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PERSPECTIVE

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Sequencing to ratchet up climate policy stringency

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The Paris Agreement formulates the goal of GHG neutrality in the second half of this century. Given that Nationally Determined Contributions are as yet insufficient, the question is through which policies can this goal be realized? Identifying policy pathways to ratchet up stringency is instrumental, but little guidance is available. We propose a policy sequencing framework and substantiate it using the cases of Germany and California. Its core elements are policy options to overcome barriers to stringency over time. Such sequencing can advance policy design and hopefully reconcile the controversy between first-best and second-best approaches.

Recent research suggests that for ratcheting up climate policy ambition dynamic processes are key, and specific policy sequences may play an important role[1,2]. Increasingly, this idea has also found its way into quantitative analysis of climate policy[3,4]. Building on these contributions and the theoretical literature on path dependency, we propose a framework of ratcheting up in climate policy through sequencing and draw on the cases of California and Germany to empirically substantiate it. In doing so, we take a first step with the goal of stimulating further discussion and research to bridge the social science disciplines and enable solution-oriented exchange between researchers and policymakers.

One particular debate that we aim to address is the long-lasting controversy between advocates of first- and second-best approaches to policy. The former typically draw on welfare economics, arguing that incremental cost-ineffective policies reduce welfare, which eventually prevents higher stringency. The latter typically draw on political theory to emphasize the value of politically achievable incremental progress — even at the expense of cost effectiveness. To bridge this difference, we describe policy sequencing as an approach to policymaking that aims to incrementally relax or remove barriers over time to enable significant cumulative increases in policy stringency.

The core element of the framework is the conjecture that barriers to stringent climate policy exist, but can be removed or at least lowered through a policy sequence that enables dynamic ratcheting up. In that way, policies that might be essential to achieve high levels of stringency (but are currently confronted with considerable barriers, such as significant carbon pricing) can eventually be implemented at a later stage. Sequencing thus implies policy pathways in which policies change over time, and wherein each stage is conducive to achieving the subsequent, more stringent one. Sequencing may occur intentionally or not, and given the high complexity of the policy process unanticipated outcomes may often prevail. Intentional, strategic sequencing mandates the anticipation of barriers and how to overcome them as a core policy design principle. It can therefore be said that strategic sequencing would embody Marcus Aurelius' principle that "the impediment to action advances action. What stands in the way becomes the way."

The selection of Germany and California as cases to substantiate the framework was motivated by their past successes in ratcheting up climate policy, as indicated by the increasingly more stringent climate and renewable policy targets implemented in both jurisdictions that are suggestive of sequencing (see Fig. 1 and Table 1). Accordingly, we aim to find evidence for whether and how this progress may have been the result of policy sequencing. Case selection therefore followed a 'most likely' approach[5] that is typically used to falsify propositions. That is, if policy sequencing cannot be observed in Germany and California, it is unlikely to be observable elsewhere. Yet we also acknowledge that sequencing might not be the only explanation for ratcheting up, and that the counterfactual analysis plays an important role.

This Perspective proceeds as follows. First we develop the framework. We then identify the main barriers to increasing policy stringency and related sequencing options and mechanisms, drawing on observations from Germany and California to demonstrate how sequencing has taken shape. Finally, we discuss the framework and provide an outlook.

Framework

Economics[6,7] and political science[8–13] have both examined institutional path dependency in recent decades. A common focus is conceptualizing institutional and policy change as a series of interlinked and often incremental steps, potentially cumulating towards large-scale change over time. This contrasts with a punctuated equilibrium model of policy change that focuses on sudden large changes[14], although historical institutionalists would view this as interrupting a pathway with critical junctures and thus subsume it as a part of path dependency. Regardless, at the most general level the concept of path dependency emphasizes that specific temporal institutional patterns or event chains have deterministic properties.

Two types of sequencing and various underlying causal mechanisms have been discussed in the literature. Self-reinforcing sequences are characterized by the formation and long-term reproduction of institutional patterns that exhibit self-reinforcing characteristics[9,10]. Related mechanisms include increasing returns, positive feedback loops and increasing costs of reversion over time[15].

