Designing an Effective Climate-Policy Mix: Accounting for Instrument Synergy

J. van den Bergh[a,b,c,d], J. Castro[a], S. Drews[a], F. Exadaktylos[a], J. Foramitti[a,d], F. Klein[a], T. Konc[a], I. Savin[a,e]

[a] Institute of Environmental Science and Technology, Universitat Autònoma de Barcelona, Spain

[b] ICREA, Barcelona, Spain

[c] School of Business and Economics, VU University Amsterdam, The Netherlands

[d] Institute for Environmental Studies, VU University Amsterdam, The Netherlands

[e] Graduate School of Economics and Management, Ural Federal University, Yekaterinburg, Russian Federation

Contact: jeroen.bergh@uab.es

Second revision after editorial suggestions, March 2021

Acknowledgements

This study has received funding through an ERC Advanced Grant from the European Research Council (ERC) under the European Union's Horizon 2020 research and innovation program (grant agreement n° 741087). IS acknowledges financial support from the Russian Science Foundation (RSF grant number 19-18-00262).

Abstract

We assess evidence from theoretical-modelling, empirical and experimental studies on how interactions between instruments of climate policy affect overall emissions reduction. Such interactions take the form of negative, zero or positive synergistic effects. The considered instruments comprise performance and technical standards, carbon pricing, adoption subsidies, innovation support, and information provision. Based on the findings, we formulate climate-policy packages that avoid negative and employ positive synergies, and compare their strengths and weaknesses on other criteria. We note that the international context of climate policy has been neglected in assessments of policy mixes, and argue that transparency and harmonization of national policies may be key to a politically feasible path to meet global emission targets. This suggests limiting the complexity of climate-policy packages.

Key policy insights:

- Combining technical standards or targets, such as renewable-energy quota, or adoption subsidies with a carbon market can produce negative synergy, up to the point of adding no emissions reduction beyond the cap. For maximum emissions reduction, renewable energy policy should be combined with carbon taxation and target expensive reduction options not triggered by the tax.
- Evidence regarding synergy of information provision with pricing is mixed, indicating a tendency for complementary roles (zero synergy). Positive synergy is documented only for cases where information provision improves effectiveness of price instruments, e.g. by stimulating social imitation of low-carbon choices.
- We conclude that the most promising packages are combining innovation support and information provision with either a carbon tax and adoption subsidy, or with a carbon market. We further argue that the latter could have stronger potential to harmonize international policy, which would allow to strengthen mitigation policy over time.

Keywords: instrument interaction, technical standards, carbon pricing, adoption and innovation subsidies, information provision, mitigation policy packages.

1. Introduction

Many academic writings on climate policy are concerned with the performance of single instruments targeting greenhouse gas emission reduction. In reality, however, one typically finds an extensive set of policy instruments implemented simultaneously, often on different regulatory levels. There are many potential reasons for using multiple instruments. The instruments might be complementary or even create positive synergy in terms of the associated goal. More specifically, they might deal with distinct market failures (Jaffe et al., 2005; Freire-González, 2018). Another important reason for combining instruments is that they can accomplish multiple objectives, such as effectiveness, efficiency and equity. In more abstract terms, a policy mix can reflect a second-best (non-optimal) response to a first-best (theoretically optimal) single instrument not being feasible – because of monitoring of pollution being imperfect, the control span of policy being limited, or the existence of political constraints. The additional instruments then compensate for the non-optimal level of the main policy instrument (Bennear and Stavins, 2007). More practically, multiple instruments might arise from political compromises between stakeholders with distinct policy preferences, or from adding instruments to compensate for the insufficiency of already available instruments (Bouma et al., 2018). Finally, in line with the Tinbergen (1952) rule, a distinct type of policy mix results from the presence of multiple objectives, such as climate change mitigation and limiting biodiversity loss (Braathen, 2007; Sterner et al., 2019).

There are also several reasons to be careful about combining instruments into a policy mix. As will be illustrated for various cases in Section 3, policies may overlap or create negative synergies. This can even lead them to offset each other in terms of emissions reduction. In such cases, a policy mix would perform no better or even worse than a single instrument. Taking into account that each policy instrument generates an additional cost for the regulator or government in terms of expenditures and human resources – including transaction costs of political and policy processes until implementation, cost of monitor and control, and sometimes serious budgetary sacrifices (such as with subsidies) – policy-makers may want to limit the number of instruments in the policy mix. Moreover, given that policy instruments often cause unintended market distortions, employing multiple instruments runs the risk of introducing potentially multiple distortions into the economy. Finally, policy mixes complicate the comparison of policy stringency among regions and countries compared to single instruments. Schmidt and Sewerin (2019) demonstrate this for renewable-energy policy mixes in nine OECD countries. Difficulty to compare policies in turn confounds policy integration between distinct governance levels within a country or within a supra-national system like the European Union (Howlett et al., 2017). As we argue in Section 4, reducing the complexity of climate policy might increase the feasibility of international policy harmonization.

