ETS and excise taxes), and averages during 2020.

Sources: IMF (2022c).

There is a need to reconcile wide ranges of carbon pricing. The IMF is proposing a methodology to monitor various price-based and non-price-based climate mitigation instruments, both domestically and across countries. This is done by assessing the carbon price that would yield the same emissions reduction as non-pricing policies such as environmental regulations (Black et al. 2022a, 2022b). These *economy-wide carbon price equivalent* (ECPE) indicators are computed at the national level, and can support the design of cost-effective mitigation strategies and permit international comparisons and monitoring.

What are the aims of carbon pricing? Carbon pricing is potentially the most important climate policy instrument in most countries. It has various intended effects and transmission channels, including:

- **It induces a shift in energy systems**. Higher carbon prices raise the prices of carbon-intensive fuels and electricity. Therefore, the costs for domestic goods and services with higher carbon content increase, which is a terms-of-trade effect ('competitiveness channel'). Thus, carbon pricing provides an incentive for all economic agents to reduce carbon-intensive energy use and shift to cleaner fuels. Strategies include promoting innovative research in green technologies and

fostering investments in energy savings infrastructures. It also impacts the relative prices of energy sources by penalising the most carbon intensive fossil fuels (e.g. coal and oil and gas).

- **It has a signalling effect**. Progressively increasing carbon prices at a steady and predictable pace, impacting the expectation formation mechanism, while phasing out fuel and/or electricity subsidies exhibits a clear commitment. It builds trust that the transition to net zero/decarbonisation is needed and will be pursued jointly with other climate instruments. Clear and steady climate policies foster, amongst other things, investments in green energy sources, research on green technologies and energy conservation. Carbon pricing will over time reduce the incentive to invest in the fossil fuel sector (e.g. coal and oil), with uncertain effects during the energy transition.
- **It is more flexible than other climate instruments**, such as regulatory approaches and energy standards. It leaves economic agents (e.g. energy producers, firms and households) with the choice of how they become more energy efficient and cut emissions; different carbon emitters might pursue different options.[7]
- **It generates fiscal revenues**. Carbon pricing raises fiscal revenues and yields fiscal space.

Summing up

While an explicit 'Pigouvian' carbon tax might be in principle the foremost climate instrument, in reality several new aspects have surfaced. The actual 'price', or price range, can be gauged with estimates of the social costs of carbon. The latter should guide policymakers towards carbon pricing as a wholistic concept capturing carbon taxes, fuel excise taxes and emissions trading systems. It is then indispensable to ascertain whether adequate carbon pricing across stakeholders induces a shift in energy systems, has a signalling effect, drives structural changes and generates fiscal revenues.

4 DOES CARBON PRICING WORK? YES

Incipient empirical evidence shows that carbon pricing is impactful in reducing emissions of GHGs. The OECD finds that an increase of effective carbon rates by €10/tCO_2 reduces emissions by 3.7% on average in the long run (OECD 2022). The UK has adopted a carbon price floor in the power sector which has yielded significant reductions in emissions even in the short term, of 20–26% per year on average (Leroutier 2022). A recent empirical review confirms that "*carbon pricing has significant and relatively large normalised*

7 *Sectoral carbon price equivalents* (SCPE) are also computed, for example, to guide the design of cost-effective mitigation strategies and limit cross-sectoral divergence in incremental abatement costs.

effects (i.e. accounting for the low level of prices so far), in terms of emissions reduction in general (through behavioural change, technology adoption and substitution) as well as pure innovation impacts" (van den Bergh et al. 2021).

Coenen et al. (2023) develop an extension of the New Area-Wide Model with a disaggregated energy sector and carbon emissions. The model is used to model quantitatively the macroeconomic effects of the low-carbon transition in the euro area. They find that increasing carbon taxes to an interim carbon target level consistent with net zero by 2050 produces a transitory increase in annual inflation (with a peak of 0.2 percentage points in the year following the introduction), and generates a moderate but lasting decline in GDP (of around 1.2% by 2030) while the emissions decline by about 7%.

Raising and using the proceeds from carbon pricing

Increasing carbon prices can raise significant revenues in the short to medium term, depending on how fast the carbon price rises and subsequently the tax base of emitted carbon erodes as economies decarbonise. If the net effective carbon rate (ECR) were raised to reach €120 per tonne of CO_2 across fossil fuels, European governments might raise on average between 0.3% and about 2.0% of GDP per year (OECD 2021). The pure Pigouvian carbon tax component of the carbon price (explicit and implicit) is thus far modest, with rare exceptions (IMF 2022a). There is also a wide-ranging debate concerning the allocation of such proceeds to partly alleviate their negative effect on consumption and production, by using them to:

- reduce distortionary labour taxes;
- compensate firms/sectors affected by the transition and compensate low-income households, which are most affected by an increase in energy prices (through tax cuts, subsidies or lump-sum transfers);
- pursue other fiscal objectives such as reducing public debt; or
- sustain mitigation efforts, such as by supporting innovative research and developments and investing in deployment of green technologies and green smart and digital infrastructures.

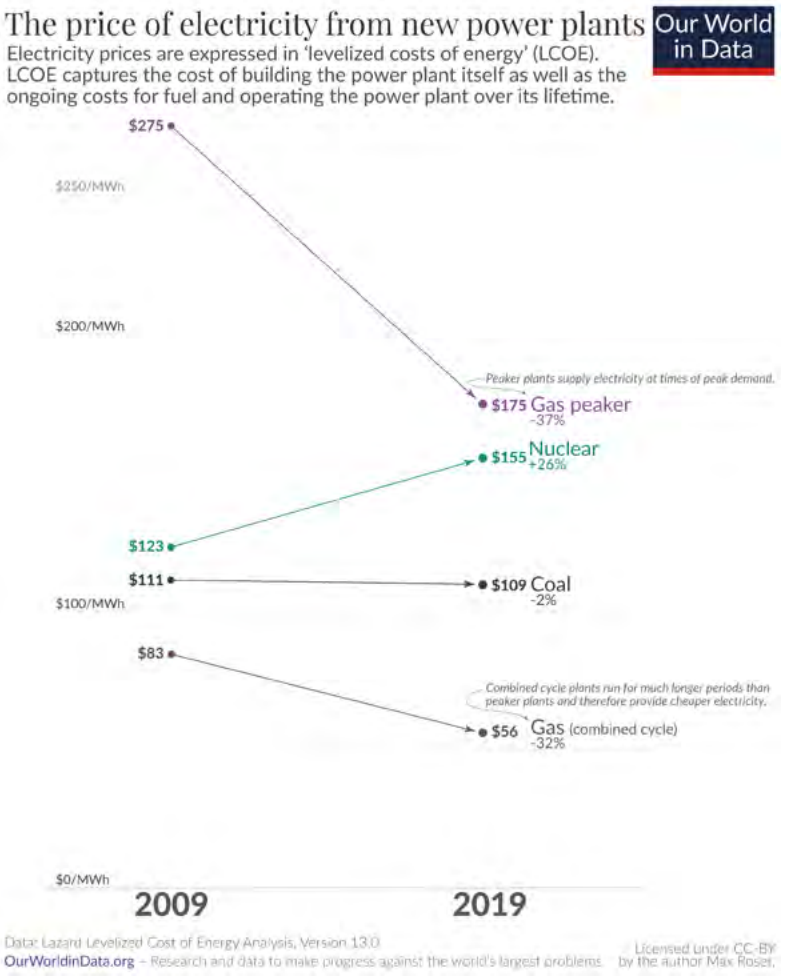
Summing up

Depending on how the carbon pricing revenues are used, they can have vastly different effects on support for the energy transition, economic activity and inflation. Ultimately, the revenues can affect the path of decarbonisation, and thus the tapering of climate risks (IMF 2022b). Incidentally, should the fiscal component of climate policies be budget neutral, as assumed by most papers? And how do we assess the rate or return and profitability of green investments that might raise the chance of reducing future climate risks?

5 OTHER DRIVERS OF THE GREEN ENERGY TRANSITION? MARKET FORCES!

Solar and wind generated electricity are already increasingly price competitive. Market forces and continuing innovation are driving down prices of renewable electricity sources (Figure 2). Adoption has picked up in recent years thanks also to a virtuous feedback cycle between increased performance and efficiency, economies of scale, feebates, favourable feed-in tariffs and other supportive policies. Thus, market forces are sustaining the green energy transition (see also Frauenhofer Institute for Solar Energy Systems 2021).[8]

FIGURE 2 PRICE OF ELECTRICITY FROM VARIOUS SOURCES, 2009-2019



8 The analysis based on calculations of the levelised cost of electricity (LCOE) capturing the average net present cost of generation by means of different generating plants over their lifetime also backs this evidence (IEA 2022a, 2022b).

Summing up

Support for renewable sources of electricity, and thus the green energy transition, will remain strong on the regulatory as well as the cost side. Technological innovations and smart grids might soon be able to address issues of intermittence and low and uneven storage capacity. However, in later sections we will look at a different troubling side of the green energy transition – the supply side for the indispensable hardware and critical climate minerals (e.g. rare earths).

6 HOW RAPIDLY CAN THE GREEN ENERGY TRANSITION UNFOLD?

Assuming that the various 'gaps' and cognitive deficits can be tackled, how rapidly could the green energy transition unfold? Several processes now based on fossil fuels are gradually being electrified, such as transportation, heating and many manufacturing activities. The share of renewable electricity has been rising steadily, but suffers from drawbacks that have to be addressed:[9]

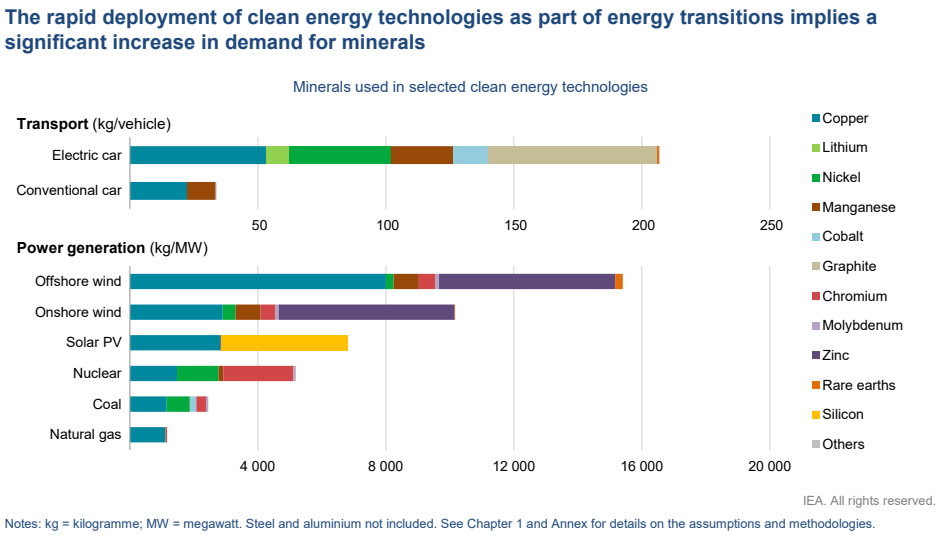
- It can be intermittent (e.g. wind generated electricity falls with no wind, and PV is absent at night and is low in cloudy weather).
- The electric grid might have to be digitalised (smart grids) and expanded to integrate diverse renewable energy sources such as hydropower and, eventually, hydrogen (green and blue), while gradually reducing the role of gas-powered plants for stop gaps and dispatchability.
- Active energy demand management will need to be encouraged to steer electricity consumption in the hours when supply of renewable electricity is strongest.
- Power and storage capabilities will need to be increased, such as with giant lithium-ion battery plants (in California, for example, four hours of electricity supply are already available on demand), pumped-storage hydropower, and eventually hydrogen (generated when renewable electricity is in high supply or as a by-product of other chemical or industrial processes).

The technology and know-how to scale up the green energy transition exists. In many respects, the technology and ability to rapidly scale up the contribution of renewable electricity exists and is already price competitive (although prices are expected to decline further thanks to innovation and economies of scale). Yet, the energy shift will need to be phased in while rising green electricity supply meets the soaring demand for EV transportation, domestic uses and industry (amongst others). Since 2010, the average amount of minerals needed for a new unit of power generation capacity has increased by 50% as the share of renewables in new investment has risen. Electric cars require

9 For a comprehensive review and several sources and illustrations, see "Technology Quarterly: The Energy Transition", *The Economist*, 25 June 2022.

considerably more climate-critical minerals than conventional cars (upper portion of Figure 9). Similarly, green energy technologies require considerably more critical minerals compared to other power generation sources (IEA 2022a) (lower portion of Figure 3).

FIGURE 3 MINERALS USED IN CLEAN ENERGY TECHNOLOGIES (CARS AND POWER GENERATION)



Notes: kg = kilogramme; MW = megawatt. Steel and aluminium not included. See Chapter 1 and Annex for details on the assumptions and methodologies.

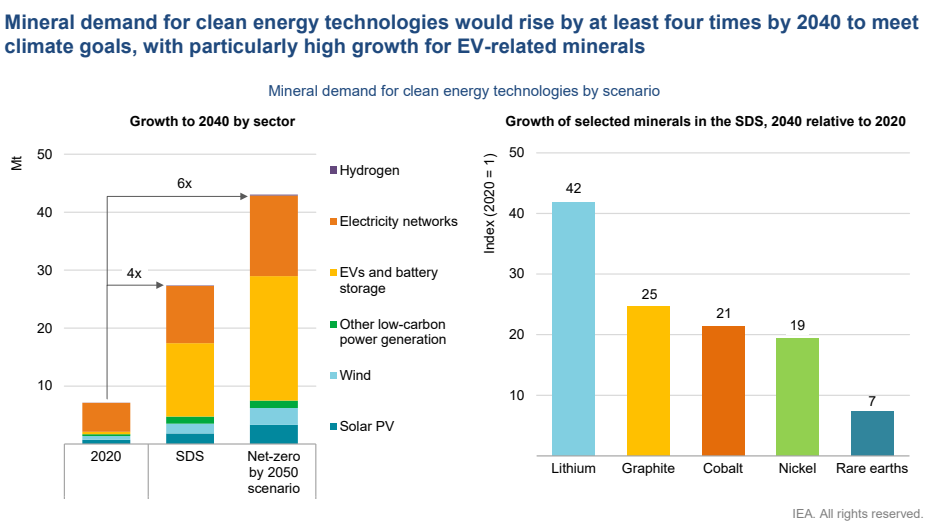
Source: IEA, Minerals used in electric cars compared to conventional cars, IEA, Paris https://www.iea.org/data-and-statistics/charts/minerals-used-in-electric-cars-compared-to-conventional-cars, IEA.

Demand for critical climate minerals will soar. The IEA calculates that the deployment of clean energy technologies as part of the green energy transition implies a significant increase in demand for minerals (IEA 2022b, Miller et al. 2022, Dees et al. 2023). Given current technologies, efforts to reach the Paris Agreement goal of climate stabilisation at "well below 2°C global temperature rise" would quadruple the overall need for critical minerals for green energy technologies by 2040 (Valckx et al. 2021). An more rapid green transition, to hit net-zero globally by 2050, entails six times more critical minerals in 2040 than today (left panel of Figure 4). The picture gets even more challenging for some critical minerals (right panel of Figure 4). By 2040, the production of nickel would have to grow 41-fold, that of cobalt 21-fold, and that of copper and graphite 28-fold, which represents an exponential trajectory for such resources.[10] Already in the short-term,

10 For example, each megawatt of electricity generated with offshore windmills, requires 16 tonnes of combined 'transition minerals', compared to 6.8 tonnes on average for photovoltaic plants.

global demand for several critical transition minerals will exceed known supply capacity – for example, by 2025 in the case of copper and 2024 in the case of cobalt, according to the IEA (2022b).[11]

FIGURE 4 TOTAL MINERAL DEMAND FOR CLEAN ENERGY TECHNOLOGIES, 2020 COMPARED TO 2040



Notes: Mt = million tonnes. Includes all minerals in the scope of this report, but does not include steel and aluminium. See Annex for a full list of minerals.