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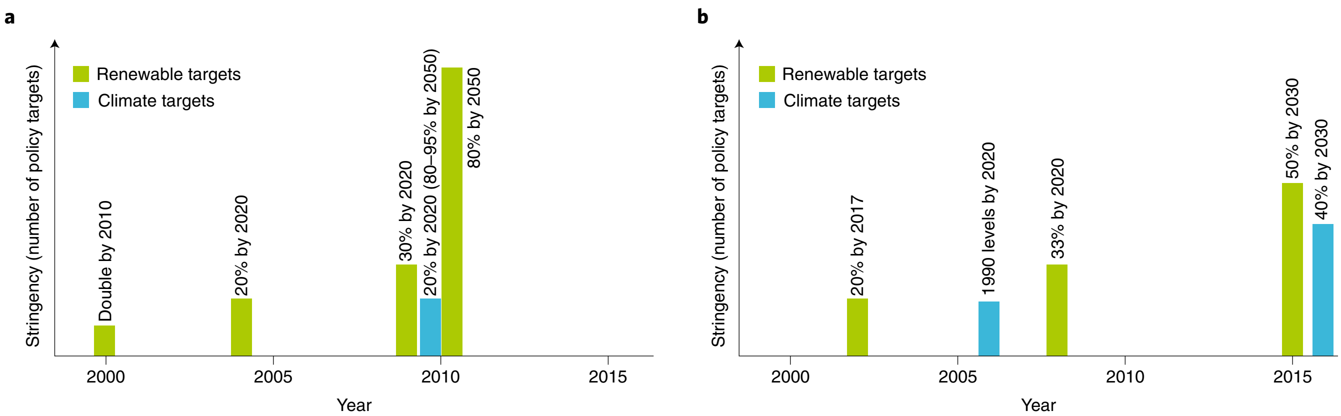

Fig. 1 | Increasing policy stringency in Germany and California. a,**b**, Renewable and climate targets have become increasingly ambitious in both Germany (**a**) and California (**b**) over time. This is an indication of increasing policy stringency.

Table 1 | Overview of past and current climate and renewable energy targets in Germany and California

Country	Year	Target
Germany	2000	Double share of renewable energies in final energy consumption by 2010 (Renewable Energy Act)
	2004	Increase share of renewables in power consumption to at least 12.5% by 2010 and 20% by 2020 (Renewable Energy Act)
	2009	Increase share of renewables in power consumption to at least 30% by 2020, and continuously afterwards (Renewable Energy Act)
	2010	Increase share of renewables in power consumption to at least 80% by 2050 (Government's Energy Concept)
	2010	Reduce GHG emissions to at least 20% below 1990 level by 2020, at least 55% by 2030, at least 70% by 2040 and at least 80–95% by 2050 (Government's Energy Concept)
California, USA	2002	Adopt regulations that achieve the maximum feasible and cost-effective reduction of GHG emissions from motor vehicles (AB 1493)
	2002	Increase retail sales from renewable energy to 20% by 2017 (SB1078)
	2006	Reduce GHG emissions to 1990 levels by 2020 (AB32)
	2006	Increase retail sales from renewable energy to 20% by 2010, acceleration of SB1078 (SB107)
	2008	Increase retail sales from renewable energy to 33% by 2020 (S-14-08)
	2015	Increase amount of renewable energy to 50% by 2030 (SB 350)
	2016	Reduce GHG emissions to 40% below 1990 level by 2030 (SB32)

Self-reinforcement leads to institutional lock-in as it becomes more and more costly and difficult to switch to an alternative, and potentially superior, pathway. The particular choice of policies at the outset is thus of high importance[16]. The history of the QWERTY typewriter is a standard example[17]. Reactive sequences, by contrast, are chains of temporally ordered and causally connected events in which each step in the chain is a consequence of a previous step, but does not feature self-reinforcing dynamics[11,13,18]. The related mechanisms include learning effects, harnessing the expertise and capacity of existing institutions, increasing competitive pressure and disruption of lock-ins. Reactive sequencing is therefore well suited to characterize changes in institutional patterns rather than their stabilization. Although the theoretical debate often juxtaposes the two types of temporal dynamics, we consider which type prevails to be an empirical question.

