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GUEST EDITORIAL

Policy instruments for limiting global temperature rise to 1.5°C – can humanity rise to the challenge?

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ABSTRACT

In order to mobilize the volume of mitigation required to reach a global emissions path consistent with 1.5°C, policy instruments need to be much more stringent than they have been to date. They will have to ensure full decarbonization of key economic sectors within one generation, which will require retirement of high-carbon assets before the end of their technical lifetime. However, political economy shows that only those instruments will be implemented that benefit well-organized interest groups while spreading costs as widely as possible. In the past, this has led to distortions such as emissions trading systems with systemic overallocation of allowances, or carbon taxes that exempt industry. Under favourable lobbying constellations strong subsidy schemes for mitigation can emerge. Renewable feed-in tariffs in Europe persisted for over two decades and were crucial for the breakthrough of wind and solar power technologies. But once competition from China led to the demise of European technology providers and the European population started to feel the pinch from the surcharges on their electricity bills, feed-in tariffs were abolished. Historically, rapid transformations of the nature required to reach 1.5°C built on either lavish public investment into the underlying infrastructure or a general notion of national emergency. Innovative forms of market mechanisms could convince policy makers that mitigation costs are lower than expected and thus accelerate mitigation. For the long-term success of far-reaching mitigation policies, it will be crucial whether they can be framed as harnessing an opportunity or whether they are seen as a grim, but grudgingly accepted response to a societal emergency.

Key policy insights

- Interest groups play a key role in the design of mitigation policy instruments and reduce their efficiency as well as effectiveness.
- Instruments generating high carbon price levels may in the future be possible if redistribution of revenues is done in a way that soothes the key interest groups.
- A mixture of market mechanisms for mobilization of mature mitigation technologies with a dedicated public investment programme for emerging technologies seems promising, provided technologies can be 'weaned off' public support at the right point in time.
- For contentious, 'emergency' technologies such as Negative Emission Technologies (NETs) or Solar Radiation Management (SRM), governance mechanisms on the international level are critical.

1. Introduction

To date, research on GHG mitigation policy instruments has rarely been done in the context of very stringent mitigation targets. Generally, it had been assumed that international climate policy would progress slowly

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and thus 'classical' environmental policy instruments could be introduced and tightened over time. Since 2015, this situation has changed. The Paris Agreement's aim of limiting warming to well below 2°C above pre-industrial levels, and pursuing efforts to limit the warming to 1.5°C, by achieving a balance between emissions and sinks in the second half of the century (UNFCCC, 2015), together with the International Panel on Climate Change (IPCC) special report on 1.5°C scheduled for publication in 2018, have triggered an urgent need for research on climate policy instruments consistent with 1.5°C emissions pathways.

How can policy makers in almost 200 sovereign nations design, introduce and enforce policy instruments that transform entire economies in one generation? How can such policy instruments contribute to the 2015 UN Sustainable Development Goals (SDGs) taking into account the highly diverse development needs and circumstances of each nation? How can the international climate policy regime facilitate diffusion of the most successful instruments and revisions of those instruments that do not perform well? We will discuss these questions below and showcase the contributions of this Climate Policy Special Issue on *Policy instruments for limiting global temperature rise to 1.5°C*, to elucidate key aspects of policy instrument choice, design and implementation.

2. The size of the challenge

As a consequence of the 1997 Kyoto Protocol and the increasing political salience of GHG mitigation, an increasing number of governments have introduced mitigation policy instruments, especially since the mid-2000s (Fankhauser, Gennaioli, & Collins, 2015). Between 2007 and 2012, the share of emissions in countries with national level mitigation policies increased from 45% to 67% (Dubash, Hagemann, Höhne, & Upadhyaya, 2013). Although many of these policies are of a regulatory nature (see e.g. IEA, 2017 for energy efficiency policies), some of them generate a carbon price (see Zechter et al., 2017 for a detailed description of carbon pricing policies); by 2017, about 15% of the world's emissions were subject to such prices.

Despite this proliferation of mitigation policies, global GHG emissions continued to increase strongly up to 2014. Although in the last two years global emissions have stabilized, it is unclear whether this is a real change in trend or just a transient blip linked to specific, but temporary factors, such as short-term abundance of low-cost natural gas (Jackson et al., 2017 predict a sizeable emissions increase in 2017 and 2018). In many countries, coal power infrastructure continues to be built but will have to be retired before the end of its technical lifetime to remain on a 1.5°C-compatible path (Spencer et al., 2018). As UN Environment (2017, p. xiv) stresses, 'there is an urgent need for accelerated short-term action and enhanced longer-term national ambition, if the goals of the Paris Agreement are to remain achievable'.