In view of these contrasting arguments, this article examines the synergy of combining specific instruments in a policy mix aimed at effectively reducing greenhouse gas emissions. To this end we consider both theoretical arguments and empirical or experimental evidence from a variety of disciplines that have devoted attention to policy mixes, notably economics, psychology, and innovation and transition studies (Jaffe et al., 2005; Bulkeley and Kern, 2006; Howlett and Rayner, 2007; Oikonomou and Jepma, 2008; Oikonomou et al., 2010; Rogge et al., 2017; Mundaca et al., 2019; Somathan et al., 2014, Section 15.7.3). This allows us to obtain a comprehensive picture of possible combinations of climate policy instruments that can achieve non-negative or even positive interactive effects on emissions reduction. Most of the aforementioned reviews do not focus on systematically assessing synergy of particular instrument combinations as we do here, nor do they include all the instrument combinations we address. Hence our study adds to the existing literature. While we focus on climate mitigation policy in the context of emission reduction, there are also reviews or synthetic studies of policy mixes for energy-efficiency (Boonekamp, 2006; Hood, 2013; Rosenow et al., 2017; Wiese et al., 2018), renewable energy (Pitelis, 2018), accelerating technological change (Rogge and Reichardt, 2016), or broader environmental issues (Lehmann, 2012).

Following the logic of Bowles (2016, Appendix 1) for the relationship between incentives and social preferences, we distinguish between four cases of interaction between policy instruments, namely (i) no (zero) synergy, (ii) positive synergy, (iii) (moderately) negative synergy, and (iv) backfire. The first case indicates that the overall effect of a policy mix is the sum of the individual instrument effects, meaning there are no synergistic interaction effects, or the instruments are independent and complementary. This is also known as additive separability. The second case describes cases in which one instrument reinforces another, meaning a positive interaction effect is at stake. This case is sometimes referred to as super-additivity, super-modularity and crowding-in.[1] An example is information provision creating awareness which in turn strengthens an incentive effect. The third case reflects that one instrument weakens another, such as when monetary incentives crowd-out intrinsic pro-environmental preferences. Here the interaction is negative, and the outcome is variably known as substitutability, sub-additivity or crowding-out. This happens, for instance, if instruments overlap in their impact on particular decisions by agents and associated emissions, so that the effect of the policy mix is lower than the sum of the isolated effects. The instruments are then (partial) substitutes of one another. An extreme version of this is the fourth case of 'backfire', denoting that one of the instruments offsets the effect of the other, causing the policy mix to perform worse than the best-performing instrument alone. This differs from moderate negative synergy, which is still reasonably effective in that it means that the combination of instruments reduces emissions more than a single instrument alone. The boundary between these two cases is what we will call "compensating negative synergy": here negative synergy results in overall emissions reduction equalling *B*, i.e. the level achieved by the most effective instrument alone. Figure 1 illustrates these various potential outcomes of interactions between two policy instruments.

[1] Note that cases (i) and (ii) are sometimes also referred to as instruments being complementary. To avoid confusion, we use in this paper the term 'complementary' strictly for case (i).

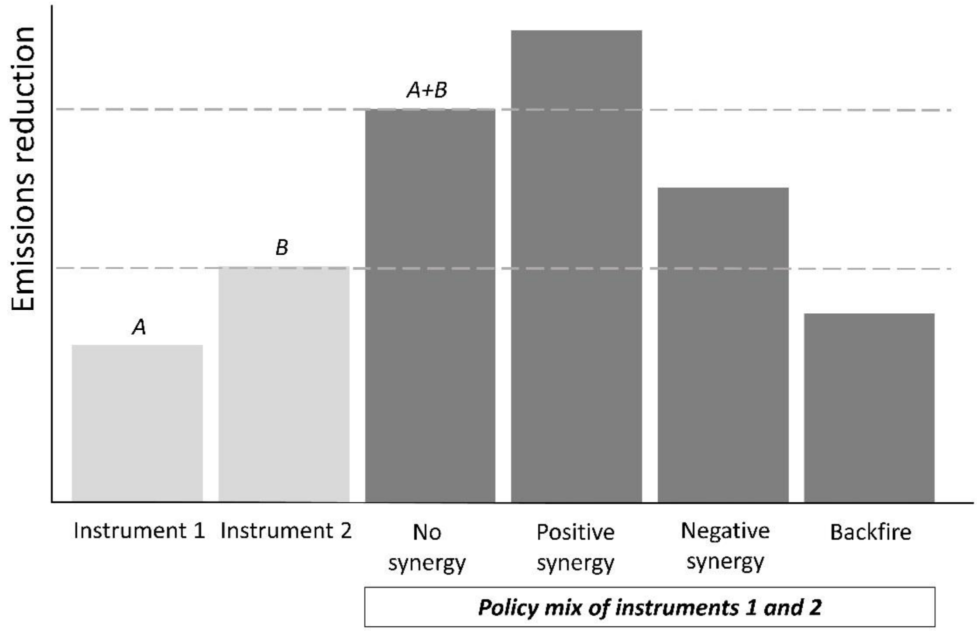

Figure 1. Potential outcomes of instrument interactions

Note: Adapted from Drews et al. (2020). The horizontal dashed line on top separates between positive and negative synergy, and the one underneath between backfire and other negative synergy.

The remainder of this article is organized as follows. Section 2 discusses the approach, consisting of identifying main categories of instruments and assessing possible interactions between these. Section 3 examines the performance of specific instrument combinations in terms of emissions reduction. Section 4 summarizes the findings and generalizes these for more than two instruments, discussing relative advantages and disadvantages of a set of potential climate policy mixes. Further, it pays attention to the international context of climate policy and its implications for policy mixes. Section 5 concludes.