These concepts have been applied to characterize lock-in of fossil fuel-based energy systems due to increasing returns, and the associated challenges in switching from high- to low-carbon energy systems[19,20]. Researchers have also applied path dependency theory to identify a variety of policy options that policymakers may harness in devising strategic climate policy design to increase its level of ambition over time[15,21–26]. Yet we lack a framework that shows how policy options can help overcome distinct barriers to stringency over time.

Our framework has three theoretical building blocks. First, we theorize that policies may initially be only second best due to stringency barriers. Second, we show how these policies can evolve along a pathway of increasing stringency that eventually leads to the first best policy through specific sequencing options. This is motivated by the economic theory of the second best[27] in which constraints to optimization are the functional equivalent of the barriers facing policymakers in our model. However, we go beyond this theory in asserting that barriers can be removed or at least relaxed by means of intermediary policies over time. Third, we describe mechanisms to underpin and specify the particular processes that enable such options for ratcheting up.

Accordingly, we define a ratcheting-up sequence as a process in which the effects of policies implemented at an initial stage (t_1) remove or relax stringency barriers over time so that policymakers can ratchet up stringency at the subsequent stage (t_2) (Fig. 2). By extension, in a ratcheting-out sequence the effects of policy at t_1 enable broader policy to be implemented over time, covering additional sectors, issue areas or jurisdictions. We denote policies that exhibit such properties as 'sequencing options' in relation to a specific barrier.

The framework is a simplification in several ways. First, it considers barriers to be independent from each other, whereas they may in reality be linked and conflated. Depending on how policymakers perceive such linkages, and what they consider the dominant or most salient barrier, they may choose different sequencing options. Second, the framework focuses on single policies and does not explicitly consider complex interactions with the overall policy mix and other policy domains. However, the existing policy mix

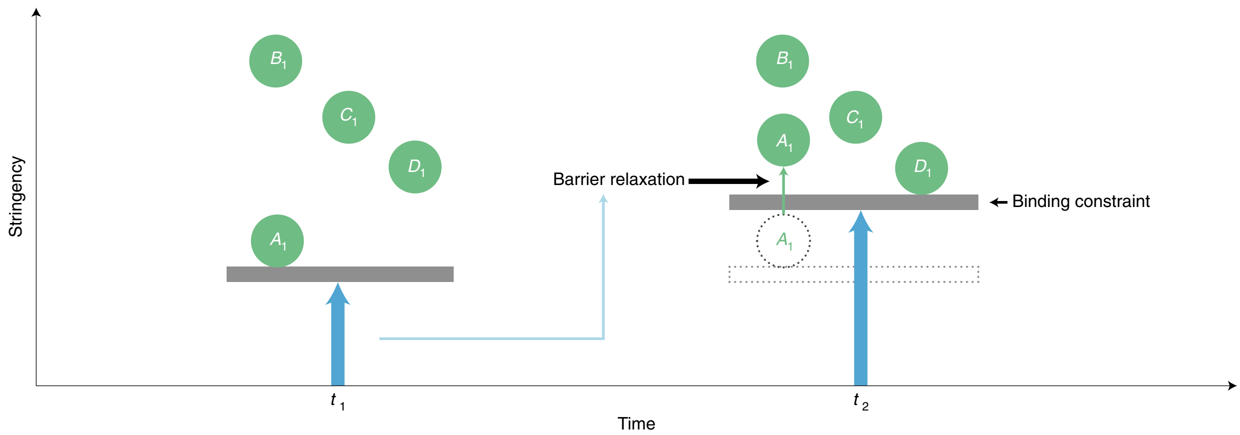

Fig. 2 | Sequencing to overcome barriers to stringency. Barriers (circles) and dynamic climate policy stringency (blue arrows) are shown for two subsequent periods (t_1, t_2). Relaxation of the most constraining barrier (here, A_1) in the first period enables increased policy stringency over time, to the level of the new most constraining barrier (D_2).

may facilitate or hamper the adoption of policy innovations[28]. At the policy domain level, issue linkage[29] between climate and other synergetic domains such as air pollution may address barriers in ways not possible for climate policy alone. Third, some policies may only temporally reduce or contain a barrier, buying time to enable developments in other directions. These issues open up an even broader domain of sequencing beyond the scope of this Perspective.