Achieving a 1.5°C-compatible global GHG emissions path requires a rapid peaking of emissions and a sustained decrease to achieve net zero emissions between 2045 and 2060 (Rogelj et al., 2015), at which point the carbon budget would already have been overshot. Correspondingly, most emissions scenarios require net negative emissions (see e.g. Millar et al., 2017). This also means that scenarios, with few exceptions, now also include global average temperature temporarily rising above the 1.5°C level. Given that many climate change damages are linked to the rate of change (O'Neill & Oppenheimer, 2004) even temporary overshoots are problematic. For all scenarios, the speed of decarbonization required exceeds all historical experiences; only during short periods in selected countries has such decarbonization been achieved in the past (see Napp et al., 2017 for nuclear power in France, Smil, 2016 for natural gas in the Netherlands and wind power in Denmark). Kuramochi et al. (2018) define in very clear terms the daunting challenge to be achieved for each sector of the global economy to stay on a 1.5°C-compatible emissions path: The current growth rate of renewables and other zero and low-carbon power generation needs to continue until 2025, and full decarbonization has to be reached by 2050. No new coal power plants can be built and the emissions from the existing plants need to be reduced by 30% by 2025, either through biomass co-firing or carbon capture and storage (CCS). The last new fossil fuel passenger car hits the road in 2035–2050. All new buildings have to be fossil-free and near zero energy by 2020, and the low-energy refurbishment of existing buildings will have to quintuple to 5% by 2020. Emissions from forestry and other land use have to fall to 95% below 2010 levels by 2030, with net deforestation ceasing by 2025 (see also Grassi et al., 2017). Given the size of the challenge unequivocally illustrated by these sectoral examples, and the current mismatch with the limited appetite of policy makers to seriously engage in climate change mitigation, some observers have openly criticized the inconsistency of climate policy (Geden, 2016).

3. The political economy of introducing '1.5°C-compatible' mitigation policy instruments

Rapid decarbonization on the demand side requires an early replacement of high-carbon infrastructure such as fossil fuel power plants (for coal see Spencer et al., 2018) and transport systems or energy-inefficient buildings (see Kuramochi et al., 2018). Moreover, new low-carbon infrastructure such as renewable energy generation, electric vehicles or highly efficient buildings and appliances generally require more capital than 'baseline' high-carbon infrastructure. Often, low-carbon infrastructure, for example in the transport sector, require significant upfront investment before they can serve the general population; a current example would be electric vehicle charging infrastructure. Policy instruments to drive 1.5°C-compatible decarbonization thus need to rapidly direct capital towards low-carbon infrastructure at a large scale. They also need to enforce early shutdown and dismantling of high-carbon infrastructure (which would then become 'stranded assets') or pay the expected loss incurred by the owners of that infrastructure. Enforced shutdown without compensation will be impossible in countries with a functioning legal system and the principle of protection of private property from arbitrary expropriation (Bos & Gupta, 2017).

In contrast to the demand side, on the fossil fuel supply side, no dedicated policy instruments, other than coal mine closure mandates in China, are under discussion in large emerging economy coal producers and consumers (Spencer et al., 2018). The only policies to address fossil fuel supply close to implementation are divestment mandates of sovereign wealth funds. Such a policy is currently contemplated by the Norwegian Sovereign Wealth Fund which currently has $35 billion invested in oil companies (Krauss, 2017).

3.1. Interest groups and policy instrument choice

Companies that operate high-carbon infrastructure or provide technologies that are emissions-intensive will fight against the introduction of stringent mitigation policy instruments (e.g. see Baranzini et al. (2017) on emitter lobbying against carbon pricing policy instruments).

In democratic systems, voters are likely to shun policy makers whose action may lead to an increase in living costs and reduce the perceived quality of life (e.g. see the discussion by Honegger & Reiner, 2018 on public opposition to CCS owing to perceived risks of storage reversal). For certain economies, the interest group cluster dependent on fossil fuel extraction is so deeply engrained that entire regions would become stranded if extraction ceased (Spencer et al., 2018). Under these conditions, the only mitigation policy instruments that can thrive are those whose benefits accrue to small but powerful groups, while the costs are spread imperceptibly across large groups (Michaelowa, 1998).

Experience regarding mitigation policy instrument design in the last decades is not encouraging with regard to the possibility of achieving a rapid decarbonization path. In most industrialized countries, mitigation policies have exempted the industrial and agricultural sectors owing to successful lobbying. Energy efficiency-related regulation usually addresses only the low-hanging fruit. It took more than two decades in Scandinavia to expand carbon taxes to the industrial sector, and this expansion is far from complete. And in most cases where the industrial sector is covered by a carbon pricing policy instrument, it is an emissions trading system characterized by overallocation of allowances, low allowance prices and special rules for sectors exposed to international competition that essentially take away any mitigation incentive.