Source: IEA, Total mineral demand for clean energy technologies by scenario, 2020 compared to 2040, IEA, Paris https://www.iea.org/data-and-statistics/charts/total-mineral-demand-for-clean-energy-technologies-by-scenario-2020-compared-to-2040, IEA

Two sensitive aspects should be taken into consideration:

- **Paradox** (1). Our dependency on fossil fuel-derived energy has inertia. This is a legacy of the current energy system mix and exposes us to 'fossilflation' (as discussed in a 2022 speech by Isabel Schnabel).[12] Although we are witnessing a shift towards renewable sources, fossil energy is needed to manufacture renewables equipment (e.g. solar and eolic plants and equipment). We can call this a 'carbon bias' of renewables that slows down the green energy transition. Thus, sustainable energy sources are by definition carbon neutral, but only after they pay off the energy and resources needed in their production.

11 Electric vehicles alone will require formidable investments in infrastructure (production, maintenance, charging stations and so on) and a willingness to switch by households and firms. Training of labour forces and reskilling can take time and be costly. Costs of transportation and installations might rise in case of expedited scaling up such as for training of personnel, bottlenecks, maintenance and so forth.

12 'Fossilflation' is to blame for much of the recent strong increase in euro area inflation. In February 2022, energy accounted for more than 50% of headline inflation in the euro area, mainly reflecting the sharp increases in oil and gas prices (Schnabel 2022).

- **Paradox (2)**. Dependency on rare earths (RE) as well as copper and other key minerals might generate 'climateflation' (as also discussed in the 2022 speech by Isabel Schnabel).[13] However, it also generates a dependency on imports for most energy producers from possibly oligopolistic countries and companies.

Summing up

The 'knowhow' for the green energy transition exists and is rapidly improving. Yet, there will be three contemporaneous strains on demand for critical climate minerals. The infrastructure to generate green energy will jack up their demand, but vehicles using the green energy will require as much or more critical climate minerals. Supply of these materials will have to rise exponentially and well beyond currently known reserves. Paradox 1, concerning 'fossilflation', will be gradually abated by a rapid shift in the energy mix during the green transition. Paradox 2, concerning 'climateflation', can be abated by innovation plus new technologies, new sources of critical transition minerals, as well as recycling and energy savings.

7 MACRO-IMPACTS OF THE GREEN ENERGY TRANSITION

Carbon pricing has asymmetric effects on exporters versus importers of energy. There is agreement that a rise in the carbon price raises costs of production, generates some inflation, lowers investments, lowers potential output, generates some fiscal space, and has some terms-of-trade effects (Holland et al. 2021). Yet, the net effects might be vastly different for fossil-fuel-rich countries versus net importers of fossil energy. Higher carbon prices redistribute revenues from fossil fuel exporters and distributors (making giant profits today!) to energy importers (Holland et al. 2021, Pisani-Ferry 2021, IMF 2022a).

It is important to consider the role of the energy intensity of output as well as the carbon intensity of energy. The National Institute for Economic and Social Research elaborates a NiGEM climate model and finds that a carbon price levied globally is expected to have a transitory impact on inflation (Holland et al. 2021). Importantly, country-specific responses will differ, depending on the energy intensity of output as well as the carbon intensity of energy in various countries, i.e. the impact might be more severe in countries more dependent on coal. Moreover, fossil fuel exporters suffer from a loss of terms of trade. Crucially, a policy that channels carbon revenue into green investments might offset the bulk of the higher transition costs at the global level (Hafner et al. 2020). Even in a such a slowly unfolding transition scenario, might 'fossilflation' still be a risk? Yes, as these are oligopolistic markets. While known reserves cover fossil fuel needs consistent with even the upper bound of the current carbon budget multiple times,

13 Today, China refines about 40% of the copper, 35% of the nickel, 65% of the cobalt and 58% of the lithium produced globally. Thus, on rare earths we can speak of a Chinese monopoly, not only in production but also in refining.

there might be incentives to restrict explorations and extraction of residual fossil fuels to maximise residual fossil fuel rents and perhaps segment energy markets. We don't know a priori. There are caveats.

Friend-shoring might not be that friendly after all. Against the background of the above empirical evidence of manageable impacts from rising carbon prices, the current debate in the green energy arena is dominated by plans to regionalise value chains. We might be moving back to re-industrialisation policies, with all the uncertainties, costs and duplication that this entails. On one hand, we see the unfolding of the Inflation Reduction Act (IRA) in the US that is the climate legislation that will channel $369 billion towards clean energy projects. It includes tax breaks for US-based companies amounting to $270 billion. This threatens to disadvantage non-US firms and lure them to the US. On the other side of the Atlantic, the Green Deal Industrial Plan in the EU would make €250 billion available from existing EU funds for the greening of industry, including offering tax breaks to businesses investing in net-zero technologies.

Summing up

Rising carbon pricing will have asymmetric effects across countries depending on their fossil fuel energy autonomy, their energy intensity of output as well as the carbon intensity of energy. These dependencies and parameters are dynamic and will shift thanks to the green energy transition. One known unknown will be the workings of competing reindustrialisation plans and clashes between economic and financial regions. This forestalls further geopolitical fragmentations and a clash of research, innovation, competing approaches and beyond – all to the detriment of decarbonization of course.

8 SOME FINAL REMARKS

The green energy transition requires sustainable shifts in all features of the energy system – including supply, distribution, and energy usage and consumption – but also industrial systems. The scale of the challenge is immense, yet in terms of contributing to reaching the goals in the Paris Agreement, it is has barely started (although progress has been noticeable already).

Experts are warning us that the new green energy mix might unfold over a long period due to inertia, the paradoxes described above, and current concerns about energy security. The transition might require further digitalisation and adaptations of electric grids, changes in habits, and might exhibit fluctuations in energy flows and require dispatchability and back-ups (even fossil fuel backups) for a certain period (see Blanchard et al. 2022 for a portfolio of policy proposals). We might have to reflect more on energy efficiency and conservation and saving during a prolonged interim period.

Several caveats apply, and further steps should build on scenario analyses (e.g. the macro-scenarios elaborated by the Network for Greening the Financial System that weight the timeliness and thrust of adaptation as well as mitigation efforts). It might help to think in terms of two extreme developments: (1) a predictable, 'orderly scenario' in which rapidly adapting to the climate challenge and mitigating its pace via a swift transition to a low-carbon economy reduces future climate risks and brings several benefits; and, at the opposite extreme, (2) a 'too little, too late' scenario marked by a disorderly transition, with inadequate climate actions resulting in increasing physical risks. Risks of extreme fossilflation combined with climateflation are substantially higher in the 'too little, too late' scenario and more moderate in the 'orderly' scenario. There may be higher and more volatile inflation in the later climate transition. The effect could be compounded by greater economic and financial disruptions stemming from serious, even catastrophic, physical damages occurring in the 'too little, too late' scenario. Admittedly, this discussion is tentative and preliminary at best.

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CHAPTER 16

The green energy transition, part 3: Climate finance opportunities, perspectives and strains

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1 INTRODUCTION

Climate change is increasingly affecting ecosystems, our society, and the economy. Scientists have long presented daunting evidence that climate trends and warming dynamics are worsening at an accelerated pace and, consequently, physical risks are on the rise (IPCC 2022, UNFCC 2022). A global policy response – to keep global warming well below 2°C, but preferably below 1.5°C, above pre-industrial levels by 2100 – was embodied in the 2015 Paris Agreement. However, progress by governments in reducing domestic carbon emissions has thus far been slow and uneven. The focus of this chapter is on the green energy transition. About 70% of today's global greenhouse gas (GHG) emissions, are emitted by the energy sector. Therefore, success in the green energy transition is central to reaching the 2015 Paris goals.

On the real economy side, many steps for the green energy transition have become clearer in recent years: a sustainable transformation of economic structures is needed. We know what to do technically and industrially, as well as how to foster decarbonisation. Moreover, renewable sources of energy are getting cheaper because innovation is advancing rapidly. Nevertheless, substantial hurdles remain, such as the availability of sufficient critical climate minerals (including rare earths), the sharing of technologies globally, and the time it takes to scale up climate-related investments.

On the financial side, a legitimate question now is: how much might the green energy transition cost and how could it be funded? A massive commitment toward 'green investments' is needed. Yet, only a few global estimates exist, and several features of this discussion are just emerging (IRENA 2022). The 2022 IPCC report flags that there is no agreed definition of climate finance. Thus, available estimates should be welcomed

1 I am grateful for comments from Andrej Ceglar, Fabio Tamburrini, Gabriel Fagan, Carol-Sue Lehmann, Jan Willem van den End, Jakob Adolfsen, Ariana Gilbert-Mongelli, Laurent Abraham, Ettore Dorrucci, and Anil Shamdasani. I am responsible for any error and omission and the views might not represent those of the ECB. In loving memory of Niki.

but also treated with prudence as they are not necessarily comparable. Underlying assumptions and approaches might vary widely – for example, around aim (1.5°C versus 2.0°C) and time horizon (2030 versus 2050).

This chapter explores some selected features of this debate. It is organised as follows. Section 2 presents several classifications of green investments. Section 3 reviews recent estimates concerning sustainable financing needs. Section 4 brings in social discount rates. Section 5 reviews the actual available sustainable financing. Section 6 presents some final remarks, new approaches and perspectives. Considerations stemming from disorderly scenarios and exacerbated climate risk premia are left out. This chapter does not present definite conclusions and isolates some trade-offs.

2 NOT ALL GREEN INVESTMENTS ARE EQUAL! SOME MAY BE 'UNPRODUCTIVE', YET ARE INDISPENSABLE

Green investments can be classified either in terms of the technologies employed or their environmental objective. In recent years, combined renewable power technologies have started dominating the global market for new electricity generation capacity. In 2020, 260 gigawatts of solar photovoltaic (PV), wind, bioenergy, hydropower, and other solar sources were installed, exceeding by fourfold fossil fuels and nuclear new electricity generation (IRENA 2022). This encouraging process must be complemented by additional types of green investments, including higher energy conservation and efficiency efforts, the electrification of end-use sectors, rising production and direct usage of clean hydrogen and synthetic fuels, and rising diffusion of bio-energies and carbon capture and storage (CCS). Each of these strands of the green energy transition raises its own challenges and has its specific financing needs.

The degree of granularity in the specific types of green investments will likely continue to increase. An example is the EU Green Taxonomy on Sustainable Finance (Regulation 2020/852). This tool helps investors, companies, issuers and project promoters to navigate the transition to a low-carbon, resilient and resource-efficient economy (European Commission 2020). In order to qualify, green investments must satisfy diverse requirements. For example, investments must make a substantial contribution to one of six environmental objectives: (1) climate change mitigation; (2) climate change adaptation; (3) sustainable use and protection of water and marine resources; (4) transition to a circular economy; (5) pollution prevention and control; and (6) protection and restoration of biodiversity and ecosystems. Furthermore, the investments must not significantly harm the other five objectives and must meet minimum safeguards such as the UN guiding principles on business and human rights. Presently, 35 activities are included in the EU Green Taxonomy.

'Productive' or 'unproductive' versus 'additional' or 'non-additional'

Green investment can also be classified in terms of its macroeconomic implications. Green investment classification differentiates between two criteria – whether the investments are 'productive' or 'unproductive', and whether they are 'additional' or 'non-additional'. 'Productive' investments raise the productive capacity of the economy. Investments in solar, wind, smart-grids, hydrogen generation, energy dispatchability, and so on qualify as productive. However, we are witnessing a rising occurrence of climate-related physical risks (for example, from climate disasters such as heathwaves, storms, floods, and fires) as well as chronic phenomena (higher average temperatures, land erosion, droughts and desertification). Thus, green investments of another kind will also be required for adaptation purposes, to safeguard lives and property and for the completion of the green energy transition. Some examples include barriers against flooding, forest management, building shelters, and cooling factories. These outlays contribute to GDP during construction but are 'unproductive', although they protect other existing productive capital. Concerning the second criteria, a green investment is 'additional' if it adds to total investment expenditures as well as GDP and is financed with new securities or by means of carbon proceedings. Instead, 'non-additional' green investments might simply displace other investments, as other expenditures are reduced, resulting in a net zero effect on aggregate demand.

Learning to live with financial and non-financial returns from green investments

The combination of the above classifications and criteria yields different effects on aggregate green investments and the green energy transition. Victor (2022) observes that only a subset of the 35 activities listed in the EU Green Taxonomy qualify as both 'productive' and 'additional', and thus might generate a genuine market return. These include "clean or climate-neutral mobility", i.e. electric vehicles (accounting for 3 out of 35 activities). Eight out of the 35 activities encompass a mix of productive and non-productive activities such as increasing the recyclability of products. The remaining 24 activities are classified as non-productive (e.g. protecting the environment from the adverse effects of urban and industrial wastewater discharges).

Summing up

Not all 'green' investments are the same. Several types, dimensions and strands of green investments exist and might display varying synergies. The intertemporal dimension is also complex. The balance between productive and unproductive green investments, as well the possible rate of financial returns, might shift over time – an urgent and sensitive topic. A critical aspect is that investment in the green energy transition represents a public good that might be underprovided. The public sector will need to step up to enable and crowd-in private investments. This pertains to investments with very high multipliers such as in research and development (e.g. pioneering research on nuclear

fusion, semiconductors, energy storage and conservation, and so on), education and reskilling of existing and new workforces, and infrastructures (e.g. grids and energy storage).

A close analogy to the green energy transition is perhaps the decades of public funding for telecom and the launch of the World Wide Web – internet infrastructures on which BigTechs and telecom companies are now grounded (Mazzucato and Collington 2023). "*This means that government incentives and direct government investment on a very large scale will be required to achieve the level of green investment necessary for a successful green transformation*" (Victor 2022). Such public funding for 'unproductive' but indispensable green infrastructures will need to come mostly from public budgets (more on this later).

"*The real challenge of financing a green transformation will be paying for green investment that generates environmental and social benefits not captured in market prices, and which offer little or no financial return to the private sector*" (Victor 2022).

3 SUSTAINABLE GREEN FINANCING NEEDS TO SUPPORT THE GREEN ENERGY TRANSITION

There is growing understanding that the transition to a green energy system will require unprecedented global investments. The International Renewable Energy Agency (IRENA) predicts that the energy transition alone will require at least doubling of global annual investments (Figure 1):[2]

- The **Planned Energy Scenario** (PES) is the benchmark based on governments' current energy plans reflected in Nationally Determined Contributions (NDCs). PES already contains a green energy shift, but is insufficient to achieve the Paris 2015 climate goal.
- The **1.5°C Scenario** (1.5-S) instead captures the more ambitious energy transition pathway aligned with the 1.5°C climate target based on known and scalable technological solutions.