Options to relax stringency barriers

We propose four general categories and related barriers to stringent climate policy, and identify sequencing options and underlying mechanisms that can relax or remove barriers over time as summarized in Table 2. The selection was guided by a review of climate policy literature; several related workshops conducted in Germany and California involving individuals from governments, regulatory agencies, business and academia; and extensive personal conversations with stakeholders. We invite further work to critically examine and extend this preliminary taxonomy.

For the cases of California and Germany we elaborate on (1) the existence of a barrier, (2) how earlier policies contributed to removing or relaxing it, and (3) whether a more stringent policy was implemented.

Economic cost. *Barrier.* Costs of decarbonization are expected to rise as ambition increases, posing a potentially decisive barrier to later-stage decarbonization. We distinguish two notions of costs. Technology costs refer to the deployment of mitigation technologies, such as the capital costs of renewable energies. Policy costs refer to policy design; for example, technology-specific standards will usually be less cost effective than policies offering more flexibility, such as tradable standards[30].

Sequencing options and mechanisms. A first option is to drive down mitigation technology costs through dedicated green technology policies, thereby reducing the respective cost barrier in line with economic theory on technology market failures[31,32] and avoiding lock-in of innovation in dirty technologies[33]. If such cost reductions indeed materialize, policymakers could capitalize on them to make a strong case for further increasing stringency. This would lead to self-reinforcement, provided costs keep declining.

A second option is to structure existing policies to become more cost effective over time. Economic theory suggests that a cost-effective policy portfolio includes a combination of carbon pricing and technology policy[34–36]. However, the latter are inefficient once cost-reducing technologies are mature[37] and when stringency increases[38]. Accordingly, technology policies should be phased out over time, because they otherwise pose a policy-cost barrier to higher stringency. This could be gradually accomplished by infusing initially prescriptive policies with incentive-based approaches[39,40] and by broadening sectoral or technological coverage. If interactions between policies are properly managed[41], technology policies can improve the design and facilitate the adoption of carbon pricing — the policy sequence is then self-reinforcing. A sequence could also be reactive if cost-ineffectiveness is revealed in a learning process, and reforms are implemented in response to such learning[42].

Observations. A striking example of technology cost-related sequencing is the evolution of support for renewable energy in Germany. Implemented in 2000, the Renewable Energy Act (EEG) created a protected niche market to promote learning for renewables that were then costly using long-term, risk-free contracts in the form of feed-in tariffs. For solar photovoltaic modules in particular, the tariff spurred significant deployment and brought down costs considerably[43]. These cost reductions enabled increasingly ambitious renewable energy targets in Germany[44].

Reactive policy cost sequencing was evident in the German EEG programme. Costs initially were moderate; however, beginning in 2008 a drop in solar photovoltaic module prices led to a surge in deployment. Tariffs adapted slowly; consequently, policy costs increased steeply, resulting in a 'cost crisis' that threatened the continued support for renewables. In response, German policymakers reformed the feed-in tariff by infusing incentives using a sliding premium determined in reverse auctions beginning in 2015[40]. Eventually this sequence brought down the subsidies to less than five cents per kWh− in 2017, making solar power competitive with coal and enabling sustained public policy support.