Policy instruments that have been successful to drive low-carbon technologies over several decades can be found in the renewable energy sector. After initial experiments with renewable energy tariff auctions in the 1990s were unsuccessful in the UK, long-term feed in tariffs (FITs) were introduced in various European countries. Especially in Germany and Denmark, FITs were crucial to driving the expansion of wind, and later, solar power. They provided the investment security financial institutions were looking for, and also benefited from the availability of skilled labour in declining sectors such as shipbuilding. Rapid upscaling of wind and solar technology manufacturing capacity ensued, and FITs diffused to Southern Europe as well as emerging economies. The political economy was favourable to FITs as the new renewable energy technology companies became a powerful lobby and could enlist lobby support from farmers benefiting from rent payments for renewable energy installations, as well as trade unions that were supporting creation of jobs for their old clientele in the manufacturing sector (see Michaelowa, 2005). Costs of FITs were spread across the general population and barely visible to the average citizen.

However, over time, the drawbacks of FITs became clearly visible. Owing to information asymmetry, governments were unable to set tariffs at a level where they would ensure technology cost reductions over time. For example, both for wind and solar technologies, unit costs remained stable over most of the 2000s and European technology producers were highly profitable. Only when China had forced Western renewable energy technology leaders to transfer their technology to China by enforcing local content requirements, and Chinese companies started a low-cost competition from 2007 onwards, did the situation change. Several Southern European governments were forced by the economic and financial crisis of 2008 to reduce public budgets for FITs and even renege on existing contracts. At the same time, European renewable energy technology producers were unable to withstand Chinese competition and many of them went bankrupt. Chinese exports to Europe skyrocketed. Protectionist movements mushroomed. Moreover, owing to the massively increasing volume of renewable electricity generated, citizens started to discover the burden of FITs and to oppose their further expansion. Thus, the political economy turned against FITs.

Therefore, in the 2010s in Europe, FITs have increasingly been replaced by auction models, even in their birthplaces. Although publicly quoted costs of renewable electricity have fallen precipitously, it remains to be seen whether projects will actually materialize or whether the 'winner's curse' of the 1990s will be repeated. Already, renewable electricity expansion rates in Europe have fallen significantly. The overall lesson of European FITs is clear: a mitigation policy instrument can benefit from a specific interest group constellation for a certain time period that can be sufficient to achieve competitiveness of specific mitigation technologies compared with fossil-based technologies. FITs were crucial to upscale renewable electricity technology and lay the foundations for the subsequent cost competition. But a favourable interest group constellation will not last forever, and thus it cannot be assumed that a currently attractive policy instrument will be available for the entire period until full decarbonization is achieved.

In most industrialized countries we currently have a situation where policy instruments generate widely varying price signals depending on the strength of the various interest groups. For example, in Switzerland, which is a frontrunner in domestic climate policy instruments, the agricultural sector with a very strong lobby is not facing any carbon price. Industry, which traditionally lobbies parliament intensively, will only mitigate at costs less than the price of allowances under the emission trading scheme, which remains below 10 $/tCO_{2e}$. Although Switzerland has neither a car industry nor oil production, and thus does not have a domestic lobby for those industries, car drivers are well organized. Thus, transport fuel importers were able to buy a mix of foreign and domestic offsets and therefore faced a cost of around 40 $/t (Climate Cent Foundation, 2014, p. 22). Households, which are notoriously difficult to organize, are subject to a carbon tax of about 100 $/t CO_{2e}, and this tax has been repeatedly increased. Finally, waste management is subject to a strict regulatory regime that for example prohibits landfilling of non-inert waste and provides high public investments for incineration plants. For an overview of mitigation costs and the related emissions levels see Figure 1.

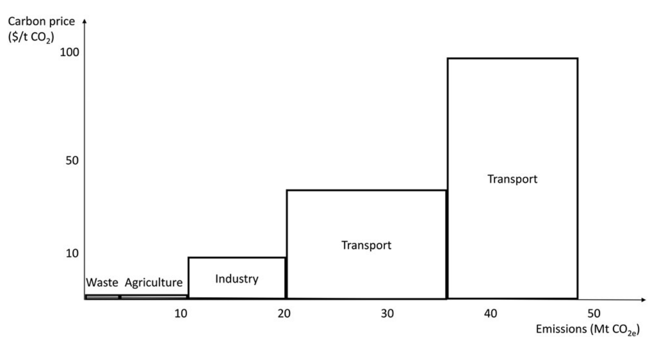

Figure 1. Cost differentials in Swiss climate policy. Emissions data source: Federal Office for the Environment (2017).