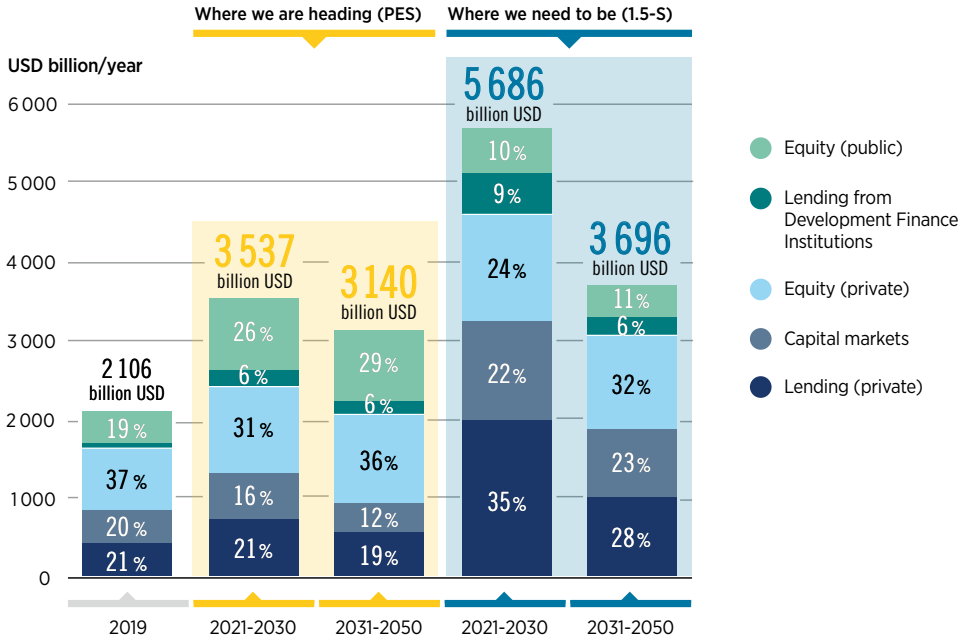
IRENA estimates that under the more ambitious 1.5°C Scenario, $131 trillion of cumulative green funds will need to flow into the energy system over the period up to 2050 (at a higher pace initially up to 2030 and declining thereafter). Thus, the annual average is about $4.4 trillion. This is equivalent to about 5% of global GDP and 20% of gross fixed capital formation in 2019. Between now and 2050, over 80% of this $131 trillion total must be invested in the green energy transition. As a background, the International

2 IRENA collects data on technology, innovation, policy, finance, and investment in all forms of renewable energy (https://www.irena.org/). It is a platform for international cooperation and supports countries in their energy transitions. See also the Global Energy Monitor (GEM) for information about energy sources (https://globalenergymonitor.org/).

Energy Agency (IEA) estimates that "[t]o reach net zero emissions by 2050, annual clean energy investment worldwide will need to more than triple by 2030 to around $4 trillion" (IEA 2021).

At the same time, this represents a 33% increase in energy investments plus a redirection of 25% of already planned energy investments! Energy investments unfold on a continuing basis. Current plans under the Planned Energy Scenario (PES) already envisage cumulative investments of about $98 trillion by 2050. This represents a near doubling of annual energy investment, which in 2019 amounted to $2.1 trillion. Substantial funds will flow towards modernisation of energy infrastructure and meeting growing energy demand. There is a $33 trillion difference, but $24 trillion of planned investments in the PES will have to be redirected from fossil fuels to energy transition technologies between now and 2050. The shares of the sources of financing also shift over time and across scenarios (more on this later).

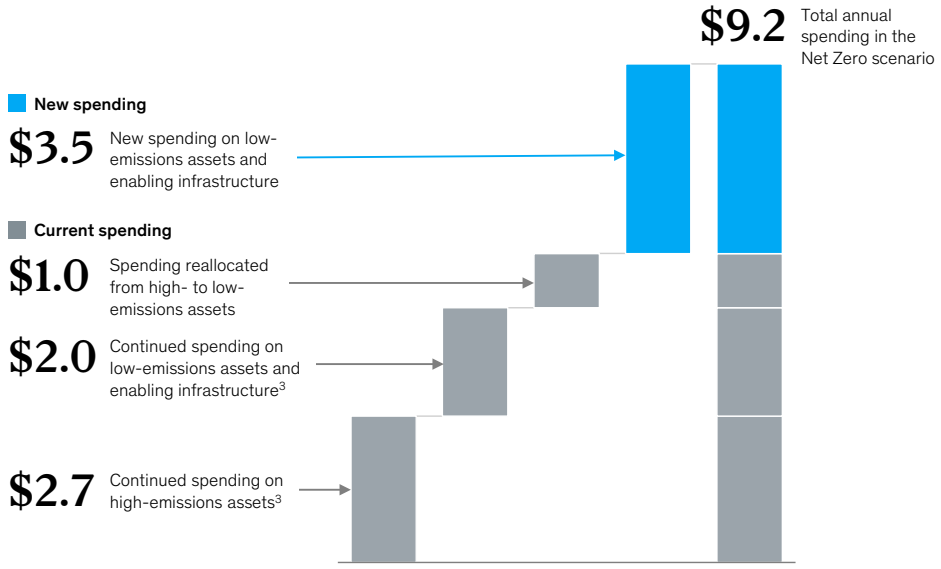
FIGURE 1 HISTORICAL AND PROJECTED ANNUAL INVESTMENT NEEDS



Source: IRENA (2021).

A similar, but higher, set of estimates of green investments exists. McKinsey estimates that reaching the goal in the Paris Agreement, i.e. net-zero GHGs by 2050, will require about $275 trillion of cumulative global investments in real capital over the next three decades (McKinsey 2022). This requires an ever-higher commitment to green investments.[3] It implies that annual spending on physical assets for energy and land-use systems in the Network for Greening the Financial System (NGFS) Net Zero 2050 scenario would rise to about $9.2 trillion annually, or about $3.5 trillion more than today (Figure 2). Moreover, $1.0 trillion of spending would need to be reallocated from high to low emission assets.

FIGURE 2 ANNUAL SPENDING ON PHYSICAL ASSETS FOR ENERGY AND LAND-USE SYSTEMS IN THE NGFS NET ZERO 2050 SCENARIO (AVERAGE 2021-50, $ TRILLION)



Note: See notes to Exhibit E5 in McKinsey (2022).

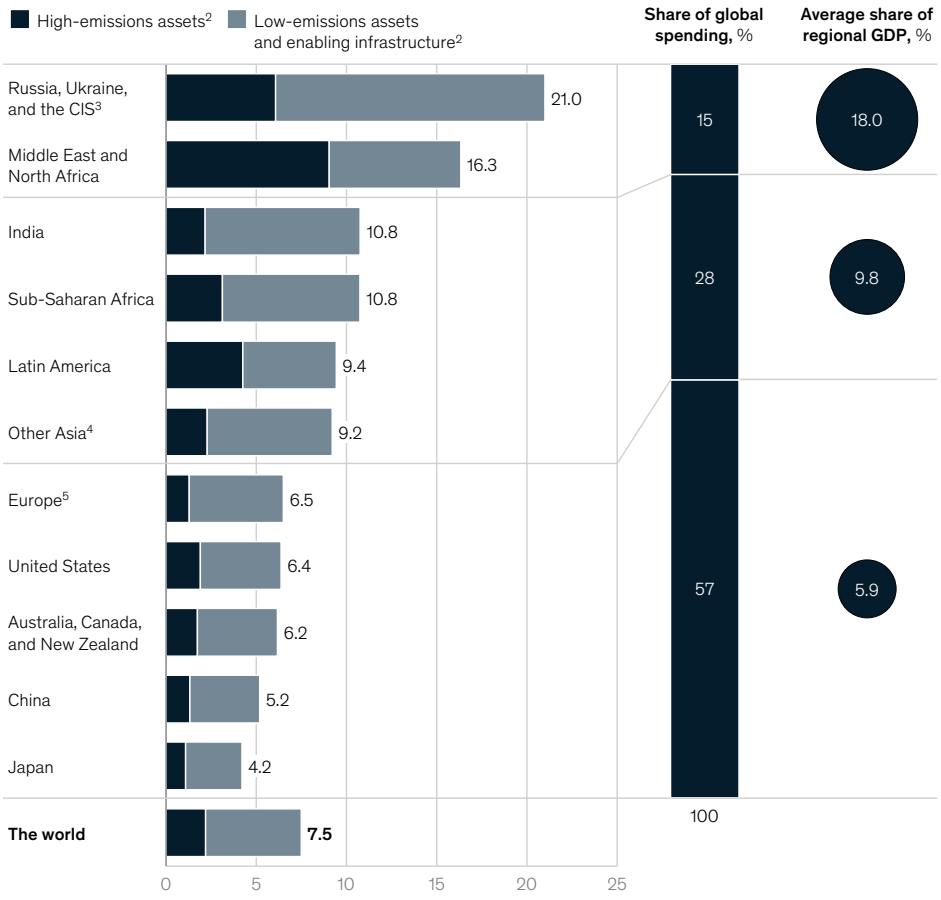
Source:: Exhibit from "The net-zero transition: What it would cost, what it could bring", January 2022, McKinsey Global Institute, www.mckinsey.com. Copyright (c) 2023 McKinsey & Company. All rights reserved. Reprinted by permission.

3 The stock of real capital that enables the functioning of the economy includes infrastructure such as roads, railways, harbors, and airports; water and sewage systems; power plants, refineries, pipelines; and buildings and equipment (Victor 2022).

As a percentage of GDP, fossil fuel-producing regions and developing countries would spend more than others on physical assets for the energy transition (Figure 3).

EU needs display a higher degree of granularity. Table 1 presents some recent estimates of the EU-wide investment needs (European Commission 2023). The estimates are what is needed in terms of green investment over the 2021-2030 period to reach the Fit for 55 objectives in comparison with averages over the previous decade. The breakdown shows that in some sectors (e.g. the power grid), the needs quadruple compared to the previous 2011-2020 decade.

FIGURE 3 SPENDING ON PHYSICAL ASSETS FOR ENERGY AND LAND-USE SYSTEMS UNDER THE NGFS NET ZERO 2050 SCENARIO (% OF 2021-50 GDP)



Note: See notes to Exhibit E10 in McKinsey (2022).

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TABLE 1 AVERAGE ANNUAL INVESTMENT NEEDS IN THE ENERGY SYSTEM AND FOR TRANSPORT, HISTORICAL TREND 2011-2020, AND FIT FOR 55 POLICY SCENARIO 2021-2030 (€ 2022, BILLION)

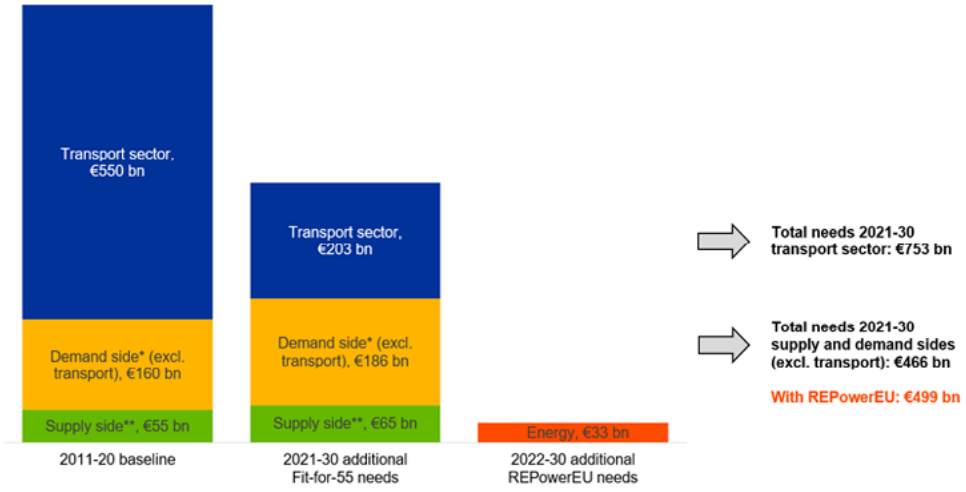
Sector	2011-2020	Fit for 55 policy scenario 2021-30	Difference
Supply side	**55**	**148**	**+93**
Power grid	15	55	+40
Power plants, incl. boilers and new fuels	40	93	+53
Demand side	**160**	**339**	**+178**
Industrial sector	12	34	+22
Residential	102	202	+100
Tertiary	46	103	+56
Total (energy system)	**215**	**487**	**+272**
Transport sector	549	754	+205
Total (energy and transport)	**764**	**1,241**	**+477**

Note: Transport includes investment in vehicles and recharging and refuelling infrastructure. It does not include investment in infrastructure such as road or railways.

Source: European Commission (2023).

European estimates of the costs of the green energy transition are progressing. The European Commission has estimated the public and private climate-related investment needs in the EU over the period 2021-30 at €466 billion on average per year (Figure 4). This excludes the sustainable conversion of the transport sector (e.g. electrification and hydrogen). As a proof that such projections are progressing, in 2022 a new initiative – REPowerEU – was adopted in the wake of Russia's aggression against Ukraine. It identifies additional €33 billion of annual green investments needs over the period 2022-30 in order to diversify European energy supplies, save energy and produce additional clean energy (Panetta 2022). It is expected that between 20% and 25% of such green investments will need to be funded by the public sector.

FIGURE 4 EU CLIMATE AND ENERGY SECURITY INVESTMENT NEEDS (AVERAGE ANNUAL NEEDS OVER 2021-30)



Sources: Panetta (2022) and ECB staff calculations based on Commission estimates of Fit for 55 and REPowerEU investment needs. Captures public and private investments recalculated in billions of euros at 2022 prices (thus the small difference with Table 1 values).

Some national estimates are also becoming available. For example, estimates by the Kreditanstalt für Wiederaufbau (KFW), the German national investment bank, suggest that the transformation of all sectors of the German economy might require investments in the range of €5 trillion, or about €200 billion per year until 2045 (KfW 2021, 2023). Presumably, such funds are additional to other investment needs (such as education, health, and defence) and principally aimed at achieving climate neutrality, thus mitigating climate change, and not adaptation.

Public finance frameworks are likely to come under severe strain. There is a growing discussion about the possible mismatch between 'climate investment needs versus fiscal space'. This discussion has started in EU member states, owing to the fact that several countries have high public debt levels (made worst by the pandemic). Given the existential threats from climate change and the need to launch the green energy transition, should the EU finance the climate transition as a 'European public good' (Panetta 2022, Buti et al. 2023) (that actually benefits the rest of the world as well)?[4]

The balance between public and private financing of the green energy transition might shift. There has always been a complementarity between, on one hand, publicly funded research and development, public infrastructures and public goods and services, and on the other hand, private initiatives (seeking financial returns). The example of

4 With reference to the IEA (2022a, 2022b) green investment estimates (about 3% of global GDP), *"[n]ot all of this has to be done through government budgets, of course. Indeed most will and should consist of private investment. But governments are responsible for making that happen. If they can crowd in six euros of new private investment for every euro they put in in incentives or investment of their own, they would still need to raise public spending by 0.5 per cent of GDP"* (Sandbu 2023).

telecoms and the World Wide Web were mentioned previously. In the case of the green energy transition, the rule of thumb ratio is 20–25% public versus private investments. Yet as we prepare for a protracted stream of higher green investments in the decades to come, this ratio might need to be re-assessed: governments are ultimately responsible for making the green energy transition happen.

Summing up

Protracted green financing on an unprecedented scale is required. Financing of the scale just mentioned must be both publicly and privately sourced, well-coordinated and sustained. Resources for public investments might in part originate from the proceeds of carbon pricing – i.e. the carbon tax, emissions trading schemes (ETSs) and excise taxes – but they will need to be complemented by additional public financing sources. Will global public financial frameworks be ready to face such a massive investment need both domestically and internationally?[5] Green investments for climate mitigation will compete with outlays such as reducing distortionary labour taxes, compensating for natural disasters, and adaptation to reduce the impact of physical risks and also respond to environmental degradation. Moreover, divestments from the fossil fuels sector might also be needed for a very long period. While global estimates are still tentative and uneven, compensation schemes across countries, that are not discussed here, will be indispensable.