2. Approach

There are many classifications of environmental and climate policy instruments aimed at altering behaviour of firms and households to achieve reductions in carbon emissions (Sterner, 2002; Bulkeley and Kern, 2006; Goulder and Parry, 2008; Somathan et al., 2014). Here we focus on a set of instruments that has received considerable attention in the literature on policy mixes:

1. Performance and technical standards. Performance standards can take various forms, such as a quota on a sector's emissions, a renewable energy portfolio target (e.g., a certain share of renewables in electricity generation), phasing out fossil fuels (e.g., coal), or banning use of high-emission cars in cities. Technical standards specify minimum criteria for consumer or production technologies, such as fuel-efficiency standards for cars or best available technologies for pollution abatement.

2. Carbon pricing means incorporating the direct and indirect external costs of CO_2(-eq) emissions in the prices of fuels, resources, intermediate products, and final goods and services. This can be done through a carbon tax or emissions trading (market creation or tradable permits), which do not necessarily generate identical outcomes (Goulder and Schein, 2013; Foramitti et al., 2021).[2]
3. Adoption subsidies encourage the adoption and diffusion of energy-efficient or low-carbon products by financially rewarding the purchase of energy-efficient or low-carbon products (e.g., hybrid or electric cars).
4. Innovation support aims to increase private investment in, and success of, research and development (R&D) on energy-efficient and low-carbon technologies and products. A common way to do this is through R&D subsidies. Many other instruments fall into this broad category (Dolfsma and Dongback, 2013): e.g., green procurement, funding basic research at universities and in research centres, or legislation on intellectual property rights.
5. Information provision and nudges address lack of information – such as limited awareness of environmental challenges, solutions or associated behavioural options – and behavioural barriers – such as limited attention, self-control issues and status concerns. Instruments of the first type include providing basic information, often in a simplified form (e.g., eco-labels and energy certificates). Instruments of the second type, targeting specific behaviours, entail reminders of excessive energy use, commitment devices, and feedback about choices of others (e.g., smart electricity meters).

One can distinguish symmetric from asymmetric instruments mixes: while in the former case all sectors are subject to the instruments, in the latter case some sectors receive different treatment than others. For example, renewable electricity is subject to future targets and feed-in-tariffs, EU-ETS is limited to large industrial and energy power firms, a carbon tax is often focused on non-export sectors, and concrete technical standards apply to particular sectors – such as fuel-efficiency standards in car manufacturing.

The approach we followed to select studies for review consists of two parts. The first is a snowball method: we looked for relevant studies in existing reviews which offered a good entry point into the literature. From there we skimmed the reference lists of all identified papers until we did not find additional suitable papers. The second part involved a search in Scopus, using the following search terms:

[2] A cap-and-trade system can itself already be regarded as a mix of policy instruments, namely a quantity-based instrument (i.e. a cap to emissions, defining the sum of all emission permits) and a price-based instrument (i.e. variable price due to trade of permits). Such a hybrid policy has various advantages (Hepburn, 2006; Grüll and Taschini, 2011). Specific additional elements add further benefits, such as limiting volatility of the carbon price through a minimum price or price floor, and avoiding unsurmountable costs for emitters through a maximum price or "safety valve" (Jacoby and Ellerman, 2004; Philibert, 2009).

("policy interaction" OR "policy synergy" OR "instrument combination" OR "instrument mix" OR "instrument interaction" OR "instrument synergy" OR "instrument combination" OR "instrument mix") AND ("climate" OR "energy" OR "emission").*

This generated a list of 273 studies of which a little over ten percent were considered relevant to our specific purpose of assessing instrument synergy in regard to emission reduction. Most of these studies are from environmental economics, while additional ones come from energy studies, environmental science, psychology and other policy areas. We excluded studies that did not focus on instrument synergy, did not provide a clear basis for their claims, or did not relate directly to climate policy and emission reduction.

3. Specific instrument combinations for emissions reduction

3.1 Carbon pricing combined with performance or technical standards

First, we consider combinations of pricing instruments, such as taxes or cap-and-trade, and direct regulation, such as quotas/targets or standards. As this topic has already been covered well in a previous IPCC report (Somathan et al., 2014), we will keep it relatively short.

With cap-and-trade the addition of specific sector targets, technical standards (Thurber et al., 2015; Beckenbach et al., 2018) or a forced phase-out of an energy source, such as coal (Osorio et al., 2020), will certainly result in negative synergy. Theoretical studies indicate this (Roberts and Spence, 1976; Christiansen and Smith, 2012, 2014). The reason is that the target and the standard reduce emissions in sectors that then need fewer permits, leading to lower permit prices and higher emissions in other sectors subject to the cap but not the target or standard. This is known as the "waterbed effect": emissions are not reduced but just appear in another place (Perino, 2018). It means that the carbon market price is determined not only by marginal abatement costs of emitting firms but possibly also by the other policy instrument, namely if it stimulates or obliges emissions reduction with a relatively high marginal cost (i.e. beyond the permit price in an isolated carbon market). The overall abatement cost will come out higher (Sijm, 2005; OECD, 2011). This holds equally for countries and multilevel systems. Well-intended energy policies by states or countries, respectively, can undercut the consistent approach aimed for by a national or supra-national policy such as the EU-ETS, frustrating the effectiveness and efficiency of emissions reduction. An assessment for the EU by Böhringer and Rosendahl (2011) finds more than 60% cost increase of achieving 25% CO_2 reductions when a renewable energy quota is set 10% points higher than the endogenous renewable energy deployment level under the EU-ETS, and that the permit price falls from €41 to €16 per ton of CO_2.