It is interesting that the sectoral requirements developed by Kuramochi et al. (2018) are less demanding for the agricultural sector than for the energy, building and transport sectors, in line with the empirical development of carbon pricing policies.

3.2. The role of sustainable development co-benefits in mobilizing policy instruments

Given the challenges to introducing mitigation policy instruments in emerging economies and developing countries, many observers have argued that policy makers should justify these policy instruments not through their mitigation benefits, but through benefits in other policy fields (e.g. Baranzini et al., 2017; Vogt-Schilb & Hallegatte, 2017). Such 'co-benefits' can take various forms. The most common classification separates economic, social and environmental co-benefits; sometimes also technological co-benefits are added. With the adoption in 2015 of the 17 UN Sustainable Development Goals, incorporating 232 indicators, a generally accepted approach for classifying sustainable development co-benefits is emerging.

In various emerging economies such as China, India and Indonesia, urban air pollution is an issue that is highly politically salient and can drive introduction of serious mitigation policy instruments. However, personal experience (Michaelowa) with the formulation and implementation of more than a dozen Nationally Appropriate Mitigation Actions in various sectors in highly diverse developing countries shows that policy makers often do not really take sustainable development co-benefits seriously. This may be due to difficulties in valuing health benefits in monetary terms as well as institutional responsibilities for mitigation policies not being vested in those institutions that benefit from improvements in SDG indicators.

A hitherto neglected area is the assessment of economic co-benefits of strong national carbon pricing policies, such as carbon taxes or auctioned emission allowances. In this regard, Siegmeier et al. (2018) stress the potential to replace distortionary taxes through revenue recycling and thereby reduce the costs of mitigation. Moreover, the pervasive distributional issues that are often brought against carbon pricing policies could be addressed through a clever redistribution policy (Baranzini et al., 2017; Vogt-Schilb & Hallegatte, 2017). However, experience with the Australian carbon pricing system, which featured a very elaborate redistribution plan and nevertheless was scrapped by a populist government, is sobering.

To sum up – the political economy of mitigation policy instruments (as underlined by Honegger & Reiner, 2018 for CCS) is challenging and there is no 'silver bullet' available. Experience with carbon pricing policies to date shows that they are unable to reach the price levels that would be required to drive decarbonization along a 1.5°C-compatible path (see Figure 2). Understanding 'windows of opportunity' for policy instrument implementation, like the one for FITs in Europe between 1990 and 2007, could be an interesting research field to enable policy makers to 'ratchet in' effective policy instruments, at least for a decade or two. The transport sector would be a clear candidate for such an approach and increasing government announcements to ban new fossil fuel vehicles from 2030 to 2040 onwards suggest that the time is ripe for an in-depth approach to the development of policy instruments in that sector. Moreover, the role of cultural and psychological aspects in the design and implementation of policy instruments requires more research.

4. Governance of policy instruments on multiple levels (international, national, sub-national) suitable for very strong mitigation outcomes

Given the public good nature of climate change mitigation, it has been extremely difficult to agree on a multi-level governance structure for mitigation policy instruments. After embarking on an international legally binding mitigation policy architecture between 1997 and 2009 in the form of the Kyoto Protocol, the failure to enlist emerging economies to take up legally binding emission targets at the Copenhagen conference led to a revival of the old principle of 'pledge and review' which was enshrined in the Paris Agreement in 2015. Of course, the latter system is only as strong as the willingness of each government to contribute to the public good. Summing up the government declarations in their (Intended) Nationally Determined Contributions NDCs, UN Environment (2017, p. xvii) finds a gap of 16–19 billion t CO_{2e} between the sum of NDCs not conditional on international financing and an emissions path consistent with 1.5°C. This gap is equal to 36% of current and 29% of 2030 global emissions. Although the Paris Agreement contains a clause that NDCs shall