4 DISCOUNTING FUTURE NET BENEFITS

What about the trade-offs between the costs and benefits of undertaking decisive climate adaptation and mitigation policies? Investments supporting the green energy transition might have very long time-horizons. The impact of lengthy time-horizons on the financing needed to implement the green energy transition necessitates an assessment of the costs versus benefits:

- The costs of the green energy transition projects and investments might be largely perceived as clear and present, and also might be quite heterogeneous. Such massive costs might crowd-out other outlays, will have to be shared and coordinated internationally, and will need to be sustained for decades.
- The benefits from the green energy transition might instead accrue after a prolonged period, even very far off in the future. The benefits might also be uncertain, uneven across types of sustainable investments, and heterogeneous across countries and

5 Stronger policy effort needs to go into finding the right frameworks to do that, both domestically and internationally. Even the most comprehensive ETS currently existing would not generate sufficient revenues to finance the public investment needed.

regions – more so than in the case of traditional public and private investment decisions.[6]

Several dichotomies emerge. As a starting point, a crucial aspect for evaluating the merit of undertaking long-term climate change-related investments pertains to how to discount their future streams of expected benefits in comparison with a stream of costs. The financial literature has formulated the concept of a social discount rate (SDR), which is a rate of interest used to calculate the present value of future benefits or costs. More generally, in the context of climate policies, the SDR facilitates calculating the net present value (NPV) of adaptation and mitigation investments, as well as the social cost of carbon (SCC).[7] Moreover, experts also warn that the net returns of climate projects might often not be immediately measurable in financial terms (profits) but rather might be defined on different grounds, for example, by reducing and or capturing GHGs emissions. Given a whole array of challenges, some types of climate related investments might not be appealing for the private sector. Such dichotomies could become important stumbling blocks.

Estimates of social discount rates vary widely. The choice of the SDR can depend on several criteria, including ethical and intergenerational considerations, the rate of return on alternative investments, and the rate of economic growth. A lower social discount rate places a greater value on future benefits and costs, while a higher social discount rate places a greater value on present benefits and costs. Hence, the SDR enables the evaluation of the trade-off between present and future consumption (Gollier and Hamitt 2014, Bauer et al. 2021). The theoretical and empirical literature presents a wide range of approaches and estimates for the SDR. For example, the Intergovernmental Panel on Climate Change has used discount rates ranging between 1% and 5% in its assessments of the impacts of climate change (IPCC 2022). Stern (2022) postulates a discount rate of 0%, whereas Giglio et al. (2021) observe that real estate is exposed to both consumption and climate risk, and therefore the term structure of discount rates is downward sloping reaching 2.6% for payoffs beyond 100 years. Dietz et al. (2018) postulate instead that the 'climate beta' is positive and close to unity for long maturities.

Summing up

The dichotomy between asymmetric (perceived) costs and benefits is complex. Moreover, there is a need to address very long-term discounting, especially because the green energy transition will require very ambitious investments whose net benefits might be uncertain for a long period. The discussion thus far has addressed the typology of green investments as well as the estimates of the overall financing needs over long term

6 The consensus is that costs of slowing and reversing climate change will be dwarfed by long-term benefits (such as general health improvements thanks to cleaner air that reduces mortality rates and morbidity from local air pollution, as well as helping to increase output, financial stability, and biodiversity) (Adrian et al 2022, IMF 2020, IPCC 2022).

7 The SCC captures the economic damages associated with emitting one additional tonne of carbon dioxide into the atmosphere, and is used to inform policy decisions as well as the design of carbon pricing mechanisms.

horizons. These assessments of the 'demand for green financing' to implement the green energy transition are intimidating (but indispensable to achieving the Paris 2015 climate goal). The next section turns instead to the 'supply of green financing' to implement the transition. Numerous sources for green financing are available, such as equities, bonds, loans, and lending from developmental financial institutions. However, there is a great deal of uncertainty over how to best utilise and combine green financing instruments and whether they will top up the required needs discussed above.

5 SUSTAINABLE FINANCE AVAILABLE TO SCALE UP GREEN FINANCING

Scaling up green financing

Private funds can originate from diverse sources including self-financing by firms, green loans by banks and other financial institutions, and issuance of green securities (IRENA 2022). Green financing holds the greatest potential for funding the green transition and the green energy transition. Yet, on some basic level, some crucial channels and mechanisms of the green financing are still unclear. What is the value added of green financing? How does it work? More evidence of its tangible economic benefits compared to conventional finance is needed. Evidence regarding the effectiveness of sustainable finance in increasing the amount, or lowering the cost, of capital for sustainability purposes is currently mixed.

Development of environmental standards, social standards and corporate governance

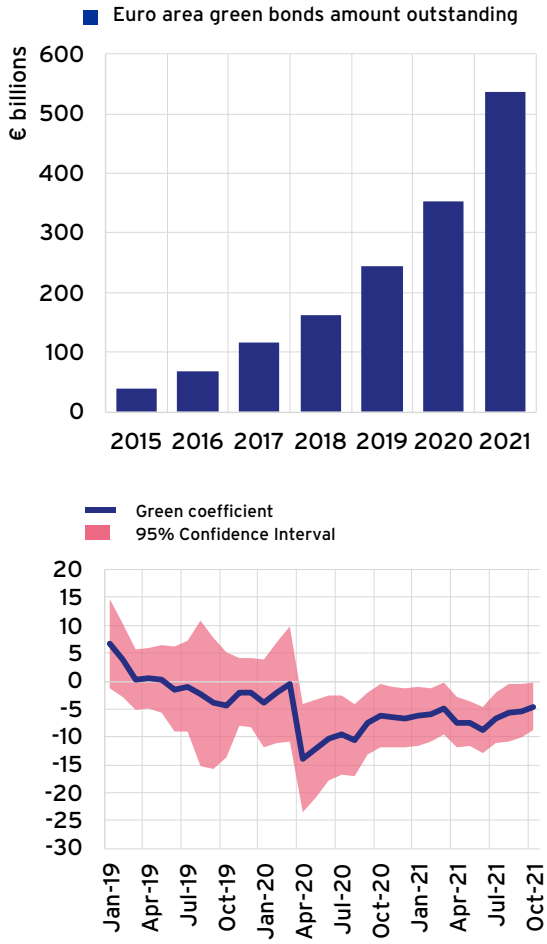
The EU has spearheaded initiatives to raise both awareness and confidence in the areas of environmental, social standards and corporate governance (well known by their now ubiquitous acronym, ESG). The EU initiatives include a set of regulation such as the EU Green Taxonomy, the Sustainable Finance Disclosure Regulation (SFDR), and the Corporate Sustainability Reporting Directive (CSRD), furthering the scope of the EU Capital Market Union (Schnabel 2022).

The physical green transition and the financial green transition are complementary, but might not always be perfectly aligned. Disclosures of information on the 'greenness' of economic activities are increasingly stigmatising non-sustainable carbon-intensive securities and firms, potentially reducing their access to financing (e.g. sustainable bank loans, bonds, and equities). The size of European green bond markets is rising steadily (top panel of Figure 5). Thus, greater disclosure of information/transparency is encouraging investors to redirect their investment toward green/sustainable projects. The latter face a lower cost of funding, known as the 'greenium' (bottom panel of Figure 5).[8] Green finance

8 At present, evidence on the greenium is far from conclusive, and anyway it is too small to compensate for higher fees and costs of issuance.

might increase the efficiency of capital markets to the extent that it allows a better match of investors' preferences for sustainability. But it also segments financial markets, hence decreasing the liquidity of each segment.

FIGURE 5 THE SIZE OF THE EURO AREA GREEN BOND MARKET AND GREENIUM



Source: Pietsch and Salakhova (2022).

Steady divestments versus sudden stranding

The NGFS has put forward various climate scenarios with different environmental, social, economic, and financial implications (NGFS 2021). Two extreme examples are the '*orderly*' scenario and the '*too little, too late*' scenario. We embrace here the first scenario, which accommodates systematic decarbonisation and a green energy shift. Efforts will also need to accommodate and raise acceptance for necessary divestment from fossil fuels assets and securities. This is no small task given the considerable weight of high-carbon equities and bonds in financial markets (Howard 2015). Howard (2015) also cites

a global movement soliciting various institutions (universities, pension funds, charitable foundations, NGOs, local authorities, etc.) to divest from coal, oil, and gas companies for both moral and financial reasons.

Summing up

More recent advancements in the ESG area and the EU Taxonomy provide a framework to guide an orderly divestment process. Instead, in the 'too little, too late' decarbonisation scenario, carbon-intensive securities might be stranded, which would entail significant financial losses and potentially disrupt the energy transition.

6 SOME FINAL REMARKS, INCLUDING NEW APPROACHES AND PERSPECTIVES

Estimates of the financing needed for the green energy transition vary widely but are considerable. Green finance will need to be supported by additional national and regional estimates under comparable assumptions. The current pace of actual flows toward green initiatives, as well as the tilting of portfolios, is less clear on a global scale, but will also need to pick up rapidly. The scale of the climate challenge is vast, and the accompanying financing needs to sustain a green energy transition face a variety of risks. In response, several new approaches and perspectives are emerging.

Investment funds, pensions funds and insurances might need to absorb very long-term climate-related securities supporting the green energy transition efforts. Public and private insurances might have to absorb and share rising climatic risks (not discussed here) while the green energy transition supports the path to net zero (ECB and EIOPA 2023). Concerning the mitigation of stranding risks, Fanizza and Cerami (2023) propose a market solution to enhance the role of the financial sector in supporting the green transition. This operates by developing a secondary market for 'brown exposures' in order to allow banks to dispose more quickly of stranded assets, thereby increasing their capacity to finance green investments.

Let's change perspective and assume that most countries would greatly benefit from the green energy transition. What then? A radically new approach – associated with Coase's bargaining and contracting theory – would be to pursue the highest possible net social benefit from a large reduction in CO_2 emissions arising from the replacement of fossil fuels with renewable energies. For example, the intertemporal net economic gains from phasing out coal, taking into account investment costs to build replacement renewable energy and compensate for opportunity costs of coal, could be around $85 trillion (cumulatively until 2050) (adopting an average social cost of carbon of $80/t$CO_2$) (Adrian et al. 2022). The net benefits will be distributed across countries, with most countries benefitting from a global coal phase-out even without any compensatory cross-

country transfers. Yet, richer countries will need to offer sufficient funding to develop renewables and compensate for the opportunity costs of the loss of cheaper coal energy during the transition (Adrian et al. 2022).

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PART IV
POLITICAL ECONOMICS OF GREEN ENERGY

CHAPTER 17

The green transition, energy security and energy independence

Tatyana Deryugina
University of Illinois

Energy resources are the lifeblood of modern economies, necessary for everything from powering homes and businesses to fuelling transportation. However, a country's dependence on fossil fuels for energy can also make it vulnerable to the actions of other nations. Two key risks that have become especially salient since Russia launched a full-scale invasion of Ukraine in 2022 are (1) the possibility of one country systematically targeting the energy infrastructure of another country during a war, and (2) the possibility of having a key energy supplier become hostile and cut off energy supplies. Transitioning away from fossil fuels can help countries reduce such risks substantially. The transition must be managed carefully, however, to minimise the creation of new risks.

Russia has consistently targeted Ukraine's energy infrastructure with missile and drone attacks, destroying about half of it. In October 2022 alone, Russia destroyed nearly a third of Ukraine's power plants (Sabbagh and Wintour 2022). The physical vulnerability of fossil-fuel generation – and of the electricity grid more generally – means that economic activity or even lives can be placed in danger by the actions of a hostile country. At a smaller scale, physical attacks can also come from within.[1] Power outages have been shown to be harmful for firms, households, and the economy as a whole, even absent a war (see Tol 2023 for an extensive list of references). Increased dependence on electricity, which is expected to accelerate as the world transitions to electric cars, makes the security of the electricity grid an even more vital issue.

A fossil-fuel power plant, such as a coal or natural gas plant, is a large and centralised facility that, if damaged or destroyed, could have a significant impact on the energy supply. By contrast, carbon-free energy sources, such as solar and wind power, are distributed and decentralised, making them less vulnerable to attack. For example, a solar plant in Ukraine damaged in a missile strike was able to be reconnected at half the capacity after the damaged components were removed (PV Magazine 2022). Wind farms, which consist of multiple wind turbines, are typically located in remote and dispersed locations, such as on hills, offshore, or in the middle of a field. This makes them harder to locate and target compared to a centralised fossil-fuel power plant, although it is worth

1 For example, a California transmission substation was attacked by snipers in 2013 (see www.npr.org/sections/thetwo-way/2014/02/05/272015606/sniper-attack-on-calif-power-station-raises-terrorism-fears).

noting that providing physical security in the first place is more difficult for renewable energy sources. While it is possible to build a larger number of smaller fossil-fuel plants to decentralise generation without switching to renewables, doing so eliminates economies of scale, making such projects less attractive compared to pursuing renewable energy.

Renewable energy can also be more reliable when it comes to downtime required for expected and unexpected maintenance, by nature of having more smaller sources. Although intermittency is a much bigger problem for renewable energy than for fossil-fuel plants, improved storage and careful planning should address this problem in the longer run. Finally, the marginal cost of operating renewable energy sources is also low compared to fossil-fuel plants, which means that the former will be less susceptible to fluctuations in energy prices than the latter, enhancing energy security.

The energy infrastructure targeted by Russia consists not just of power plants, but also other essential grid components such as large power transformers (LPTs). LPTs are particularly vulnerable to attack because they are large – making them easy for hostile parties to identify – and hard to protect from a physical attack, and they are are frequently custom-built, which means that spare parts are often difficult to come by (ICF International 2016).[2] Procuring LPTs to replace destroyed ones has been a critical barrier to Ukraine's ability to repair the electric grid in the aftermath of Russian attacks (Evans-Pritchard Jayanti 2023). Thus, one should not conclude that making the electricity supply secure consists merely of moving away from fossil fuels. Promoting more modular designs and developing self-healing systems is vital for ensuring grid security regardless of the ultimate electricity source (ICF International 2016).

It is also important to consider threats to the electricity grid beyond the currently salient ones. For example, the grid is also vulnerable to cyberattacks – perhaps more so than to physical attacks given increased reliance on interconnected and automated grid technology – and geomagnetic disturbances and electromagnetic pulses are real threats that could yet materialise in the future. Russia carried out cyberattacks on Ukraine's energy infrastructure in 2015 and 2016, and the threat of future cyberattacks is high (Zetter 2016, Goodin 2022). Thus, a comprehensive approach to energy security needs to consider a variety of threats and take cost-effective measures to prevent them. As more renewables are added and technology progresses, the grid becomes necessarily more complex. Threats to the grid (e.g. drones) are becoming more sophisticated and cheaper to implement (ICF International 2016), requiring constant vigilance. In many cases, further research and development (R&D) can enhance grid security, and governments can play a role by encouraging relevant information sharing across entities and directly funding some of the R&D.

2 While other grid components, such as transmission lines, towers, and control centers, are also vulnerable to physical attacks, they can be replaced much more quickly and easily.

It is, of course, not possible to fully protect energy infrastructure against every threat. Even if it were possible, it would unlikely be cost-effective, and energy affordability is a real problem in many parts of the world. More generally, how to pay for enhanced grid and energy security is an important issue to consider. Because there are externalities involved and because there are many fixed costs in security improvements, it may be desirable for governments to directly finance some of the necessary investments. However, some of the costs of increased energy security will surely be passed on to consumers. Here, governments should resist the urge to counter with price subsidies but instead implement targeted lump-sum transfers to those least able to afford the higher rates.

The presence of externalities also means that utilities may underinvest in grid security unless given clear incentives to invest, either in the form of financial incentives or through well-enforced standards. The latter already exist in many places, including the US and Canada, but need to be regularly reviewed and updated to ensure that they reflect the most recent threats. Governments should also make it as easy as possible for utilities to meet these standards by encouraging and enabling greater information sharing. Some information, of course, needs to be protected, as attacks on the grid can come through insiders as well.