Table 1 clarifies how synergy resulting from adding renewable energy policy (REP) in the form of standards or targets to carbon pricing differ between a carbon tax and carbon market creation (such as emission trading). With a carbon market, the outcome is compensating negative synergy (on the boundary of backfire; see discussion of Figure 1) making the second instrument unnecessary, while with a carbon tax synergy can range from negative to zero (complementarity). For maximum effectiveness REP is thus best combined with a carbon tax rather than carbon market creation. Moreover, as explained by the difference between the two cases in the columns, such policy should avoid targeting relatively cheap options that are already triggered by the carbon tax.[3]

Table 1. Emissions reduction (and synergy) of combining carbon pricing and renewable energy policy

	Combined effect (emissions reduction and synergy) with renewable energy policy	
	MAC > *p*	*MAC* < *p*
Carbon market	emissions reduction *X* implying synergy -*Y*	emissions reduction *X* implying synergy -*Y*
Carbon tax	emissions reduction *X+Y* implying synergy 0	emissions reduction *X* implying synergy -*Y*

Notes: X denotes emissions reduction of carbon pricing on its own (isolated carbon market and tax are equivalent in terms of emissions reduction, i.e. tax=market price=*p*); *Y* is emissions reduction of renewable energy policy (REP) on its own. *MAC* denotes the marginal abatement costs of renewable energy investment. Of course, a part (say *a*, with 0<*a*<1) of renewable energy investments could have a *MAC* below and the rest above *p*, in which case the negative synergy of tax and REP will be $-a\cdot Y$. Since *a* in general will be non-negative, some degree of negative synergy is likely here.

The previous problem pertains to California, China and the EU given that they all have climate policies combining emissions trading and sector-specific targets or standards (Duan et al., 2017; Schatzki and Stavins, 2012; Fankhauser et al., 2010). Many more studies report the same finding (e.g., del Río, 2011; Görlach, 2014; Delarue and van den Bergh, 2016; Tu and Mo, 2017). The overall policy mix will then perform equal to emissions trading on its own.[4] Evidence for various countries is summarized in Fankhauser et al. (2010).

Finally, low-carbon technical standards on technologies for adoption may suffer from energy/carbon rebound in the user phase, causing a loss in overall effectiveness of emissions reduction. Combining standards with carbon pricing will limit such rebound by making energy and emissions during the use phase more expensive, thus discouraging more intense use and associated rebound (van

[3] A few studies claim that despite negative synergy, the combination of carbon market and renewable energy policy can be useful: e.g., if the design of the permit market is imperfect (Lecuyer and Quirion, 2013, 2019) or energy market are imperfect (Lehmann and Gawel, 2013). Others point at long-term innovation benefits (del Río, 2017; Fagiani et al., 2014). However, direct innovation support seems more effective for this purpose and will avoid negative synergy with carbon markets (Section 3.3).

[4] This can be compensated by a market stability reserve, as in the EU-ETS (Perino et al., 2019). Reducing the cap over time is another way to reduce negative synergy; more specifically, deducting the emissions reduced by the standards from the cap neutralizes the leakage (Richstein et al., 2015). A third option is installing a carbon price floor (Flachsland et al., 2019). Perino (2018) warns, though, that this may not be a permanent solution.

den Bergh, 2011; Font Vivanco et al., 2016; Freire-González, 2020). As a result, technical standards and carbon pricing have positive synergy in terms of emissions reduction.

3.2 Carbon pricing combined with adoption subsidies

Combinations of taxes and adoption subsidies take different general forms, including feebates, deposit-refund systems and environmental tax revision. The connection is particularly relevant for carbon pricing, as both revenues from carbon taxation and permit auctioning can serve to finance a subsidy, rebate or refund. In fact, the carbon tax and its revenue recycling can then be regarded to form a policy mix.

Adoption subsidies as an additional instrument to carbon pricing can be motivated in various ways. First, they create protected niche markets for low-carbon technologies and products, which stimulate expansion of associated production capacity, in turn creating scale and learning effects. This causes the low-carbon alternatives to become more competitive with incumbent high-carbon options (Hoppmann et al., 2013). Second, adoption decisions are often subject to peer pressure and hence early adopters may have a positive external effect on late adopters. For instance, houses with solar photovoltaic panels on rooftops have been found to increase the probability of neighbours installing it as well (Bollinger and Gillingham, 2012). Third, with only carbon pricing, adoption and thus diffusion of low-carbon options may be hampered by behavioural factors such as myopia, warranting tailored incentives like adoption subsidies. An alternative to overcome behavioural barriers is information provision, as discussed in Section 3.4.[5]

Despite these advantages, adoption subsidies for low-carbon options are best not implemented on their own, but complemented by carbon pricing. Support of investment in renewable energy capacity through subsidies alone makes energy use overall generally cheaper and can thus increase demand for energy, thus limiting overall emissions reduction (Murray et al., 2014). In particular, while adoption subsidies stimulate purchase of low-carbon options (e.g., low-carbon vehicles), they effectively lower energy costs per unit of use (e.g., km driven). This in turn tends to give rise to energy/carbon rebound through more intense use (more trips or longer distances travelled with the vehicle). As argued in Section 3.1, carbon pricing will limit such rebound and thus generate positive synergy. Hence, one should be careful using adoption subsidies to stimulate the purchase of products whose use causes carbon emissions, such as electric vehicles running on electricity that is not entirely carbon-free; without a carbon price in place emissions could rebound and even rise.