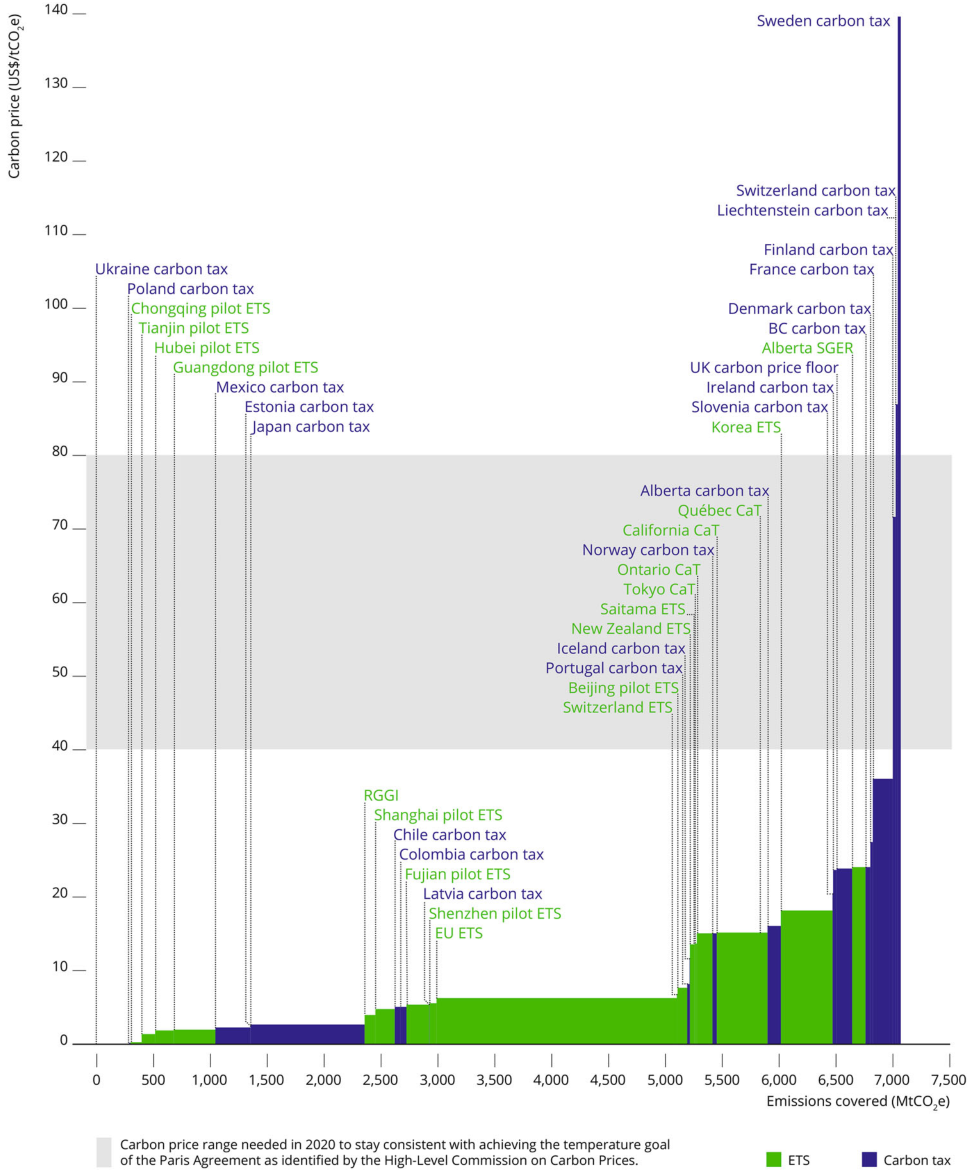

Figure 2. Carbon prices around the world and covered emissions. Source: Zechter et al. (2017, p. 29).

be ratcheted up over time, the agreement has no means to enforce that process. Various researchers have proposed to form a 'club' of ambitious countries that would provide sticks and carrots for mitigation (Eckersley, 2012; Keohane, Petsonk, & Hanafi, 2017). Essentially the club would 'fence itself off' against foreign competitors not subject to mitigation policies through a border tax adjustment. Despite a lot of research on this issue, it remains unclear whether such a measure would violate the rules of the World Trade Organization (Horn & Mavroidis, 2011; Ismer & Neuhoff, 2007).

For contentious technologies such as Negative Emission Technologies (NETs) or Solar Radiation Management (SRM), governance mechanisms on the international level are proposed by Honegger and Reiner (2018) and Nicholson, Jinnah, and Gillespie (2018). These would aim to ensure that no negative impacts regarding sustainable development occur due to these technologies, while also seeking to unlock their potential contribution to achieving the 1.5°C goal. Past experience with international market mechanisms shows that countries are not willing to give up their sovereignty to define what mitigation activities generate sustainable development co-benefits or at least prevent harm. Therefore, it is unlikely that a mandatory set of rules can prevent negative impacts. Relevant lessons can be drawn from the international regulation of CCS under the United Nations Framework Convention on Climate Change (UNFCCC), which took many years to emerge and only became less contentious when the technology was facing implementation problems (Krüger, 2015).

In the case of countries whose governments are unwilling to engage in mitigation policy instruments, subnational jurisdictions might be able to introduce such policy instruments. This could particularly apply to states / provinces in countries with a federal structure. Precedents with regards to emissions trading and carbon taxes exist in the US (California, North-Eastern states) and Canada (British Columbia, Ontario). However, competitive pressure will limit the stringency of the instrument.