The second key risk when it comes to energy resources is that when a country is heavily dependent on energy from a single supplier, it becomes vulnerable to the actions of that supplier. European countries that were heavily dependent on natural gas from Russia had their economies disrupted when Russia drastically reduced or completely cut off supplies to them. They also turned to the liquified natural gas (LNG) market, driving up LNG prices and creating spillover effects on the rest of the world. For example, because of the high LNG prices, Pakistan has been unable to procure LNG, leading to extensive blackouts and a long-term energy shortage (Hindustan Times 2022).

Expanding the use of renewable energy sources reduces these risks. The generation of electricity solar, wind, and hydropower are not dependent on a single location or supplier and can be generated within a country's borders. But renewable energy brings its own energy security challenges.[3] Electric car batteries, solar farms, and wind farms require significantly more minerals to build than traditional energy sources, including copper, lithium, nickel, cobalt, manganese, silicon, silver, zinc, and a variety of rare earth elements. A new unit of power generation capacity required 50% more minerals in 2021 than in 2010 (IEA 2021). Some of these, such as silver and silicon, are available from a variety of suppliers. But the production of many of these minerals is more concentrated than that of oil and natural gas – for example, the world's top three produces of lithium, cobalt, and rare earth elements account for over three-quarters of world output (IEA 2021, Valckx et al. 2021). Substantial disruptions in these countries' supply of minerals in which they dominate can handicap renewable energy supply chains.

3 Intermittency of renewable resources is another challenge not discussed in this chapter.

It is also estimated that supply of some of these minerals – especially of nickel, vanadium, cobalt, and graphite – will not be sufficient to satisfy expected demand through 2050 (Valckx et al. 2021). Similarly, IEA (2021) estimates substantial shortfalls in lithium, cobalt, and copper by 2030 if existing climate goals are pursued. Although supply surely responds to expected demand, future demand growth is highly uncertain because it depends on the aggressiveness of climate policy, which renewable technologies will growth more rapidly, and how new technology will affect mineral demand. Copper and lithium also have high water requirements, and over half of current copper and lithium production takes place in areas with high water stress levels (IEA 2021). New mines often take over a decade to develop and bring online, and if demand grows faster than expected, the resulting high prices may stall the energy transition in some places. Price volatility, a long-known energy security issue when it comes to fossil fuels, can also pose a risk to carbon-free energy.

Governments thus need to be forward-looking and take the above-mentioned trends and risks into account when developing policies to facilitate their energy transitions. Resources development can be sped up through publicly financed geological surveys and R&D efforts, more efficient permitting processes, and initiatives that take some of the financial risk off developers. Here, international cooperation is vital, as many countries lack the mineral deposits to develop their own resources. However, all countries can participate in supporting this aspect of the energy transition with public funds, where deemed appropriate. Part of the reason for the expected supply shortfall may also be relatively weak signalling about governments' commitment to the energy transition, and this is also something that an international coalition of governments can aim to address.

Because these minerals are only needed for *new* energy installations, there is limited mineral risk to *existing* renewable energy installations. By contrast, a fossil-fuel plant cannot continue to operate if the supply of fuel is disrupted. However, once a country becomes heavily saturated with renewable energy, the ongoing mineral needs for replacement energy can be significant and a disruption to their supply could lead to energy shortages over longer time scales. Developing improved mineral recovery/recycling capabilities and practices can offset some of these risks and lower costs. R&D efforts to reduce the amount of minerals needed for carbon-free technology could also counteract potential problems posed by mineral supply issues. Finally, strategic stockpiles can be useful, but it is important for countries to keep these stockpiles reasonable given the expected mineral shortages.

By diversifying its energy mix and increasing the proportion of renewable energy, a country can reduce its dependence on a single supplier and protect its energy security. However, one should not confuse energy independence with autarky, as that can significantly harm the green energy transition. For example, if countries that are key suppliers of metals necessary for electric cars, solar panels, and wind turbines increase import restrictions, the cost of the green transition increases, and the transition will be slower (*The Economist* 2023). Because greenhouse gas emissions are a global externality,

a country prioritising its own clean energy transition at the expense of other countries is ultimately counterproductive. Energy independence also requires reliable *domestic* suppliers. A country should not consider itself energy-independent if its domestic supply is unreliable or concentrated. Instead, energy independence should be pursued through a diversified supply chain consisting of both foreign and domestic sources and a resilient electricity grid powered by renewable energy.

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CHAPTER 18

Unextractable minerals and metals for the energy transition

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The green transition will require moving towards an economy that relies more heavily on minerals and metals (for example, through the use of batteries and other electrical components) in order to substitute away from fossil fuels. The costs associated with climate change are much greater than the expected cost of the green transition. However, extraction of minerals and metals – including prospecting, exploration, construction, operation, maintenance and expansion of a mine – can have large impacts on local social and environmental systems. Recent research highlights that if mining can yield a range of benefits to local communities through greater economic activity and access to infrastructure, it may also cause human rights issues and conflicts and generate violence against the local population. This can happen either because mining activities are not formalised, often leading to unsafe working conditions, or because groups fight for control of the economic rent or compete for land use. Similarly, mining can negatively impact neighbouring communities in several ways – by contaminating their water through the chemicals used in mining operations, by using their water excessively, or by physically displacing communities from their homes. We denote all these costs of mining extraction as the 'social cost of minerals and metals'.

This short chapter has two objectives. First, it will summarise the knowledge in the energy sciences literature regarding the future *demand for minerals and metals* implied by the energy transition. It will highlight various sources of uncertainty underlying these demand projections and the kind of data that would allow us to obtain more reliable projections. Second, we will turn towards the *supply of minerals and metals* and summarise the main sources of the 'social cost of minerals and metals' associated with extraction. We will argue that accounting for this social cost – for example, by integrating it in prices through a 'materials tax' – might allow the green transition to be achieved at a lower overall cost and greater efficiency. We believe that, otherwise, we might end up in a situation where large-scale extraction creates issues so important that its social costs impair the green transition because of 'unextractable' minerals and metals. We conclude by highlighting that the rigorous quantitative evaluation of these social costs is necessary for efficient pricing, pointing to a fruitful area of future research.

THE ENERGY TRANSITION AND THE DEMAND FOR MINERALS AND METALS

To limit climate change to 1.5°C or 2°C above pre-industrial levels, the global energy system should reach net zero emissions of carbon dioxide by mid-century or just after (Davis et al. 2018, IPCC 2022). This goal requires an ambitious and holistic technology strategy to fundamentally transform the whole energy system: increase energy efficiency and electrification; transition to zero- and low-carbon energy generation and synthetic fuels (e.g. hydrogen or ammonia); and develop infrastructures to capture, transport, reuse and dispose of carbon dioxide (Davis et al. 2018). For example, a net zero goal in the EU requires a 90% reduction in emissions by 2050 (Tsiropoulos et al. 2020). Coal, oil and natural gas plants will need to be phased out and the share of renewable energy sources, especially solar photovoltaic and onshore and offshore wind, should reach 65–100% of total final energy, depending on the demand scenario and whether nuclear power and carbon capture and storage are available. Between 65% and 90% of transportation needs should be served by zero-emissions vehicles, translating to 50–75% share of electricity in the transport sector. Even if there are some degrees of freedom regarding which technologies are needed and to what extent, the sheer scale of this transformation is enormous, as it involves rebuilding the energy system from its foundations.

The recent scientific and policy literature has pointed to the substantial increase in the need for around 20 minerals and metals that this transition will create. These include cross-cutting elements of copper, nickel, chromium, molybdenum, manganese, lead, aluminium and zinc that are used by multiple technologies (World Bank 2020, IEA 2021). Other elements are relevant for specific technologies, such as cobalt, lithium, graphite or vanadium for electricity storage, indium for solar photovoltaic, and neodymium and iron for wind power (World Bank 2020, IEA 2021). Quantification of how much of these minerals and metals would be needed by 2050 is at a nascent stage, where first estimates come from a handful of incomparable studies with different energy transition scenarios, system boundaries and assumptions. But all these studies converge on the fact that the increase will be substantial (Table 1). These minerals and metals already exhibit volatile prices and, in some cases, could face shortages due to resource limits and degrading quality of ores (Sovacool et al. 2020, European Commission 2022). Even in the short term, some instabilities could be caused by insufficient mining capacity due to long lead times for opening new mines to follow the rapidly increasing demand, especially for batteries (Sovacool et al. 2020).

TABLE 1 ESTIMATED INCREASE IN THE GLOBAL DEMAND FOR SELECTED MINERALS AND METALS IN ENERGY TRANSITION SCENARIOS IN 2050 AS COMPARED TO TODAY

Minerals and metals	Demand increase in 2050 (i.e. predicted demand in 2050 divided by current demand)	References
Copper	1.2 – 2.4	IEA (2021), S&P Global (2019), Vidal et al. (2013)
Nickel	1.0 – 2.9	IEA (2021), IRENA (2021), Sovacool et al. (2020), World Bank (2020)
Cobalt	4.6 – 5.9	IEA (2021), Sovacool et al. (2020), World Bank (2020)
Lithium	4.9 – 10.0	IEA (2021), IRENA (2021), Sovacool et al. (2020), World Bank (2020)
Graphite	3.8 – 5.0	IEA (2020), Sovacool et al. (2020), World Bank (2020)
Neodymium	0.4 – 17	IRENA (2021), Sovacool et al. (2020), World Bank (2020)

Note: These estimates are only indicative because different studies use different energy transition scenarios, system boundaries, and assumptions. * World Bank (2020) and Sovacool et al. (2020) provide estimates for copper too, but caution that their estimates are strongly underestimated. These estimates are hence excluded here.

Bottom-up energy system models (Bhattacharyya and Timilsina 2010) that represent the whole system with its energy flows, from resource extraction through transformation and transmission to final consumers, could be used to quantify future needs of minerals and metals. The advantage of these models is that their technology explicitness allows future transition scenarios to be connected with detailed analysis of mineral and metals (Hertwich et al. 2015). As in the case of fuels, these models could account for extraction cost curves and flows of minerals and metals of interest in order to estimate required quantities and geographical distribution of supply and demand in various transition scenarios. The increase in the demand for minerals and metals associated with the energy transition cannot be fully avoided because climate change poses a much greater risk that must be solved. Energy system models, coupled with an assessment of minerals and metals, could help identify solutions for how to design energy transition in a way that decreases the challenge. For example, not all technologies depend on the same materials, meaning that energy technology mixes could diversify the amount and quantities of minerals and metals needed.

However, the key limitation today is the data on minerals and metals, which are rarely complete or reliable. The European Commission (2022) documents the available data and gaps throughout the whole supply chain in a comparative way for main minerals

and metals. While energy system modellers are able to work with deep uncertainty (Yue 2018), systematic long-term collection of life-cycle data on minerals and metals, including the rates of reuse and recycling, is key to improving the reliability of the analysis.

THE SOCIAL COST OF SUPPLYING MINERALS AND METALS

Despite the large uncertainties in the estimates of future demand for minerals and metals, it is very clear that extraction will increase sharply with the energy transition. Regarding the supply of minerals, a salient feature of energy transition minerals is that they are more geographically concentrated than coal, oil or natural gas (Sovacool et al. 2020). For lithium, cobalt and rare earth elements, the world's top three producing nations control well over 75% of production. In some cases, they are concentrated in one country – for example, 64% of cobalt resources are concentrated in the Democratic Republic of Congo – or are exploited by a handful of large firms – for example, Sociedad Química y Minera de Chile, Pilbara Minerals and Allkem currently mine nearly 40% of all lithium for batteries in electric vehicles (IEA 2022). By contrast, resources in Europe are generally low. This concentration of resources in countries with weak institutions generates a specific set of externalities that must be quantified properly.

The negative socioeconomic impacts of mining activities are documented for some specific regions (mostly Sub-Saharan Africa and South America). For example, the links with human rights risks of sourcing cobalt from the Democratic Republic of Congo have been widely documented (UNEP 2020, Sanchez de la Sierra 2020). The prevalence of artisanal and small-scale mining (ASM) in the cobalt supply chain creates challenges for establishing responsible sourcing practices, with unsafe working conditions and child labour (documented in both large-scale mining and artisanal mining areas) the two most salient human rights risks. The lack of formalisation of artisanal mining activities, the lack of free schooling and the weak enforcement of laws exacerbate these widespread and persistent human rights issues linked to mining activities in the DRC (UNEP 2020).

Similarly, recent literature highlights that mineral extraction is linked to an increase in conflict risk. It shows evidence that an increase in mineral prices is associated with an increase in battle and civil conflicts in areas extracting the resource. One reason for this is that as the gains from expropriating resources rise, conflict becomes more likely (Dube and Vargas 2013, Sanchez de la Sierra 2020, Adhvaryu et al. 2021). Resources can also enrich the state and be used to fund repressive and destructive activities (Mitra and Ray 2014, Nunn and Qian 2014, Caselli and Tesei 2016). Finally, mineral extraction can allow rebel groups located around the mines to finance future fighting activities (Berman et al. 2017) and can fuel the use of violence against citizens as armed groups violently appropriate local resources from citizens (Fourati et al. 2022). The literature shows that the cost of conflicts tends to be disastrous, with some studies estimating that it ranges from 10% to 15% of national output (Collier et al. 2003). More recent estimates are needed, however, for precise quantification.

Last, mining can have large environmental impacts, differentiated depending on the ecosystems it affects (e.g. boreal or subtropical regions), the technology of extraction that is used (e.g. industrial mining versus artisanal mining) and the strength of local environmental regulations enforcements (IEA 2020, UNEP 2020). The main environmental impacts identified by the literature are (i) land use change, which is the main source of direct and immediate impacts on people, biodiversity and ecosystems; (ii) water use, as mining generally requires large volumes of water for its operations and can also be a source of water contamination; and (iii) waste generation, as extraction and preparation of minerals and metals results in massive amounts of residues. Furthermore, it is expected that for many mining countries, climate change will amplify these negative effects of extraction through increased pressure on water availability or land degradation. These environmental costs are likely substantial. A recent study featuring a life-cycle analysis of the global environmental costs of mining and processing for 38 materials provided global estimates ranging from €0.4 trillion (low) to €5 trillion (high) per year for the world (Arendt et al. 2022).

SHOULD WE PRICE THIS SOCIAL COST OF EXTRACTION?

Absent any regulation, economic rationale will push firms to extract the pools of minerals and metals with the lowest marginal cost of extraction first. This will be mostly determined by the size of the pools of resources, the ease of access, the availability of inputs needed for extraction (e.g. water) and the local cost of labour/capital required in the extraction process. As highlighted above, the potential issue is that these pools of resources might be located where the social cost of extraction is high – for example, in countries where internal conflict is raging or where low institutional quality prevents the protection of workers and the environment.

The question, therefore, is about the rationale of imposing a 'materials tax' that would incorporate the social cost of minerals and metals in the market prices of these materials. In practice, this would imply that minerals and materials extracted in conflict-affected areas – or in areas with high levels of environmental pollution – would be priced higher than others, by an increment equal to the social cost generated by the extraction. Similar to a 'carbon tax', pricing the externalities would allow market forces to (i) regulate consumption of minerals and metals to an efficient level, and (ii) allocate the extraction spatially toward areas where the social cost of extraction is relatively lower (at the cost of a higher private cost of extraction). This would generate a more efficient pattern of extraction, at the (potential) cost of a more expensive green transition in the short run. We believe that it might sustain the transition in a more robust way, as it will avoid some costs in the long run.