According to Fankhauser et al. (2010), feed-in tariffs (FITs) to support renewable energy obligations for a sector that is also subject to a cap-and-trade system will weaken the carbon price and thus decrease emissions reduction, compared to the sum of emission reduction potential for each instrument in isolation (see also Sorrell et al., 2009; and Twomey, 2012). Fais et al. (2015) analyse

[5] Stoneman and David (1986) compare adoption subsidies and information provision in their role as instruments to encourage diffusion.

interdependencies between the EU-ETS and the German FITs for renewable electricity using a bottom-up energy system model. They find that permit prices decline by between 1.9 €/tCO2 and 6.1 €/tCO2 and the burden sharing between participating countries changes, distorting the cost-effectiveness of cap and trade, with additional costs under FIT between €44 billion and €57 billion over the period 2013–2020. To this, one has to add the pure cost of the FIT which is €320 billion in the same period. So, while not adding extra emissions reduction, i.e. causing negative synergy, the FITs also contribute to significant additional costs.

Feebates (fee + rebate) or bonus-malus schemes combine a carbon tax (or a sales tax with a carbon component) on high-carbon options with an adoption subsidy for low-carbon alternatives. The simple idea behind it is that the high-carbon option is discouraged and the low-carbon one encouraged. However, like a pure adoption subsidy, a feebate suffers from the above-discussed rebound problem (Haultfœuille et al., 2014) and requires a consistent price on all carbon to limit more intense use of the low-carbon option. An advantage of feebates is that, instead of requiring a high carbon tax to shift consumer decisions to low-carbon options, which has been politically infeasible so far, one can combine a lower carbon tax with a rebate, which might be more politically acceptable. Ideally, the combination of these instruments creates the same price gap between high- and low-carbon options as achieved by the high carbon tax alone. Another advantage is that the system can be self-financing, namely the subsidy (rebate) can be paid out of the fee revenues. However, it may be impossible to satisfy the two conditions – i.e. an optimal price gap and revenue or budget neutrality – simultaneously. In addition, governments have to address the challenge that an effective carbon tax erodes the emissions base of tax revenues, requiring them to think about timely implementation of additional revenue-raising taxes.

A disadvantage of feebates, and adoption subsidies generally, is that overall consumption is encouraged compared to an equivalent carbon tax (i.e. with the same price gap between low- and high-carbon), given that low-carbon usually also involves carbon emissions (in production and use phases).[6] However, as diffusion may go faster, there is uncertainty about the net effect on emissions in the long run. Exact outcomes depend on the precise design including whether it satisfies self-financing or not. For instance, Durrmeyer (2018) finds that under a flat rate tax, the feebate scheme favours individuals in the middle-income class, while if the tax is proportional to income, the feebate redistributes some income from the richest to the poorest households. Unlike a pure carbon tax, where revenues can be used to compensate lower-income households, in the feebate approach no funds are automatically generated to pay for such compensation. Note that both instruments have a rebound effect: carbon-tax revenue recycling to poor households creates a positive income effect on consumption; and the feebate's rebate stimulates consumption of the low-carbon option.

3.3 Innovation support combined with other instruments

[6] An overall comparison of feebate and carbon tax should also account for any emissions reduction or increase due to use of carbon tax revenues.

The traditional economic perspective on climate policy recognizes two externalities that require a policy response. The first is negative, namely environmental externalities, which are tackled through pricing of external costs. The second is positive, namely knowledge-related spill-overs of R&D driving innovation in low-carbon technology, due to incomplete appropriability of innovation benefits. These can be regulated with adequate innovation policy, including protection of intellectual property rights and subsidies for risky R&D with an uncertain or long-term payback. This policy approach finds support in both economics and innovation studies (Jaffe et al., 2005). A third challenge for climate policy is the problem of social, economic and political lock-in of undesirable (high-carbon) technologies and practices or lifestyles (Geels et al., 2017). Others refer to "system weaknesses" and the need for "structural build-up of innovation systems" in this respect (Jacobsson et al., 2017). All in all, this results in what has been called "a triple-externality problem" (van den Bergh, 2013a).

Lock-in denotes that a dominant technology or practice is so much more attractive to potential future adopters that it is difficult to escape from it (David, 1985; Arthur, 1989). It is the outcome of a path-dependent process driven by increasing returns to scale on supply sides (e.g., economies of scale, learning and technological complementarity) and on demand sides (e.g., imitation or network externalities) (Seto et al., 2016). The issue of lock-in is relevant to the adoption of low-carbon options, such as renewable energy (Zeppini and van den Bergh, 2020) or electric vehicles (Cowan and Hulten, 1996).

Implementing only environmental regulation/pricing or only technological policy in the presence of all these externalities has a disadvantage. For instance, renewable energy support in isolation can reduce fossil fuel prices, in turn leading to more rapid extraction of fuel resources as a second-order effect –known as the "green paradox" (Sinn, 2015). To avoid it, one should also make fossil fuels more expensive through environmental pricing (van der Ploeg and Withagen, 2015). However, if the only policy instrument is environmental regulation/pricing, energy technologies that are cost-effective will survive, while promising but less developed alternatives (i.e. expensive but with a steep learning curve) will not be selected. This then gives rise to early lock-in of currently cost-effective options, even though these may not be optimal in the long run. Implementing innovation policies that encourage expensive and risky R&D can avoid such lock-in, as it keeps promising technological trajectories open (Way et al., 2019). In particular, innovation support counters the short-term selection pressure against such technologies created by regulatory instruments (standards, targets) or carbon pricing. Another consideration is the riskiness of private investment and R&D in low-carbon options. A combination of environmental and technology-specific policies reduces this uncertainty, and consistently shapes the direction and speed of low-carbon innovations towards maximum emissions reduction in the long run.