5. Which instruments have led to transformations of entire economic sectors in the past?

Human history has seen multiple transformation of economies due to path-breaking innovations. Critical components of the energy system have been transformed several times in the last centuries – from traditional biomass to fossil fuels, and from steam to electricity (Fouquet, 2010, 2016; Sovacool, 2016). In some countries, electricity generation technologies have shifted from one fuel to another. Likewise, in the transport system, animal draught power was replaced by fossil-powered vehicles and sea passenger transport was replaced by air traffic. Most of these transformations were not foreseen and occurred relatively quickly once a penetration threshold of the underlying technology had been crossed. However, Fouquet (2016) and Smil (2016) stress that even the most rapid global transformations have taken several decades.

Although sometimes transformation has happened due to the superior performance of an innovative technology – e.g. in the context of electric lighting – government policy intervention was frequently a crucial component in the more rapid transformations (Sovacool & Geels, 2016). The performance of aircraft was significantly improved through wartime investment programmes in both the First and Second World Wars (Ruttan, 2006). The breakthrough of private cars was linked to heavy investment in roads and motorways (Brown, Morris, & Taylor, 2009). Penetration of electricity benefitted from public investments in large power plants, e.g. the Tennessee Valley Authority in the US (Kitchens, 2014) and the Austrian (Landry, 2014)/ Swiss (Wyer, 2008) investments in large dams in the Alps. These activities were politically framed as mobilizing the 'white coal' available in the mountains (Veyret & Veyret, 1970). Likewise, nuclear energy deployment was triggered by large public investment programmes (Dawson, 1976).

Overall, historical experience shows that a certain level of accumulated know-how seems to be necessary before a breakthrough can occur. Once this is the case, public investment plays a critical role in setting up the infrastructure that allows penetration of a new technology. In a number of cases, emergency situations, such as wars, were triggers of such investments. It should, however, be noted that public investment programmes often chose technologies that eventually did not perform; a particularly striking example for that is nuclear fusion (Merriman, 2015). An important aspect is also whether the innovative technology can harness a nationally available resource that has previously not been exploited.

Experiences in dealing with the losers of transitions are rather sobering. Historical phaseout of coal 'historically was often poorly anticipated and poorly managed, leading to long-term social dislocation with persistent below-average social and economic performance in coal regions' (Spencer et al., 2018).

6. Design of incentives to achieve a fast and deep 1.5°C-compatible transformation consistent with desired development pathways

As shown by the discussion on the political economy of policy instruments, it is difficult to get the political buy-in for instruments that provide a long-term and sufficiently strong incentive to drive deep mitigation. The empirical assessment of policy instruments points towards the important role of public investment programmes to mobilize new mitigation technologies.

6.1. Different policy instruments for different portions of the marginal abatement cost curve

Grubb (2014) sees three types of policy instruments for climate change mitigation – direct regulation to address information failures and mobilize 'no-regret' mitigation, carbon pricing to mobilize mitigation options linked to relatively mature technologies and a more complex bundle of public investment support to mobilize innovation. He stresses that all instruments need to be integrated to achieve deep decarbonization.

Direct regulation to harness profitable mitigation that is not undertaken owing to lack of information, lack of managerial attention and split incentives is not very attractive from a political economy point of view. The mitigation it generates through highly distributed energy efficiency improvement is not 'fancy' or visible to important interest groups. Industry is typically interested in running plants smoothly and does not want to incur production losses due to installing energy efficient technologies. Typically, such regulation can be introduced when a 'window of opportunity' arises, such as a national energy security crisis; good examples are the Fukushima accident in Japan in 2011, or a strong drought in Brazil in 2001. Given that technologies evolve over time, it is important to ensure that regulation is ratcheted up over time when 'windows of opportunity' open.

Market mechanisms such as baseline and credit systems, as well as cap and trade systems, have shown that they can mobilize significant private sector mitigation in a short period across a wide range of technologies. This has particularly been the case of the Clean Development Mechanism (CDM) under the Kyoto Protocol in its first years (Michaelowa & Buen, 2012). However, it has been difficult to ensure the long-term stability of the instruments, and industrial lobbying has led to long-term pressure on prices as well as a supply glut, exacerbated by protectionist restrictions by some countries on the acquisition of credits. Only a small minority of carbon markets currently have price signals commensurate with levels that would mobilize mitigation options in line with 1.5°C requirements. This jeopardizes the future of these instruments, which could fulfil a key role in ensuring that the lowest cost mitigation options are actually taken up. Bodnar et al. (2018) propose to increase trust in the market by providing a novel instrument, where entities that want to mitigate can bid for the right to get a minimum price for their mitigation regardless of the actual future market price. They show that several pilot programmes applying this concept have worked well. From a political economy perspective, ratcheting up of national mitigation ambition as suggested by the Paris Agreement is contingent on policy makers trusting not only that further mitigation options are available once the cheap options are exhausted, but also that liquid markets can underpin such trust.