Making a parallel with fossil fuels, we are shifting out of oil not because of its scarcity (as forecasted in the 1970s) but rather because it is plentiful, cheap and harmful to the climate. The low price of fossil fuels (with respect to their high energy content) was the

reason why these fuels became central in production and drove the stark accumulation of carbon dioxide in the atmosphere. One might fear that extraction of minerals and metals will follow a similar pattern; the negative socioeconomic effects of extraction on land use, water usage and conflicts might become great hurdles for the long-run transition toward a green economy. Early pricing of the social cost of extracting these minerals and metals might generate short-run costs, but it would certainly contribute to generating long-run patterns of extraction that are more respectful of local resources and avoid major human rights and environmental issues. In the long run, it might help the green transition to avoid creating another large unsolvable issue for the next generations. The exact values of these 'social costs of minerals and metals' is a fruitful area for research in our view and will help design efficient extraction policies.

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CHAPTER 19

On the new geopolitics of critical materials and the green transition

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THE NEW AGE OF NATIONAL SECURITY

The global economy has entered a new age of national security. The pandemic has first brought to the fore the risk of over-reliance on global supply chains on top of the failure of coordination over global health matters. But what really enacted the new age of national security for the global economy is the decision of Russia to invade Ukraine and the deliberate sabotage of the global economy.

Beyond the human and economic toll the war is having on Ukraine, the invasion marked an escalation between the Western and Eastern blocs respectively centred around the US and China. Russia has attempted to weaponise its energy and food supplies to divide Europeans and sought to instill unrest in developing countries. China has sided with Russia, affirming its support for Russia security concerns. Tensions over Taiwan, a dominant player in semi-conductor manufacturing, is another emerging flashpoint between China and the US. Heightened concerns over national security tend to fragment the global economy.

Historically, the US has never had a rival that was both an economic and strategic rival. The Soviet Union, while a strategic rival, was never an economic rival. China is now such a dual rival. Geopolitics are shifting between the major economic blocs in a multipolar world. Geopolitics are also shifting between these blocs and the rest of the world. Indeed, the size of trade between China and rest of the world helps explain the shifting alliances vis-à-vis the US. The voting pattern of many developing nations, including African ones, at the United Nations at the onset of the invasion of Ukraine surprised their US and European counterparts.

There is some indication that economic fragmentation is underway. The Trump era certainly presented a hangover to organisations supporting free markets, which then seem to have lost their anchors. In a recent speech, Janet Yellen articulated the concept of 'friend-shoring' to give direction to the strategic response of the US to the growing rivalry from China (Yellen 2022). In a nutshell, friend-shoring would help incentivise countries to align with the Western bloc by integrating them in value chains through foreign investments. The difficulty is in defining the 'friend' category, with the risk of

ending up with a rather small group depending on the criteria used. In parallel, there have been announcements by China (and Russia) about work on alternatives to multilateral organisations and to the international payment system and attempts to move away from dollar-denominated trade, including for oil.[1]

In this chapter, we focus on one important dimension of the strategic rivalry, namely, the race which is raging among the superpowers over critical materials to power the simultaneous energy and digital transitions the world is experiencing. Such a discussion is especially relevant for Europe, which should not repeat the mistake of its over-reliance on Russia for gas by making itself dependent on China for the rare earth materials needed for the green transition.

THE RACE FOR CRITICAL MATERIALS

While the energy and digital transitions both rely on technologies that require these critical materials, the clean energy transition is most prominently associated with the intensive use of such materials. Indeed, as Table 1 indicates, technologies including wind turbines, solar PVs, electricity networks, electric vehicles and nuclear power require materials such as copper, lithium, nickel, silicon, cobalt, rare earth elements and uranium.[2]

The compartmentalisation of sourcing of key supplies such as critical materials could escalate further through non-tariff barriers motivated by national security concerns. There are enormous trade-offs between efficiency and national security. Deviating from globalised markets will no doubt decrease efficiency and leave hundreds of millions worse off. In this new environment, where issues of security of supply have become paramount, the design of value chains will have to eliminate the risk of weaponisation. In addition to 'friend-shoring', the response of the superpowers to concerns over security so far has been in the form of industrial policy, including subsidies that risk undoing trade and investment norms.

The risk of fragmentation over the race to power the energy transition is real. The risks of weaponisation of critical materials are exacerbated by demand- and supply-side factors. The rapid deployment of clean technologies as part of the energy transition could be slowed by several bottlenecks from the sourcing of materials, but also their processing into clean energy equipment and distribution of the latter. Understanding the market structure of the supply chain for critical materials is important, considering the tensions which are building between major powers.

1 See www.businessinsider.com/china-russia-alternative-swift-payment-cips-spfs-yuan-ruble-dollar-2022-4?r=US&IR=T
2 See the US Geological Surveys list of critical materials and their respective usage at https://www.usgs.gov/news/national-news-release/us-geological-survey-releases-2022-list-critical-minerals

TABLE 1 DEMAND FOR MINERALS BY SECTOR (THOUSAND TONNES, kt)

	Sustainable development scenario		
Total demand by sector	**2020**	**2030**	**2040**
Low-carbon generation	**1,692**	**4,820**	**4,749**
Solar PV	743	1,753	1,822
Utility-scale	453	875	1,038
Distributed	290	879	785
Wind	644	1,602	1,705
Onshore	565	1,156	1,199
Offshore	79	446	506
Hydro	81	194	128
Biomass	25	47	59
CSP	4	138	361
Central tower	3	108	299
Parabolic troughs	1	30	62
Geothermal	144	961	606
Nuclear	51	125	68
Electricity networks (copper only)	**4,975**	**7,311**	**10,007**
Transmission	1,837	2,705	3,252
Distribution	2,743	3,857	5,907
Transformer	395	748	848
EV and battery storage	**426**	**6,905**	**12,650**
EV	401	6,603	11,803
Battery storage	26	302	847
Hydrogen	**0.1**	**21.8**	**79.1**
Electrolyser	0.0	8.4	17.5
FCEV	0.1	13.4	61.5
Total	**7,094**	**19,058**	**27,485**

Source: International Energy Agency website (accessed 1 March 2022).

TABLE 2 TOTAL DEMAND BY CRITICAL MINERALS (THOUSAND TONNES, kt)

	Sustainable development scenario		
Total demand by mineral	**2020**	**2030**	**2040**
Arsenic	-	0.2	6.9
Boron	0.1	0.3	0.3
Cadmium	0.2	0.3	0.3
Chromium	134	574	459
Copper	5,715	10,705	15,147
Cobalt	21	262	455
Gallium	0.0	0.1	2.8
Germanium	0.0	0.01	0.01
Graphite	156	2,641	3,849
Hafnium	0.00	0.01	0.01
Indium	0.0	0.1	0.1
Iridium	0.0	0.0	0.0
Lead	8.3	19.5	14.4
Lithium	22	378	904
Magnesium	2.8	25.4	57.2
Manganese	82	438	664
Molybdenum	18	68	51
Nickel	196	2,225	3,804
Niobium	0.1	1.6	2.9
Platinum	0.00	0.04	0.12
Selenium	0.0	0.1	0.1
Silicon	390	831	904
Silver	2.0	3.8	2.7
Tantalum	0.1	0.3	0.2
Tellurium	0.2	0.3	0.3
Tin	0.7	1.7	1.8
Titanium	4.7	15.1	13.6
Tungsten	0.0	0.1	0.1
Vanadium	0	19	219
Zinc	335	812	876
Zirconium	0.3	1.7	2.5
Rare earth elements (REEs)	**6.4**	**34.2**	**46.6**
Neodymium	4.9	26.9	36.7
Other REEs	1.4	7.3	9.9
Total	**7,094**	**19,058**	**27,485**

Source: International Energy Agency website (accessed 1 March 2022).

Demand for these materials is expected to grow quickly as the clean energy transition gathers pace. In the face of that growth in demand, the limited supply of critical materials is already putting upward pressure on prices. The International Energy Agency (IEA) forecasts that mineral demand for clean energy technologies will rise at least four-fold by 2040 to meet climate goals, with particularly high growth for materials needed for electric vehicles (IEA 2022). Table 2 shows that graphite, nickel, lithium, and rare earth materials are expected to witness explosive demand under the scenario of meeting climate goals.

GEOGRAPHY OF CRITICAL MATERIALS PRODUCTION AND PROCESSING

Figure 1 indicates that the production of critical materials is relatively scattered. Yet, the salient issue is where the residual production of critical materials net of domestic consumption (i.e. exports), especially of raw critical materials, is concentrated. The production of critical materials is highly prevalent in the major economic blocs, namely, China, the US and the EU. These blocs typically consume more of what they produce, making them dependent on exporters of raw critical materials. Australia, Russia, Kazakhstan, Democratic Republic of Congo, Mozambique, Chile, South Africa, and Zimbabwe, as well as many others, are important exporters of raw critical materials and are thus courted by the superpowers, which strive to secure supplies of these materials.

FIGURE 1 SPATIAL DISTRIBUTION OF CRITICAL MATERIALS

Source: Labay et al. (2017). U.S. Geological Survey data release (https://doi.org/10.5066/F7GH9GQR.)

Taking the example of lithium, Table 3 shows that in 2022 mining was concentrated in a very small number of countries. Almost half of global lithium mining is currently in Australia, almost a third in Chile, about 15% in China, and 4.6% in Argentina. All other countries are responsible for much smaller fractions of global lithium mining.

TABLE 3 MINING OF LITHIUM 2022 (IN TONNES)

Australia	61,000	46.9%
Chili	39,000	30.0%
China	19,000	14.6%
Argentina	6,200	4.6%
Brazil	2,200	1.7%
United States	900	0.7%
Zimbabwe	800	0.6%
Portugal	600	0.5%
Other countries	500	0.4%
TOTAL	**130,200**	**100%**

Note: Figure for the US is for 2021.
Source: BP Statistical Review of World Energy.

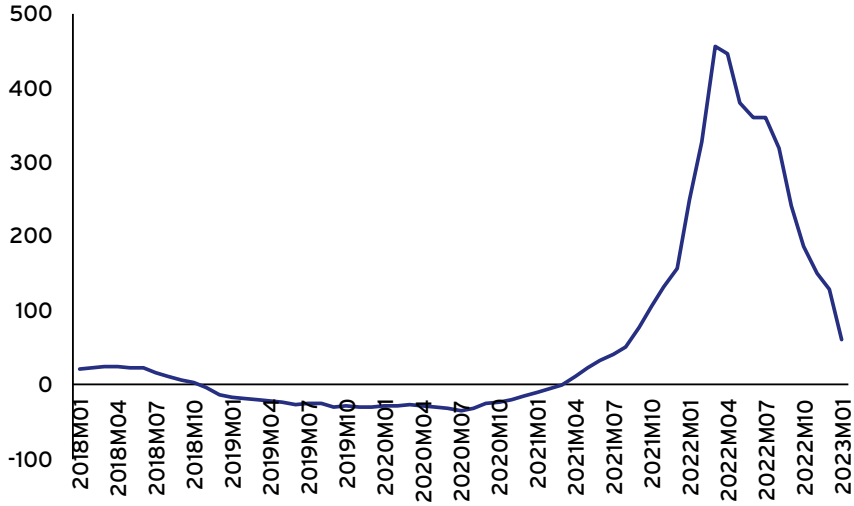
Of course, many countries are trying to increase lithium production in light of the pending green revolution and the need for batteries in electrical cars and other products. For example, the EU has made it a top priority to be less reliant on lithium imports from China, Iran, and other countries. France has unveiled a lithium mine project in the centre of the country with the aim of becoming the leading contributor in Europe's quest for battery materials for electrical vehicles. However, as can be seen from decades of resistance against a new mine in Covas do Barroso in the north of Portugal, lithium mining is not popular due to environmental costs, loss of nature areas, and the inevitable 'not in my backyard' (NIMBY) politics. The cobalt boom in the Democratic Republic of Congo (DRC) has led to horrific conditions in mines putting thousands of workers at risk, a hell on earth (Zuckerman 2023).

The geography of mining versus the processing of critical materials is very telling. China dominates in the processing of copper, nickel, cobalt, rare earths and lithium, but it only dominates in the production of rare earths, with Chile and Peru dominating in the production of copper, Indonesia dominating in the production of nickel, DRC dominating in the production of cobalt, and Australia and Chile dominating in the production of lithium. It is mind-boggling that China is the dominant global producer of offshore wind, onshore wind, solar, and electrical vehicles and has global shares of 40–45% in the production of fuel cell trucks, heat pumps, and electrolysers.

Many developing countries, including Zimbabwe, have attempted to maximise the value of their raw critical materials by setting up cartels. Historically, in response to the unfair share they believed they received from the exploitation of these critical materials, developing countries have set up producer cartels, such as the Organization of the Petroleum Exporting Countries (OPEC). While these cartels may get higher prices for critical materials and add revenue to government coffers, in practice advanced economies eventually find alternative suppliers (for example, non-OPEC producers) or develop alternative products (such as synthetic palm oil or shale oil). Moving up the value chain would be a better route, but that too has proven difficult. The risk of cartelisation is another source of concern for major economic powers dependent on exports from developing countries.

The uneven distribution of production of critical materials is, however, likely to diffuse as elevated prices steer exploration investment efforts and eventually lead to more discoveries (Arezki et al. 2019). A case in point is lithium production, the price of which has fallen after fears of scarcity in the face of extraordinary demand growth (see Figure 2).

FIGURE 2 PRICE OF LITHIUM, 2018-2023 (PERCENT CHANGE FROM PREVIOUS YEAR)



Source: International Monetary Fund website (accessed 1 March 2023).

Among the newcomers, Argentina and Bolivia are touted as potential major exporters of lithium, helping smooth the tensions on lithium markets. Over the medium term, innovation is also expected to help reduce the critical mineral intensity of batteries and other equipment for the clean energy transition. The balance between these different forces on the supply and demand fronts will eventually determine how smooth the access to critical materials will be. But in the new age of national security, concerns over the

supply for critical materials running from upstream (extraction of critical materials) to the downstream segment (processing and distribution of these materials) will remain pervasive.

While the US and the EU represent major poles of consumption of these materials, China's role in the supply chain is central in the global economy, and understanding this centrality is paramount. Leruth et al. (2022) find that China's significant control over supply chains involving the processing of critical materials and rare earth elements extends beyond what is commonly assumed. This oversized control over supply chains, coupled with the concentration of production of these critical materials, has raised concerns in the US and the EU. A White House Report on national security highlights that China already owns two thirds of all critical earth materials in the world (White House 2021). The US sees this as a major geopolitical risk. China already dominates the processing of critical materials in the production of electrical vehicles, with close to 60% of global lithium produced in China according to the IEA. It is now stepping up investment in mines in Africa and elsewhere, while Western operators struggle to keep up.

NEW INDUSTRIAL POLICIES NEEDED FOR THE TRANSITION TO NET ZERO

Both the EU and the US have launched plans to secure access to critical materials and secure homemade supply chains to limit dependence on China.[3] The US is actively supporting mining of critical materials in Canada to reduce dependence on China and other suppliers perceived as 'non-friendly'. The Inflation Reduction Act spearheaded by President Biden, which uses tax credits extensively to promote clean energy investment at home, can be seen as a reaction to China's industrial green policy, which has propelled the country to become a super-processor of critical materials and producer of solar PVs and other critical equipment. *The Economist* reports that the incentives selected clean technologies are largest for green hydrogen, utility solar, utility battery and storage, CCS, and efficiency in homes.[4] Total investment spending on renewables, electricity transmission, and other clean technologies and energy spending in the Act amounts to more than $1.6 trillion.

The Inflation Reduction Act has, however, raised concerns in the Western camp. European leaders have expressed strong discontent over the risk of them losing out on green investments at home, including from corporations headquartered in the EU. The concern of European leaders is acute because the economic bloc has been hit by the energy crisis resulting from the invasion of Ukraine. In addition to contributing to limiting greenhouse gas emissions, the acceleration of the energy transition in the EU is essential to reducing its fossil fuel dependency from Russia (Arezki and Nysveen 2022, Arezki and Paduano 2022).