This combination may still be insufficient, however, to escape from locked-in fossil-fuel based energy and transport systems. A particular "unlocking policy" may be needed that counters increasing returns to scale on demand and supply sides of markets. One option is to set a very high carbon price, even above the optimal (Pigouvian) level. An applied model study by Mercure et al. (2014) show that a carbon price alone can achieve escape from (fossil fuel or carbon) lock-in but that a policy mix with regulatory instruments like technical standards in addition allows to do so with a lower, arguably more politically feasible, carbon price. Alternative policies and strategies to evade lock-in include setting a clear future goal (e.g., California's ZEV program) and creating semi-protected niche markets for innovative technology (e.g., with adoption subsidies or public procurement) (van den Bergh, 2013b). One can think of more daring strategies as well, such as restricting the advertising of high-carbon products or reinforcing social norms and status associated with uptake of low-carbon products and services. These instruments complement innovation policies, so would give rise to a policy mix with potentially positive synergy. Axsen et al. (2020) elaborate this for transport emissions.

Use of innovation policy instruments will also allow other types of instruments, such as adoption subsidies or carbon taxation, to have more impact in stimulating a shift from high- to low-carbon consumption. Conversely, the impact of public R&D support can be greater at the margin if accompanied by FIT, particularly in periods of technological maturity, as shown by Lindman and Söderholm (2016) using wind-energy patents. The reason is that learning-by-doing feeds back to the innovation phase by driving lower prices and higher sales, in turn affecting innovation investments and direction. Hence, one can expect positive synergy between innovation and adoption incentives over longer time periods. In addition, positive synergy is also feasible with regard to innovation speed and direction as these not only depend on innovation policies but also on regulation or pricing (Popp, 2002; Aghion et al., 2016). This is because innovating firms take expectations about future costs and prices into account. Therefore, regulation and pricing are not only relevant for short-term emissions reduction but also for the speed and direction of innovation, and hence long-term emissions reduction.

3.4 Information provision combined with other instruments

There seems little opposition against instruments of information provision, arguably as their administrative cost is relatively low and they leave people free to act while they do not have inequitable effects. On their own, information policies do not have a strong emissions reduction effect: on the order of 5-10% of prevailing emissions, according to various meta-analyses (Delmas et al. 2013; Andor and Fels, 2018; Wynes et al., 2018). In addition, their effects tend to fade out quite quickly (Nisa et al., 2019). But information provision can complement other types of instruments, sometimes creating positive synergy with these, though it should be said that effectiveness varies strongly between different types of information provision and nudges (Abrahamse and Steg, 2013; Schubert, 2017).

Relatively few studies offer a theoretical analysis of the interaction of information provision and other instruments. The general argument for a complementary role of information and nudges with other policies is that behaviour takes different forms (e.g. one-shot vs. habitual) and is underpinned by different drivers (Stern, 2020). These can be accounted for by tailored information and nudges. Several studies suggest that a combination of regulation/pricing and information provision can be more effective than each alone (Stern, 1999; Nyborg et al., 2006; Stiglitz, 2019). A study by Gsottbauer and van den

Bergh (2014) develops a model of consumption influenced by norms or status in combination with commercial advertising. It finds that to achieve socially optimal outcomes, next to an adapted Pigouvian tax on pollution to limit the negative environmental externality, one needs also a tax on advertising or public provision of information to restrict the positive externality of norms and status that magnifies consumption. Information provision to counter advertising is by itself insufficient as it does not completely cancel the magnifying effect, necessitating a tax on advertising in addition. This is consistent with findings from Glaeser and Ujhelyi (2010), who develop a model of advertising as misinformation, showing that it is welfare-improving to impose a ban or tax on advertising, and under some circumstances to provide public information about the real cost and benefits of advertising.

The interaction of information provision and regulation, notably carbon pricing, can also be considered from the angle of social networks. Konc et al. (2021) illustrate this through a model of consumption decisions driven by socially-embedded preferences, which are formed under the influence of consumption choices by peers in a social network. It shows that the effectiveness of carbon taxation is improved due to a social multiplier effect that depends on four factors: the strength of social influence; the initial preference distribution; the specific network topology; and the income distribution. It is argued that some of these factors may be influenced by specific kinds of information provision, namely: comparative feedbacks can reinforce the social context in the formation of preferences; information correcting misperceptions about climate change can shift preferences towards low-carbon options; and information aimed at highly interconnected agents in a social network can drive them to adopt low-carbon options, in turn accelerating their diffusion. Hence, such information provision can create positive synergy by increasing the social multiplier effect of a carbon tax.

Empirical evidence is varied on how information provision influences the effectiveness of the instrument with which it is combined (Trechner and van der Heijden, 2019). For example, an informational campaign that justifies to car users the introduction of a tax on transport fuels is likely to make this tax more salient, increasing the responsiveness of consumers (Li et al., 2014). In particular, information provision affects behavioural tendencies that moderate the effectiveness of instruments; by making taxes or subsidies more salient, information provision can increase or decrease consumers' responsiveness (Alcott et al., 2015; Perino et al., 2014), or by providing repetitive feedback it can increase the effectiveness of monetary incentives (Matthies et al., 2011).