With regard to Grubb's (2014) third policy instrument category – public investment support to mobilize innovation – it should be noted that public funding aimed at bringing CCS to maturity has, so far, been a failure. CCS, which was seen as a potential 'game changer' for mitigation in the mid-2000s (Azar, Lindgren, Larson, & Mollersten, 2006), has strongly underperformed to date despite significant public subsidy programmes (see IEA, 2016; Global CCS Institute, 2017 for current activities regarding CCS), not least due to persistent public opposition to specific CCS projects (e.g. Ashworth et al., 2012, 2015). Taking into account this sobering experience we look at how public policies could mobilize two fledgling technology categories: negative emissions technologies (NETs) and solar radiation management.

6.2. Policy options for mobilizing negative emissions technologies

NETs, such as bioenergy with carbon capture and storage (BECCS) (Kemper, 2015) or direct air capture and storage (DACS), are increasingly seen as necessary, in addition to deep emissions cuts, for achieving a 1.5°C path in the long term. If we do not achieve the highly disruptive programme laid out by Kuramochi et al. (2018), NETs become decisive to keeping hope alive that a 1.5°C scenario can be realized. However, these technologies are currently only available at the laboratory scale and are highly expensive. Honegger and Reiner (2018) stress that, in contrast to other mitigation technologies, NETs do not seem to offer co-benefits besides mitigating climate change, and there are significant concerns regarding possible negative impacts on sustainable development of their large-scale implementation. For these and other reasons, their political economy is likely to be challenging (Buck, 2016). Their costs depend on locational factors such as availability of biomass resources and geological storage capacity.

With regards to public investments for research and development into highly innovative technologies, past experience has shown that double-digit billion dollar expenditures can be mobilized globally if the technologies are seen as promising and enjoy the support of powerful interest groups. Whether the latter holds for NETs remains to be seen; it could happen if the private sector expects good business opportunities in NET implementation and the costs of the policy for the general population can be kept ‘below the radar’. But given that the incremental investment needs for a 1.5°C scenario are probably two orders of magnitude higher than current public research investments (Hof et al., 2017, p. 35), the latter is unlikely. It would, at a minimum, require a positive framing by a widely respected political leader, akin to the ‘Apollo Programme’ announced by US president Kennedy in the early 1960s. Moreover, given that a normalization of the interest rate from today’s artificially subdued level would push public budgets into deep deficit, the long-term appetite for large public investment seems doubtful. This means that scarce public funding needs to be spent wisely. In order to maximize the efficiency of public investment programmes, the offer of a guaranteed price for future emission reductions would maximize mitigation per unit of public investment, while incentivizing private investment (Bodnar et al., 2018).

6.3. White knight or Pandora’s box? How to deal with solar radiation management

Given the multiple challenges faced by stringent mitigation policy instruments, an increasingly vocal group of observers argues that it is high time to assess whether climate engineering, especially manipulation of the world’s radiative properties, could come to the rescue once it becomes clear that ‘classical’ mitigation is pursued with insufficient rigour to keep the world on a 1.5°C path (the most far-reaching example is probably Keith, 2013). Although various SRM technologies, such as marine cloud brightening (Latham et al., 2012) or cirrus cloud thinning (Lohmann & Gasparini, 2017), have been discussed, the most relevant one seems to be Stratospheric Aerosol Injection (SAI), i.e. the deliberate dispersal of sulphur particles in the upper layers of the atmosphere so that they reflect sunlight and thus cool the surface. The particularly problematic nature of SRM, and in particular SAI, is that it can, in theory, be undertaken by a single state or even a wealthy individual, as technology costs seem to be relatively low. Moreover, its potential negative effects on wind and precipitation regimes are only just starting to be understood. In an acrimonious debate, views range from completely prohibiting SRM research to proactively testing it in real-life sized experiments. Nicholson et al. (2018) propose a set of governance objectives to deal with SRM in order to avoid the scenario whereby it is side-lined at first, and then suddenly bursts into the international policy discussion in reaction to a perceived or declared state of climate emergency. The key aim is to guard against potential risks and negative impacts of SRM. Moreover, SRM should only be considered as part of a portfolio of mitigation responses and not as a single ‘silver bullet’. Research should be legitimized by active and informed public and expert community engagement under a democratic system of control. In order to ensure that the governance goals are respected, and that SRM can be assessed as objectively as possible, Nicholson et al. (2018) suggest introducing three governance mechanisms: a transparency mechanism for SRM research, a global forum to facilitate public engagement in the discussion about SRM, and using the regular global stocktake under the Paris Agreement to evaluate SRM technologies.