California's first major climate policy triggered policy cost-related policy sequencing. AB 1493 in 2002 targeted emissions from new motor vehicles and relied on tradable fleet emissions technology standards, followed later that year by an electricity sector renewable portfolio standard (SB 1078). These sectoral policies demonstrated the feasibility of emissions reductions, enabling the adoption of an economy-wide emissions cap in 2006 to be achieved by 2020[45]. Regulatory measures were expected to produce over 80% of the emissions reductions[46]. But to achieve the cap, and improve cost effectiveness, emissions trading took effect in the electricity sector in 2013, ratcheting out to the entire economy in 2015. The state ratcheted up stringency of the cap-and-trade system in 2016, enacting a tighter emissions cap for 2030. The state's new plan identifies regulatory measures as sufficient to achieve only 60% of the

Table 2 | Barriers to stringency and possible sequencing options to overcome them

	Specific barrier	Possible sequencing options
Economic cost	High technology costs	Drive down technology costs through dedicated green technology (industrial) policies
	Lack of policy cost-effectiveness	Phase out technology policies once technologies are mature Expand carbon pricing and adapt its design
Distributional dynamics	Interest group opposition	Employ compensation, via free allocation of certificates, for example, and exemptions to buy time Use policies to foster the entry of new firms
	Lack of supporting coalition	Prioritize policies (such as green industrial policies) that expand supporting population and constituencies Use (carbon pricing) revenues to make investments that promote programme goals and strengthen support constituency Use issue linkage to broaden political support
Institutions and governance	Lack of expertise and capacity	Build on existing agencies and policy tools by doing related work to set up new climate policy authorities Implement policies that complement and thus facilitate the adoption of subsequent, more stringent policies
	Veto power of opposing units in government	Allocate key competencies to agencies with progressive objectives and personnel Use policy options initially that do not require a supermajority
Free riding	Free riding and heterogeneous preferences	Align or link climate policies via multilateral institutions Engage in policy experimentation to create and disseminate knowledge to other jurisdictions

more stringent goal, relying on an expanded role of carbon pricing to make up the difference[47].

Distributional dynamics. *Barrier.* The lack of a sufficiently large supporting coalition can be a barrier for increasing stringency. If policy costs are borne by concentrated and well-organized groups such as energy-intensive industries in the present, while benefits are widely diffused across nations and generations, a veto coalition will be easier to organize than a supporting coalition[48]. Conversely, conferring policy benefits to concentrated and well-organized groups will facilitate a supportive coalition[49].

Sequencing options and mechanisms. One approach addresses the political resistance from groups bearing significant and concentrated costs by fragmenting regulation (and opposition) via sectoral policies with differentiated stringency[50]. Targeted exemptions and compensation to soften opposition, potentially involving the use of carbon revenues, are also options[51–53]. From a sequencing perspective, these routes may create new distributional barriers if the costs of required compensation persist (or even increase) over time, and the opposing groups are not eventually 'creatively destructed'[54]. Thus, it might be that these options only temporally circumvent a barrier rather than actually relaxing it, or even lead to lock-in if new barriers dominate.

A second approach involves creating winning coalitions[1]. This can be achieved by providing concentrated benefits through subsidies and other payments to form or grow interest groups such as renewable energy industries or other novel constituencies that advance mitigation options[24] (M. Dorsch et al., manuscript in preparation). Such winning coalitions can be advocates for higher stringency that counterbalance opposing interest groups, thereby reducing the respective barrier. The underlying mechanism involves a positive feedback loop[15] that generally leads to self-reinforcing sequencing.

Issue linkage offers a third mechanism. Policies addressing multiple issues may allow the realization of co-benefits between areas. However, we note that issue linkage is a double-edged sword. While it may expand the support coalition, it can also act to constrain zones of agreement[29] and thus lead to reactive sequencing that prevents further ratcheting-up.

Observations. A major barrier for scaling up support for renewables in Germany was the increasing costs of electricity threatening the international competitiveness of energy-intensive German industries. To overcome this barrier, policymakers implemented exemptions from the EEG surcharge, initially only for very large firms. By 2016, these exemptions were extended to more than 2,100 companies, totalling around 25% of German power consumption. This had considerable distributional impacts and created controversy as the policy cost was mainly born by households[55,56]. Exemptions can buy time, but in the long term may pose new barriers if they are considered unfair by relevant constituencies.

Job creation was also instrumental in sustaining German renewable policy after the Green Party left the government in 2005 and opposition to renewables from utilities increased[57,58]. Employment in the renewables sector peaked at around 400,000 in 2012. Despite the recent decrease in jobs, including a substantial decline in the solar industry[59], 'clean' industries remain an important constituency.