3 See www.whitehouse.gov/briefing-room/statements-releases/2022/02/22/fact-sheet-securing-a-made-in-america-supply-chain-for-critical-materials/ and https://ec.europa.eu/docsroom/documents/42849.
4 www.economist.com/business/2023/02/14/what-european-business-makes-of-the-green-subsidy-race

In response to Biden's Inflation Reduction Act, the EU has presented a plan to build and subsidise the transition of European manufacturing towards net zero. But it must do more than this. It must formulate a comprehensive policy response to the proactive industrial policy that both China and the US have enacted. After years of rejecting plans for an EU industrial policy, in light of the Covid-19 pandemic, the war in Ukraine and Biden's green policies, the time finally seems ripe. Kleimann et al. (2023) argue instead that the EU should not mimic the US and China's policies. The authors suggest that the EU should formulate a trade policy response that includes reform of the international subsidies regime and develop an instrument for EU-level subsidies that focuses on early-stage development and increasing EU resilience to trade disruptions.

SHIFTING GEOPOLITICS BETWEEN MAJOR BLOCS AND THE REST OF THE WORLD

The ramping up of mining activities for critical materials will have severe environmental, health, and social consequences. Mining activities can cause irreversible damage to the environment and are also an important source of emissions of greenhouse gases, thus undermining climate goals. Mining of critical materials is intensive in the use of water and can also contaminate water, especially in places where standards and controls are weak. Moreover, in places where labour standards are weak, working conditions can be very harsh and child labour may be rampant, such as in the Democratic Republic of Congo. Despite huge governance challenges, however, the DRC has become the darling of the US, the EU and China.

The risk of environmental damage is exacerbated by NIMBY politics in industrialised countries, which consume these critical materials in abundance. There is ample room here for international corporations, especially those headquartered in industrialised countries, to step up their efforts and adhere to their home standards to avoid an environmental and health disaster in the most vulnerable countries where these materials are extracted. If not confronted, these environmental degradations will leave behind people in the developing countries where critical minerals are extracted.

The race for critical materials by the major powers is far from new. One historical example is the competition among 19th century European empires for access to critical materials such as copper, tin, rubber and timber, as well as diamonds and gold. The advance of steam-engine navigation made access to and transport of these critical materials much easier for these empires. The resources were essential to powering industrial revolutions. But people in the colonies, where the resources were located, benefited little, if at all. As a result, former colonies have a complex history with which many, including in Africa, continue to grapple.

Leaders of countries like the DRC have been courted simultaneously by China and the US, despite a poor track record in terms of governance and human rights abuses. This new geopolitical environment in which developing countries have become the

centre of attention of major powers is likely to slow down or reverse democratisation in many developing countries. That is because 'geopolitical rents' for leaders aligning with superpowers are back. This does not augur well for citizens and for the prospects of improved economic governance in developing countries.

Moreover, the bonanza from critical materials is not necessarily good news. Developing countries have traditionally not managed the proceeds from the exploitation of their natural resources well, at the expense of their citizenry. The new geopolitical environment may make things worse.

GETTING GOVERNANCE OF CRITICAL MATERIALS RIGHT

The track record of developing countries in managing their natural resources has been so subpar that the term 'resource curse' was coined to describe the paradox of countries rich in natural resources performing worse than countries that are resource-poor (van der Ploeg 2011). The macro-institutional consequences of traditional resources offer lessons in what to avoid when managing booms from critical materials.

Macroeconomic volatility, loss of competitiveness, excessive indebtedness, excessive rent seeking of revenues from the sale of raw materials, and internal and external conflicts have been found to be behind the poorer performance of traditional resource-rich countries. Unfortunately, worsening of the rule of law and of the quality of institutions tends to be part of the curse too. On the other hand, Mehlum et al. (2006) have shown that good institutions, unsurprisingly, moderate the natural resource curse. But which ones? There are two key areas:

- The policies and institutions that govern the opening of the natural resource sector to attract investment and hence generate revenues for the state.
- The quality of redistributive institutions that govern how the proceeds from the exploitation of these resources are used to benefit people, including in terms of human capital.

Regulation at the national level has often failed to address issues of over-exploitation of natural resources as well as displacement, environment degradation, and risk to biodiversity, which are often best managed by local communities. The work of the late Elinor Ostrom shed important light on the design of self-organised user communities to achieve sustainability in the exploitation of natural resources (Ostrom 2009), which can be salient for getting the governance of critical material booms right.

The various international initiatives in existence have focused mainly on transparency, including the Extractive Industry Transparency Initiative and the Natural Resource Charter. Several non-governmental organisations have also been very active in this space. Legislation in the US and the EU strives to hold accountable their multinational corporations by mandating that companies disclose their payments in countries in which

they operate. It is more difficult to hold state-owned enterprises accountable because of lack of transparency and a complex web of interests and cross-subsidies. The development of environmental, social, and corporate governance (ESG) norms has roots in the socially responsible investing movement that began in the 1970s. These are means by which investors and others can gauge how responsibly a corporation behaves environmentally. But it is unclear whether ESG assessments are sufficient to force firms to internalise the complex sets of externalities at different levels required to achieve sustainable behaviour. It is also unclear whether and how ESG norms could be enforced. One encouraging sign is that consumers in advanced economies appear to be changing their behaviour with regards to the environment. But investor behaviour, especially in developing countries, may not be so amenable to change. The challenge with all these initiatives is the difficulty in translating them into the right context and fostering ownership, especially at the local and national levels. More needs to be done to integrate local, national, regional, and global actors to achieve better outcomes.

The EU's and North America's relationships with regions such as Africa and the Middle East, and especially with China, will be crucial to shaping the international governance of critical materials. Countries like Albania might want to cut China out of critical material deals, while Canada has ordered three Chinese firms to divest from its lithium mines with the aim of avoiding supply chain instability. Canada also now has the Investment Canada Act, which aims to stop foreign direct investments that threaten national security and critical minerals supply chains at home and abroad. Both the EU and the US currently produce insufficient quantities of the critical materials necessary for the pending boom in electrical vehicles and other goods. They therefore need to reach out to other friendly countries for mutually beneficial trading relationships as well as investing in the exploration and exploitation of critical materials. A transatlantic treaty could be designed to make countries commit to stronger supply chains and fight unfair trade practices in the field of critical materials.

Governance should account for the interdependencies related to peace and stability, global health and environmental and climate issues in a world that is increasingly organised into blocs. If externalities are to be internalised, it will require the following:

- Technology transfers from advanced to developing economies to provide the tools to address the threat of climate change and meet climate goals, including by moving value chains of critical materials.
- Access to international capital markets through, for example, green, nature or blue bonds instead of opaque, resource-backed loans with non-traditional creditors such as China.
- Ways to ensure that foreign direct investment delivers on local content, environmental protection and jobs, in order to address rising discontent in communities where mining or other extractive industries operate.

CONCLUSION

The transition towards net zero implies an explosion in the demand for critical materials, but the required boost in the supply of such materials is hampered by political, environmental, and economic obstacles. Concerns over the supply chains of critical materials to power the energy transition must be seen in a broader context. The tensions over access to and control of critical materials could derail the transition towards clean energies. Indeed, the rolling out of subsidies, tariffs and non-tariff barriers could make the transition increasingly costly due to efficiency loss from economic fragmentation. While climate negotiations have focused on commitments to climate goals and the finance to promote them, strategic rivalries risk creating new hurdles that could make the energy transition much more difficult or even impossible. It is high time for the major superpowers to rebuild trust to ensure that economic wars over critical materials do not undermine the goal of limiting climate change which united humanity at COP21 in Paris.

At the same time, in a multi-polar world the US and Europe should not repeat the mistakes of the past. Europe was too dependent on gas supplies from Russia, and the West should not become too dependent on China for the critical materials needed for the green transition. What is needed is new economic thinking about the structural transformation towards a green economy, taking full account of the geopolitical risks and implications. This is especially relevant given the EU's ambition to have more strategic autonomy on all fronts, from defence and chips to medicines and natural resources.

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CHAPTER 20

Mineral extraction and conflict in the era of green technologies: Implications and consequences

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The accelerating transition to a low-carbon economy has led to the rapid adoption of green technologies (such as wind turbines, solar panels and energy storage). For example, the global number of electric vehicles tripled between 2018 and 2022 (to 16 million) and the International Energy Agency (IEA) estimates that there will be 200 million electric vehicles on the road in 2030 (IEA 20220, leading to a drastic increase in battery demand. While estimates are highly dependent on the stringency of climate policies and the assumptions of the scenarios, the annual demand for minerals by clean energy companies is predicted to double or even quadruple by 2040 (IEA 2021). The rapid expansion of the green technology industry and the resulting surge in demand for minerals raises significant concerns about the potential socioeconomic implications for mineral-producing countries. These concerns are compounded by the historical precedent of resource-rich nations bearing the brunt of the negative effects of global economic shifts. It is therefore imperative to address the urgent need for equitable and sustainable practices in the mining sector to ensure that the transition to a low-carbon economy benefits all nations, regardless of their resource endowments.

WHAT CAN WE LEARN FROM THE LITERATURE?

The ways in which mineral resource endowments shape short- and long-run economic and political outcomes has been the subject of a huge theoretical and empirical literature (Engerman and Sokoloff 1997, 2002, Torvik, 2009, Rajan 2009, van der Ploeg 2011, Brollo et al. 2013; see Cust and Poelhekke 2015 for a literature review). In examining the numerous micro and macro consequences of mineral exploitation on income, inequality, health and the environment, it is crucial to understand the dimension of conflict. A rich theoretical literature has proposed various mechanisms to explain how the extraction of mineral resources can constitute an important catalyst of conflict. The first involves the looting of resource-rich communities, the extortion of extractive firms and the collection of illegal taxes along transportation routes. This creates a situation in which mineral resources can generate a significant financial windfall for armed insurgent groups. There

is a plethora of anecdotal evidence indicating that the exploitation of mineral resources fosters rebellions. For example, the United Nations Environment Programme (UNEP) points out in a 2015 report that while 98% of the profits from the illegal mineral trade in the Democratic Republic of Congo accrue to international criminal organisations (including some that are active in the Democratic Republic of Congo), the remaining 2% (equivalent to about $13 million per year) are captured by local armed groups, thus providing financing for approximately 8,000 combatants. Recently, it has been reported that in Eastern Senegal armed groups are leveraging their influence in gold-mining regions to finance their activities, similar to the longstanding situation in Northern Mali.

Second, the presence of mineral resources increases the 'prize' to be won through the capture of territory or takeover of a state. Thus, the presence of mineral resources increases the appetite of armed groups to take control of resource-rich regions. For instance, in 2002 a United Nations report on the plundering of the Democratic Republic of Congo's mineral resources explicitly mentioned how the Rwandan Patriotic Army had attacked villages in order to seize natural resources (United Nations 2002). More recently, the Institute for Security Studies (2022) reported that the Allied Democratic Forces in the Democratic Republic of Congo has adopted an explicit strategy to terrorise communities rich in mineral resources (gold, coltan and cassiterite), with the goal of expropriating their land and gaining exclusive access to the mines.

Third, grievances of the local population with regard to their economic or political situation have been cited as a major driver of violence. Particularly in the context of industrial operations (as opposed to small artisanal mines, whether legal or illegal), mining activity generates frustrations and grievances among local populations. This is all the more so when the extraction is capital-intensive, since it leaves little room for local communities to participate in the extraction activity. The local population is often banned from lucrative mining jobs or excluded from profit-sharing during boom periods. Furthermore, the degradation of the environment – in particular, as a result of the pollution of land and waterways – and the expropriation of land (often ancestral) without consultation or compensation further fuel the grievances of local communities. For example, in the case of South Africa, Human Rights Watch (2019) has voiced multiple concerns about the effect of large-scale open mining on the Xolbeni community since 2007. The risk of displacement and the environmental damage has led to strong resistance against these kinds of activities.

Finally, there are numerous historical examples (such as the Gold Rush in the US, the situation in South Africa in late 19th century, and so on) as well as contemporary ones (Burkina Faso, Ghana, Tanzania, etc.) that highlight the strong pull that mining activity exerts on migration flows. These in turn modify the local ethnic, age and gender profiles of the population, which can create fertile ground for the recruitment of armed groups, especially in poor and unstable regions. On the other hand, there is a mechanism through which mineral resource extraction can dampen the attraction of joining an armed group. The academic literature clearly shows that the income that can be earned

in mining increases the opportunity cost of soldiering and thus reduces the ability of groups to recruit combatants. Consequently, a fair and equal distribution of the wealth generated by resource extraction among local communities can reduce or eliminate conflict dynamics in resource extraction areas.

On the basis of these theoretical mechanisms and the accessibility of reliable data on the timing, nature and location of armed conflicts, it has become possible to empirically quantify the role of mining activity in creating or exacerbating conflict.[1] In the case of Colombia, Dube and Vargas (2013) show that the effect of increasing the price of a resource on the level of violence is intrinsically related to the technology used to produce it. They show that an increase in the price of a labour-intensive good (such as coffee) reduces violence, primarily by way of the increase in individual income (which increases the opportunity cost of soldiering). On the other hand, an increase in the price of a capital-intensive good (such as oil) increases violence – especially in the absence of a redistribution mechanism – by increasing the incentives to capture the oil rent. From 1997 to 2010, the global prices of many minerals almost tripled, creating a staggering wealth effect in the resource-producing regions. Berman et al. (2017) estimate that the recent increase in the price of mineral resources helps to explain up to a quarter of local conflicts in Africa during this period, thus undermining the hypothesis that resources can have a pacifying effect through the distribution of the wealth created. By examining the nature of violent events, they find that spikes in mineral prices fuel both low-level violence (riots and protests) and organised violence (armed resistance). Interestingly, they investigate the diffusion over space and time of mineral resource-induced violence, a crucial factor in understanding how local violence escalates to the regional or national level. They show that the effect on organised violence, which is quantitatively significant, is well explained by a relaxation of the financial constraints faced by armed groups, which allows them to significantly extend their activity to increasingly distant regions and for increasingly longer periods. Andersen et al. (2022) corroborate this mechanism for 132 countries during the period 1962–2009 by showing that countries rich in offshore oil are less exposed to conflict, while countries rich in onshore oil are more exposed. They argue that offshore oil production is less likely to be disrupted by armed groups, unlike onshore production which increases the number and activity of such groups. Such studies corroborate the importance of industrial mineral extraction in understanding the roots of violence.

1 The Armed Conflict Location & Event Data Project (ACLED) and the Uppsala Conflict Data Program (UCDP) are two datasets that have been widely used in the recent conflict literature. They contain crucial information on the dates and location (longitude/latitude) of conflict events within each country, and the nature of the actors on both sides of a conflict. Events are compiled from various sources, including accounts in the regional and local media, humanitarian agencies, and research publications.

THE FOCUS ON ARTISANAL AND SMALL-SCALE MINING

The unprecedented increase in the demand for minerals raises legitimate questions as to how their supply will be increased. Historically, most of the increase in demand for minerals was met by the investment of resources by large mining companies. However, given the pressure created to quickly ramp up mineral production, many analysts have emphasised the increasing role of artisanal and small-scale mining. In contrast to industrial mining, this type of mining is low-tech, labour-intensive and largely operated informally or illegally and therefore is able to respond to rapid changes in demand. Given the differences between these two mining sectors, there is reason to believe that the mechanisms through which they affect the level of violence will also differ. Understanding the nature of violence induced by artisanal and small-scale mining is also crucial in determining whether it can escalate from the local to the global level. For instance, there is plentiful anecdotal evidence on the recurrent clashes between artisanal mine workers (or local communities) and large-scale mining operators in, for example, Ghana, Tanzania and Sierra Leone. The grievances are numerous: competing claims over the discovery of the deposit, disputes over land access, expropriation of artisanal mine communities by large-scale mine operators, and so on. As in the case of industrial mines, artisanal mines are often linked to various types of environmental damage, including land degradation, deforestation, the discharge of polluting substances and the contamination of soil and water, which exacerbate the situation.