7. Revision of mitigation policies over time given uncertainty in the carbon budget for 1.5°C and the ratcheting up of nationally determined contributions

The future global cumulative emissions budget available to remain consistent with a 1.5°C temperature path will always be contentious, although this uncertainty naturally declines as the target temperature is approached. Even now, researchers provide highly differing numbers ranging between 260 (Rogelj et al., 2016) and 730 billion t CO_{2e} (Millar et al., 2017) from 2015 onwards, i.e. a difference of almost a decade at the current emissions level, for a similar nominal probability of maintaining temperatures below 1.5°C. Assuming that such differences persist, they will have an impact on the design of policy instruments. That said, all authors agree that retaining a substantial probability (with room for debate over exactly what level this corresponds to) of maintaining temperatures below 1.5°C requires immediate peaking of CO_2 emissions followed by a decline to net zero around mid-century. Since this is far more ambitious than current mitigation plans, it is open to question whether uncertainty in the future carbon budget has any practical policy significance in our current situation: whatever the budget may be, current policies need to be strengthened, and by the time they have been strengthened, the position will be clearer both on the reduction rates required and the policies needed to deliver them. Unfortunately, policy makers may just use uncertainty as an excuse for inaction, but this would be a misreading of the current state of the science. It is uncontested that CO_2 emissions are likely to need to peak soon and decline to zero at historically unprecedented rates, in order to maintain temperatures below 1.5°C: as long as emissions are still rising, and the mix of policy instruments required to achieve a global emissions decline remains entirely untested, uncertainty in the required rate of emissions decline is entirely irrelevant. Only when sustained global emission reductions are already underway will it become clear what it will actually take to achieve the policy goal, and the measures required to initiate sustained reductions are much the same, regardless of subsequent developments.

The Paris Agreement includes a process to take into account changes in the knowledge on the gap to a 1.5°C path in the revision of NDCs. Every five years, a Global Stocktake (GST) will assess the size of the gap and what could be undertaken to narrow it down (see Peters et al., 2017 for a list of indicators that should be checked during the GST). The first GST is scheduled for 2023 and will take into account the results of the IPCC 6th Assessment Report. In 2018, a test run is being done under the label 'Talanoa Dialogue'. The GST process allows the showcasing of national mitigation policies that have been successful and can contribute to an accelerated diffusion of highly performing policy instruments.

Nevertheless, revision of policy instruments based on the outcome of a global process without 'teeth' will not be easy. The natural inertia built into policy development and highly differing national policy cycles are difficult to reconcile with the five-year periods of the GST.

8. Business opportunity or societal emergency: framing policy instruments for the 1.5°C transition

Anthropogenic climate change remains one of the most urgent challenges for humanity in the twenty-first century. Keeping global temperature increase below 1.5°C is a challenge whose repercussions on policy design and decision making have not really sunk in. We have identified pervasive challenges to getting effective policy instruments agreed and implemented. The key question is now whether we should be satisfied by second- or even third-best policy instrument implementation and hope for a 'magic bullet' technical solution to emerge, or whether we can develop approaches that allow us to go beyond what political science and economics generally regard as feasible.

In this context the framing of the climate change challenge plays an important role. Can we credibly frame climate change mitigation not only as a necessity but also as a business opportunity? This narrative has been pushed by a number of political leaders, especially by the former head of the UN climate change secretariat, Christiana Figueres (e.g. see Figueres, 2013). This would mean that the private sector would be the key addressee of policy instruments. Given that it reacts quickly and consistently on economic incentives, a mixture of market mechanisms for mobilization of mature mitigation technologies, combined with a dedicated public investment programme for emerging technologies, would be a promising way forward. The key challenge here would be to decide when a technology can be 'weaned off' public support and can compete on the market.

If such a framing is unsuccessful, we might be constrained to apply an approach that has frequently functioned in the past, but also seen spectacular failures – get ourselves on a 'war footing'. National emergencies have often mobilized surprising resources in money, willpower and creativity. The problem is that, today, we have to deal with a global emergency whose impacts are not always directly visible to citizens on a daily basis. Will we care sufficiently for humanity as a whole, or just for ourselves and our communities? The challenge is immense, and we need to collaborate on many levels and for long periods, and in unprecedented ways, to address it properly.

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