In California, policies beginning in the 1970s produced a supportive coalition involving renewable energy manufacturing and installation, energy-related investment and venture capital[60]. In 2010 the green business industry played a prominent role in opposing a ballot initiative supported by oil companies that would have overturned the state's climate policies[61]. Additional opposition came from interest groups that represented lower-income communities, who voiced concerns that renewable policies would increase electricity prices and that cap-and-trade might have deleterious effects on local air quality by incentivizing greater utilization of facilities in populated areas[45]. Policy addendums addressed this by directing the proceeds from allowance auctions to investments to improve environmental outcomes in disadvantaged communities[62].

In California, issue linkage helped legislators representing disadvantaged communities to evolve from initial resistance to eventual support of cap-and-trade schemes. In 2016 and 2017, the extension of carbon reduction targets and emissions trading was accompanied by legislation that explicitly linked climate goals and conventional air pollution, bringing crucial support from the legislators in impacted communities. Issue linking is also fundamental to another of California's flagship policies — mandates for zero-emitting (electric) vehicles. These mandates faced resistance because internal combustion vehicles have dramatically improved fuel economy, and increased costs associated with vehicle mandates may keep existing less-efficient cars on the road[63]. The efforts of the California Air Resources Board to link air quality with climate objectives addressed political opposition to both objectives.

Institutions and governance. *Barrier.* There may be significant limitations to the effectiveness of and support for government institutions and processes that are required to implement ambitious climate policy. Real or perceived lack of capacity or authority, technical or enforcement expertise, data reporting and management or public trust in the relevant government bodies can impede policy development —particularly when initiating climate policy pathways[24,64].

Sequencing options and mechanisms. A lack of expertise and capacity in a governing agency at the very initiation of climate policy is a barrier, but it can be overcome with policies in related issues. An integral part of enhancing expertise may thus be learning from earlier experiments. This can positively influence more stringent climate policy adoption at a later stage, especially when policies complement each other[28]. Such mechanisms often reinforce existing pathways, to the extent that policymakers tend to rely on 'proven' policies. Learning from policy failures or about diminishing returns can also provide impetus for reactive sequencing.

A second set of options concerns the allocation of regulatory competencies among competing units of government with differing climate policy-related objectives. Granting (and withholding) competences in early steps will influence the relative power of competing policy coalitions in subsequent steps, and may lead to self-reinforcing dynamics expanding or entrenching the political power of certain units of government. For example, entrusting important competencies to units that support more stringent climate policy, and removing or reducing the veto powers of opposing units, can facilitate ratcheting up and may help further entrenching the position of progressive units[65].

Observations. In Germany, the Federal Environmental Ministry (BMU) was originally responsible for nuclear safety and environmental policy and had limited expertise in energy policy-making. However, it developed capacity to apply regulatory tools beyond prescriptive regulations. In 1991 the BMU was authorized to implement the first feed-in tariff, which allowed its staff to develop technical competence ahead of the ground-breaking 2000 Renewable Energy Act (EEG). In 2002 the BMU was granted exclusive ministerial authority for renewable energy, which enabled the development of more ambitious renewable policies[66].

In California, decades of air quality regulation allowed the California Air Resources Board to build technological competence, a strong institutional foundation and a long-term relationship with state legislature that were instrumental for later climate policy[45]. After overcoming veto points, the 2006 legislation authorized the state's cap-and-trade programme as a regulatory fee, thus avoiding the two-thirds majority needed to win a legislative vote for a tax. Subsequently, the programme gained political support, in part by raising funds for a range of complementary programmes to address climate change. Eventually, that support helped to facilitate renewal of the programme with a two-thirds supermajority in 2017.

Free-riding concerns. *Barrier.* Successful climate policy requires that actions are taken globally, but any one jurisdiction can avoid the costs of action while accruing benefits from the efforts of others. Economists have described this problem as free riding or a multilateral prisoner's dilemma[67–69]. The potential for free riding, as well as different levels of ambition resulting from heterogeneous climate policy preferences, undermines domestic actions to increase stringency[70].