Negative income shocks are a first-order determinant of violence in Africa, especially in rural areas (McGuirke and Burke 2020). By using various proxies for income variability at the local level – such as variations in climatic conditions (Harari and La Ferrara 2018), changes in the global demand for agricultural commodities (Berman and Couttenier 2015), labour productivity shocks (Cervellati et al. 2022) and fluctuations in input prices (Berman et al. 2021) – the literature clearly demonstrates the contribution of income shocks to the diffusion of conflict, especially by way of the opportunity cost mechanism. On the other hand, anecdotal evidence emphasises the insurance role played by artisanal mines in smoothing income shocks arising from agricultural price variations or poor harvests. Therefore, it is likely that the artisanal mines mitigate the impact of negative income shocks on conflict. Due mainly to the absence of reliable time-varying and exhaustive data on the location of artisanal mines (and also when they started operating), little empirical work has been done to precisely estimate the net contribution of artisanal mines in generating conflict. In a recent paper (Couttenier et al. 2022), my co-authors and I combine machine learning techniques with satellite images over a region of 1.75 million km^2 in West Africa in order to collect time-varying information on the location of artisanal mines. This kind of information is crucial in order to identify the specific channels that link artisanal mine activity and conflict, and in turn to better inform policy makers.

ARE CURRENT POLICIES EFFICIENT IN REDUCING THE EFFECT OF MINERAL EXTRACTION ON CONFLICT?

In the 1990s, the publicity gained by the mining of blood diamonds, particularly in Angola, the Democratic Republic of Congo, Liberia, Sierra Leone and the Central African Republic, was one of the first signs that the international community is becoming aware of the need for greater transparency and traceability with respect to the origin of minerals. Part of this process was the launch of the Kimberley Process in 2000 (followed by a United Nations Resolution in 2001 with similar intent), which promotes the issuing of certificates that document the origin of a diamond, with the goal of limiting the ability of armed groups to finance themselves through illicit trade in diamonds. Subsequently, numerous international initiatives have been launched to promote greater transparency with regard to the origin of minerals and the payments made by mining companies (such as The Extractive Industries Transparency Initiative and the Mineral Certification Scheme of the International Conference on the Great Lakes Region). In 2010, the United States approved Section 1502 of the Dodd-Frank Act, the goal of which is to monitor the supply chain of publicly-listed US companies by requiring that they disclose the origin of certain minerals (tin, tantalum, tungsten and gold), especially if they are extracted in conflict zones, to the U.S. Securities and Exchange Commission (SEC). Following a decade of negotiations, Europe passed legislation in 2021 that imposes a duty of care on companies which import those minerals, with the goal of promoting responsible sourcing. It is essentially based on the assimilation of a management system within companies which will facilitate supply chain transparency, risk management and verification by an independent third party of the origin of minerals.

Studies of the effectiveness of these policies in severing the link between mineral resource extraction and conflict indicate that they have had little or no impact. For example, in the case of the Republic of Congo, studies show that the Dodd-Frank Act has deprived local communities of income from artisanal mining and has failed to address the root causes of the conflict. In response to this policy, many armed groups have intensified their violence against civilians and increased looting, particularly in gold-rich areas, while diversifying their income through trade in charcoal, palm oil and cannabis (Stoop et al. 2018). On the other hand, other studies of resource transparency and international traceability initiatives indicate that the link between resources and conflict has been mitigated to a modest extent.

In light of the predicted trend in the demand for minerals and the limited impact of public policies, there is an urgent need to increase efforts to understand how resource extraction fuels conflict. In particular, emphasis should be placed on the role of artisanal mines in the approaching ecological transition. The sustainability of the green revolution will depend on the success of such efforts.

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CHAPTER 21

Clean energy, clean politics: The key importance of decentralisation, transparency and local empowerment for the green transition

Dominic Rohner
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The world is again at a crossroad, with one avenue leading straight to environmental disaster and meltdown and the other one to a green transition. It is not the first crossroad, and up to now our journey has been characterised by missed opportunities and short-termism. We are on the wrong road, and the later the path of sustainability is selected, the bigger the detour and the more painful the transition to get back on (the right) track. This analogy captures well the dimension of timeliness and the trade-off between smaller pain today versus waiting and facing greater pain tomorrow. Yet, what it ignores is the fact that there are not only different timeframes but also different ways of 'going green'. As argued in this chapter, the age of fossil fuels has not only brought looming environmental disaster to humankind but has also led to toxic politics. If history is not to repeat itself, we must make sure that when we move to an age of green energy, we do not commit the same mistakes as in the past when oil was king.

OIL AND BLOOD

What exactly is the trouble with fossil fuels? First of all, and obviously, our dependence on oil, gas and coal are key factors that fuel global warming, creating an existential threat to the environment. Second, and maybe less obvious, oil corrupts sound politics in a variety of ways. First of all, oil corrupts literally – when a larger share of state revenues are from resource rents, this tends to increase the use of graft and bribery, worsen governance and hollow out democracy in general (Ross 2001, 2012, 2015, Caselli and Michaels 2013, Caselli and Tesei 2016).[1] Note that while corruption hurts a country as a whole, opportunities for bribes are attractive to the ruling elite, which means that this may constitute a reason

1 While the lion's share of the literature on fossil fuels focuses on oil (and gas), there is also evidence of a resource curse for coal, whereby coal-producing areas have ended up poorer due, among other reasons, to lower human capital accumulation, driven by more hostile views towards education (Esposito and Abramson 2021).

for corrupt politicians to oppose the green transition. If decarbonising electricity leads to fewer opportunities to fill their pockets, they may oppose energy reform for entirely selfish reasons.[2]

Sadly, this is not the end of the story. Various econometric studies have found that oil rents fuel the risk of civil conflict (Humphreys 2005, Ross, 2012, 2015, Dube and Vargas 2013, Lei and Michaels 2014, Morelli and Rohner 2015),[3] of mass killings of civilians (Esteban et al. 2015) and of interstate wars (Caselli et al. 2015).

WHAT FEATURES OF FOSSIL FUELS MAKE THEM TOXIC FOR POLITICS?

Drawing on the literature on the economics of conflict (see Rohner 2023 for a recent survey), a series of features of fossil fuels have been highlighted that increase the risk of appropriation – by a corrupt regime or through armed conflict. First of all, and quite evidently, these commodities are valuable and hence constitute an attractive 'prize' to grab (Ross 2012). Tellingly, recent evidence (Nordvik 2019, Andersen et al. 2022) finds that the impact of oil in terms of fuelling political violence is confined to situations where it is relatively easy to appropriate by armed groups (i.e. onshore as opposed to offshore oil). Second, the exploitation of fossil fuels is capital-intensive, which means that they tend to increase the returns of capital while – if anything – lowering local wages, reducing the opportunity costs of recruiting rebel soldiers (Dal Bó and Dal Bó 2011, Dube and Vargas 2013). Third, the geographical distribution of natural resources tends to be unequal, which implies that resource-rich areas close to country borders may have incentives for secessionism or may constitute potential targets for international conflict (Caselli et al. 2015, Morelli and Rohner 2015). Fourth, further aggravating incentives for capturing natural resources and smuggling of illegal output is the lack of transparency/traceability of supply chains. It has been found that regulation championing traceability can reduce the scope for armed conflict, at least as far as the mining sector is concerned (Berman et al. 2017). Fifth, oil production frequently triggers grievances among the local population (Koos 2018), who (often rightly) find that they miss out on a fair share of oil cash and who suffer from local environmental degradation due to polluting oil and gas production activities (Sovacool 2014).

2 Of course, there are further reasons for the harmful delay of pressing green reforms, such as short-termism. Even if championing the green transition as early as possible is optimal, hyperbolic discounting may put an exaggerated weight on the short-run costs of transition, leading to procrastination bias (Akerlof 1991). And politicians may be weary of implementing necessary yet unpopular decisions in the aim of maximising (short-run) popularity.

3 Cotet and Tsui (2013) find little robust evidence that oil discoveries boost political violence, yet uncover that oil discoveries increase military spending in non-democracies.

WHAT CAN WE LEARN FROM TOXIC OIL POLITICS FOR DESIGNING THE GREEN TRANSITION?

As stressed above, features of fossil fuels (and other natural resources) that contribute to their detrimental political effects include their geographical concentration, their large financial value, the capital intensiveness of extraction, the lack of transparency of supply chains, the relative exclusion of local stakeholders from their windfalls, as well as local environmental degradation linked to resource extraction. Drawing on these large-scale findings, we can formulate key principles that should be followed when transiting towards a novel, greener mix of energy sources.

Decentralisation of energy production

To counter the incentives of corrupt governments or greedy warlords to get their hands on concentrated and highly valuable resource rents, such as giant oil fields, a country may want to decentralise as much as possible the production of energy (see also the discussion in Rohner et al. 2023). Remember that in the current economy hooked on fossil fuels, stealing becomes child's play for corrupt rulers who often do not even have to face the hassle of thinking about production; they can simply sell extraction rights to international companies and pocket the royalties. Moving to renewable energy production does not automatically solve the problem. If, for example, a giant solar park is created in a very hot and arid region of a given country, this may be quite efficient in terms of energy generation, yet the rents from valuable energy creation are, again, concentrated and quite easily appropriable by the ruling regime and/or an attractive target for rebels.

In contrast, if much of the electricity is produced, for example, by locally managed roof-top solar panels, this decentralisation of production makes it much harder for crooked politicians or rebel leaders to appropriate the value created by this electricity production than when production is concentrated. This helps to combat corruption, toxic petro-state policies and conflict. While widespread roof-top solar panels are maybe an extreme form of production decentralisation, other renewable energy sources also have the potential for decentralisation. For example, wind turbines could be positioned in various regions of a given country, making them in principle well-suited for decentralisation. Or take hydraulic plants: in Switzerland, for example, there are 682 hydraulic (water) power plants that reach a plant-level performance threshold of above 300 kilowatts (Bundesamt für Energie 2023), jointly accounting for 58% of Swiss electricity production. They come in all shapes and sizes and are spread throughout various regions of the country, enabling decentralised electricity production.

While in the above we have focused on concerns about rent-seeking fuelling corruption and armed violence, there is an additional reason why decentralization is key. As stressed by Tatyana Deryugina in her contribution to this eBook, when power plants become a military target for hurting the opponent during a war, decentralisation increases energy security and independence.

Providing local jobs

As mentioned above, capital-intensive fossil fuel extraction – if anything – lures capital away from the rest of the economy, to the detriment of labour markets, driving down salaries and hence lowering the opportunity cost of appropriative activities and rent-seeking (Dube and Vargas 2013). In fact, dozens of studies have found poverty and the absence of economic perspectives to be among the most powerful determinants of armed conflict (Rohner 2023).

Hence, it is key to inverse this harmful side effect of our fossil fuel addiction. In particular, investments in green energy should create jobs and vitalise local labour markets. Roof-top solar panels, for example, require substantial local labour for installation and connection to the electricity grid, generating much local value-added. Decentralisation of other types of renewable energy production also has the potential to create a significant demand for local labour. In contrast, when huge solar parks in remote arid areas or wind parks in far-off windy pastures are created from scratch by multinationals drawing exclusively on a non-local workforce, potential local labour market gains are absent (or even negative). Integrating the local workforce in green projects also has the upside of building local expertise that not only boosts the local economy but may also prove useful when urgent repair works are needed.

Equal distribution of benefits

As mentioned above, the unequal geographical distribution of fossil fuels increases the risk of armed conflict (Caselli et al. 2015, Morelli and Rohner 2015). This inequality in resource location can easily trigger distributional conflicts where, for example, the central national government aims to control the lion's share of resource rents while a resource-rich region may have incentives to split in order to avoid sharing the windfall with the rest of the country. Thankfully, this can be largely prevented by the clever geographical distribution of green energy production. It should be ensured that some form of electricity production takes place in different parts of the country, which is often feasible. If, for example, mountain regions have steep rivers suitable for dams, the plains and valleys may benefit from more wind. Further, the potential for conflict is much reduced when not only the distribution of production is decentralised and geographically balanced, but the benefits are also distributed equitably and widely, with local communities benefitting from the fruits of their energy provision. Receiving one's fair share of the benefits of green energy crowds out incentives for separatism and smooths potential local resistance against power plants.

Avoid local environmental degradation

As discussed in depth above, local environmental degradation harms local communities who (often rightly) feel that their livelihoods are destroyed and that they do not receive a share of the windfalls. Thankfully, green energy can be often produced without causing local pollution. Think, for example, of roof-top solar panels that have only a marginal impact, if any, on local environmental health. Similarly, (small) water-power plants can typically accommodate local environmental concerns (although giant dams may of course fundamentally alter the local environment and trigger popular resistance, see Eberle 2020). Wind power has only limited environmental impacts, but it needs to be designed well as it can be dangerous to wildlife (in particular, birds). In a nutshell, compared to the large-scale pollution of oil and gas extraction, in most contexts, (reasonably sized) green energy plants have only relatively small environmental effects on the local environment.

CONCLUSIONS

Fossil fuels are toxic for both the environment and for politics. As surveyed in this chapter, oil and gas fuel autocracy, corruption and several types of armed conflict. Thus, rapidly unhooking from fossil fuels is not only key for limiting global warming, but will also strengthen peace and sound governance, contributing decisively to human happiness.

Now of course the million-dollar question is how to manage this urgent transition to green energy. In particular, we need to avoid repeating the same mistakes that gave rise to ill-fated petro-states in the past. Crucial principles to follow include decentralising the provision of green energy, ensuring that renewable energy champions local jobs, enforcing fair sharing of energy benefits and protecting the local environment. This will enable a fresh start towards clean energy and clean politics.

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CENTRE FOR ECONOMIC POLICY RESEARCH

There is growing awareness worldwide of the existential threat posed by climate change and the need for a green transition. Yet, specific ecological policy proposals are routinely rejected by large segments of the population. As argued in this 21-chapter strong eBook, while this may be partly due to freeriding or the utopic hope of saving the planet without sacrifices, a key role is also played by the fact that policy proposals are often badly communicated and ignore political economy incentives and adverse distributional effects. Yet, unintended distributional impacts of green taxes are by no means unavoidable, as a clever design can make any levy progressive. For example, a carbon tax with a targeted redistribution of the 'carbon dividend' is able to fight both climate change and inequality, without increasing the total tax burden.

Another overlooked political economy aspect of the green transition are price effects. As highlighted in the eBook, relying solely on supply-side policies (say, banning fossil fuels) triggers energy price spikes, which serve as ammunition for populists. In contrast, supplementing supply-side measures with carbon taxation and/or policies that curb energy demand (Part I of the book) and boost green energy supply (Part II) ensures a macroeconomic market equilibrium with moderate energy prices that supports popular acceptance (Part III).

Finally, our fatal fossil fuel addiction has grim political consequences, ranging from galloping corruption and mismanagement to domestic and international warfare. Several chapters of Part IV study how the green transition can detoxify politics and how best to manage mineral needs for renewable energy. Core policy principles are elaborated that make sure that green energy does not entail the same 'resource curse' as fossil fuels. The stakes could hardly be higher – a well-designed green energy transition yields the double-dividend of saving the environment and fostering peace and sound governance.

ISBN: 978-1-912179-74-9

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