In the area of energy-conservation policies, supplementing regulatory/pricing policies with information measures can compensate asymmetric information that hampers the diffusion of energy-efficient technologies (Lehmann, 2012). Improving agents' knowledge about available energy-efficient options will allow them to respond well to monetary incentives by policies like carbon pricing. For example, in the housing sector, the landlord may be required to inform the tenant about the energy efficiency of his building by way of an energy certificate. Empirical studies show such measures can reduce energy use, depending on the market, technology and the overall policy mix (Lehmann, 2012). According to Sorrell and Sijm (2003) information provision is most useful as an additional instrument for households and small or medium-sized firms as these tend to have little knowledge about relevant options, large energy-saving potential, and low energy-price elasticities.

Studies using mostly field experiments to test synergy between incentives and information provision or nudges offer mixed evidence: positive synergy (Hilton et al., 2014, List et al., 2017), negative synergy (Dolan and Metcalfe, 2015; Sudarshan, 2017), no synergy (Mizobuchi and Takeuchi, 2013; Tørnblad et al., 2014; Schall et al., 2016; Pellerano et al., 2017; Handgraaf et al., 2013; Panzone et al., 2018). For example, a study by Panzone et al. (2018) examined how a carbon tax combined with a moral nudge affects food choices in an online supermarket in the UK. When considering the instruments in isolation, both the carbon tax and, to a lesser extent, the nudge encouraged people to choose food products with a lower carbon footprint. However, the study found no positive synergy from combining the instruments. An important caveat is that only a minority of studies include a full analysis required to arrive at robust conclusions. Drews et al. (2020) propose how to improve this kind of experimental research, recognizing that not only monetary incentives may crowd-out non-economic motivations, but also nudges or information provision can crowd out the effectiveness of monetary incentives. What matters further is how information is framed and provided, such as through feedback, advertising, contextual information, descriptive social norms, etc. (Abrahamse et al. 2007).

3.5 Other interactions, including within an instrument category

Innovation or technology policy itself makes use of multiple instruments, which has received quite some attention in the literature (Borras and Edquist, 2013; Herrmann and Savin, 2017). One classification is into mission- and diffusion-oriented design (Ergas, 1987). A combination of diffusion- and mission-oriented instruments is common as it stimulates economies of scale and technology maturity, while supporting a diversity of technologies and start-up firms, which in the longer run can transform the economy towards low-carbon. For example, Palage et al. (2018) find that public R&D support of solar photovoltaic innovation is more effective if it is accompanied by a FIT scheme.

The literature on innovation studies further proposes to use multiple instruments to benefit from technology push and demand pull. To achieve the first, one can use instruments of innovation support, such as R&D subsidies or technology transfer (Bozeman, 2000; Martin, 2012), while the second can be encouraged through pricing of environmental externalities (punishing dirty options) or adoption subsidies (rewarding clean options). Di Stefano et al. (2012) mentions various reasons for positive innovation synergy between demand and supply (policies), such as user-producer interactions and firm innovation being driven by supply- and demand-driven opportunities.

Interactions between multiple standards and targets happen frequently in multi-level regulatory systems such as the EU and USA. Using a partial-equilibrium structural model of agricultural and energy markets, Whistance et al. (2017) examine interactions between a national renewable fuel policy in the United States, namely the Renewable Fuel Standard, and a state-level renewable fuel policy, namely the Low Carbon Fuel Standard in California. Both aim at reducing greenhouse gas emissions. The study finds that there is no interaction in terms of national-level effectiveness, but that a shift occurs in renewable fuel use toward California at the cost of other regions.

A study by Brandon et al. (2019) on electricity demand reduction in the US tests crowding-out[7] between multiple information-provision instruments, regarding peak time energy consumption, and social norm comparison. In their natural experiment involving around 42,000 households, they set up three treatment groups, finding a positively synergistic effect (6.8% versus 5.9%).

There are also some insights about very specific instrument combinations. For instance, regarding adoption subsidies, an agent-based model study by Silvia and Krause (2016) examines how these influence diffusion of electric-battery vehicles. They find that combining such subsidies for vehicle purchase with investment in extending the charging network and governmental purchase of vehicles (procurement) leads to the highest number of adopted vehicles when compared to scenarios with isolated policies at higher stringency. Another example of particular instrument mixes concerns fleet standards and policies encouraging adoption of low-emission vehicles. Jenn et al. (2016, 2019) show that state mandates (zero-emissions vehicle policy) increasing alternative-fuel vehicle sales are counteracted by federal policy requiring automakers to meet aggregate criteria for fleet-fuel efficiency, such as "Corporate Average Fuel Economy" (CAFE) standards. The authors find that these standards are relaxed when more alternative-fuel vehicles are sold to the extent that overall emissions increase considerably.

4. Suggestions for effective policy mixes

There are many considerations when evaluating climate policy, such as effectiveness, efficiency, equity, political feasibility and harmonization of international policy. In line with the focus of this article, in this section we examine more complete instrument mixes from the angle of synergy in terms of emissions reduction, while giving attention to these other dimensions as well.

We first summarize in Table 2 how the previous knowledge about instrument interactions, as documented in Section 3, translates into the design of complete climate policy packages. Regarding the evidence (last column), theoretical modelling can separate clearly and precisely the effects of each instrument alone and their interactions, but inevitably tends to abstract from real-world complexity. By comparison, empirical studies include many relevant factors that play a role in reality, but have more difficulty in separating the effects, and thus interactions, of multiple instruments. Laboratory experiments can compare behavioural responses of people to single and multiple instruments, but only by abstracting from economic, social and political factors that play a role in reality. Looking across results from the three techniques used to study instrument combinations will provide a stronger basis for the design of climate policy.