Sequencing options and mechanisms. One approach to overcome free riding is the incremental alignment and coordination of climate policies across jurisdictions[70–72]. This can involve coercion[73] in the form of establishing international rules and norms for more stringent climate policy[26,74]. Eventually this may lead to climate clubs that are able to protect themselves and willing to impose sanctions on free riders[69,75,76]. Once such a club is established, it may grow, leading to self-reinforcing sequencing.

Alternatively, one might facilitate policy diffusion by actively providing information and incentives for adoption[77], or by building capacity in recipient jurisdictions[26]. Imitation and learning are important channels of diffusion[73] that might change the cost–benefit ratio of policies leading to their adoption. The suitable sequencing option is thus to engage as a first mover and initiate policy experiments that other jurisdictions may learn from, thereby lowering their costs and risk for implementation. Such sequencing is also self-reinforcing if it does then lead to increasing adoption elsewhere.

Observations. Germany has invested significant resources into building multilateral regimes for climate policy coordination, including in the European Union, the UNFCCC and the G7/G20. In the domestic policy debate, reference to these international regimes and the prospect of other economies adopting similarly stringent policies over time has been essential for justifying the adoption of national climate targets and policies and ratcheting up. The German Federation of Industries has pointed out that it would support ambitious domestic carbon pricing policy if this is part of comparable global or at least G20-level policy coordination[78]. At the EU level, the introduction of carbon pricing for the German power and industry sectors via the EU emissions trading scheme, and subsequent efforts to increase its level of ambition, were considered possible partly because of the initial choice of multilateral policy scope[79].

Free riding is a particular concern in California, given the absence of climate policy at the federal level. In response, the state has actively pursued the diffusion of environmental protection standards to other jurisdictions[80]. Regulatory initiatives in California have frequently been taken up by other states and propagated to the federal level, only to have this process repeated, as California ratchets up policy through 'iterative federalism'[81]. For instance, California and other states adopted efficiency standards for appliances, prompting the introduction of pre-emptive uniform federal standards. Under the federal Clean Air Act, California has a unique ability to enact mobile source emissions standards (for conventional pollutants and more recently for GHGs) that are stricter than the federal standards. Other states have adopted California's stricter standard in place of the federal standards only to have California again adopt yet more stringent standards[82]. Similarly, California's adoption of 'best available control technology' for stationary sources iteratively ratcheted up the default standard for other states[83]. California has also explicitly pursued engagement with other states and Canadian provinces, as part of the Western Climate Initiative, which launched in 2007 and linked with the Quebec emissions trading program in 2014, and with Ontario in 2018.

Discussion and outlook

Our sequencing framework recognizes that incremental steps are essential to achieving ambitious long-term goals and that individual climate policy steps will be different from first-best policy measures both in degree and form.

We intend this framework to be of both theoretical and practical use. The development of a more comprehensive testable theory of climate policy sequencing is needed. This entails more empirical substantiation than can be provided here. We employ the counterfactual that without sequencing the observed ratcheting up would either not have occurred, or occurred to a lesser extent. Further research advancing the framework should carefully consider whether sequencing has taken place. It should also expand on the complex relationships between sequencing and other mechanisms, and sequencing in the context of policy mixes and multiple policy domains.

In terms of practical use, this framework offers insight into how to sequence in the presence of multiple barriers. There might be various routes though which to break out of a constellation of barriers, and relaxing one barrier might tighten others or create new ones. A policy sequence is successful if it relaxes barriers — even in a circuitous way — so that the pathway evolves towards greater stringency and cost effectiveness. A necessary condition for that is relaxing at least one barrier without sliding backwards with respect to others.

The primary value of the framework lies in highlighting important policy properties that typically get lost in standard conversations between advocates of the first best and proponents of incrementalism. More research is required to advance and test this framework. In the meantime, we believe much would be achieved if policy discussions become more nuanced by incorporating the sequencing perspective.

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Competing interests

The authors declare no competing interests.

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