[7] This is one of the few studies that includes the four required treatments: no policy, either instrument in isolation, and their combination. Note that crowding-out (in) means that the combined effect is smaller (larger) than the sum of the two isolated effects.

Table 2. Which instruments to be combined or not in a climate policy package

Instruments	**Main role**	**Recommendable combination** (zero or positive synergy)	**Caution required when combined with** (negative synergy)	**Uncertain combinations** (research gaps)	**Supporting theory and evidence**
Performance & technical standards	Assures that investment decisions by firms and purchase decisions by consumers focus on low -carbon alternatives.	With carbon tax to avoid rebound (intensity of use).	With carbon markets (i.e. cap and endogenous carbon price) as this will cause intersectoral leakage, and to a lesser extent with a tax as this may also lead to negative synergy.	Interaction with adoption subsidies, innovation support and information provision needs attention.	Theoretical modelling and empirical studies (Sections 3.1 and 3.5).
Carbon pricing	System-wide consistent regulation/pricing, controlling leakage, and controlling rebound effects due to intensity-of-use and re-spending.	With innovation support for promising but still expensive technologies, to avoid early selection and lock-in of technologies that are not the best for climate solutions in the long run.	Carbon market not combined with performance and technical standards as this will reduce effectiveness. Also not combined with adoption subsidies as this reduces price and thus emission reduction in other sectors.	Interaction with adoption subsidies and information provision needs further attention.	Theoretical modelling and empirical studies (Sections 3.1, 3.2, 3.3. and 3.5).
Adoption subsidies (including feebates or feed-in tariffs)	Encouraging adoption of low-carbon options, capturing any positive externalities such as between adopting neighbours.	With carbon taxes as otherwise high-carbon options are insufficiently discouraged. Carbon tax also controls rebound through more intense use of adopted low-carbon goods. With innovation subsidies as they magnify effect of adoption subsidies.	With carbon markets as their endogenous carbon price will be negatively affected by the adoption subsidy, which reduces the effectiveness of the carbon market.	Runs the risk of subjectively focusing on a technology that does not guarantee the best performance in the long run.	Theoretical modelling and empirical studies (Section 3.2 and 3.3).
Innovation support	Keeping promising but still expensive technological trajectories open, escaping lock-in of fossil-fuel based technologies, and basic university-based research on low-carbon options.	With carbon pricing to direct innovation and adoption towards low-carbon products, services and practices. With adoption subsidies (in later stage) to increase diffusion and learning-by-doing effects.	Can be combined with most or all other instruments (no indication of negative interactions).	Runs the risk of focusing on a technology that does not guarantee the best long-run performance. Interaction with targets and technical standards needs further attention.	Theoretical modelling and empirical studies (Section 3.3).
Information provision & nudges	Reinforcing favourable social network effects, correcting behavioural biases, dealing with split incentives, etc.	With carbon pricing as specific information provision can reinforce its effectiveness.	No indication of systematic and strong negative interactions with other instruments.	Interaction with most other instruments (only partial understanding).	Theoretical modelling and experiments (Sections 3.4 and 3.5).

Next, Table 3 suggests four relatively effective instrument mixes resulting from achieving positive, and avoiding negative, synergies among instruments – informed by Table 2. The idea behind this is that one should add instruments as long as these have zero or positive synergy, but should be careful when adding instruments that introduce negative synergies, depending on the size of the latter. For example, combining renewable energy policy and carbon markets is risky because of compensating negative synergy (see discussion of Figure 1) which limits overall emissions to the market cap. For lower values of negative synergy, exact quantification and assessment of comparative abatement and policy costs is needed (i.e. implementation, monitoring and control), to decide about the exact policy mix.

Implicit in the comparison of instrument mixes is that stringencies of instruments are such that all mixes have an equal (or at least very similar) effectiveness, absent from synergy effects. This will avoid having stringency differences dominate overall effectiveness between mixes. To operationalize this, one could assess the effectiveness of each instrument on its own (e.g., through an implicit carbon price), and then sum these to assure that policy mixes have similar overall effectiveness absent accounting for synergy effects. This will subsequently allow for separating out synergy effects through comparison. Admittedly, this restriction may limit a complete comparison of instrument mixes with varying stringencies; further empirical or experimental studies would be needed to test for this. In addition, we assume – as there is little literature providing evidence – that the effects of triple and higher interactions, i.e. between more than two instruments, are small and do not overrule the effects of dual interactions. Some studies include more than two instruments but provide insufficient information about what is the exact cause of the overall synergy (e.g., Fagiani et al., 2014; Vilchez et al., 2020).

In comparing the policy mixes, next to effectiveness (associated with synergy) we consider also efficiency, and implicitly political resistance. We can do this as efficiency features of instruments – notably overall abatement costs of complying with the policy – are well known, based on extensive theoretical and empirical insights (Aldy et al., 2010).[8,9] The scores on the two criteria are shown in the final two columns of Table 3. Policy mix *A* is the least effective due to rebound being uncontrolled by pricing, and further is the least efficient because of fixed targets or standards rather than price incentives that select for cost-effective abatement options. As argued in Section 3.1, policy mix *B* can be less efficient in emissions reduction than mix *C*, if the standards select for relatively expensive abatement options that are not triggered by the carbon tax. An advantage of policy mix *B* is that the standards allow

[8] With regard to the trade-off between effectiveness and efficiency, the prices-vs-quantities debate started by Weitzman (1974) is relevant. It distinguishes between uncertainty about effectiveness of price instruments versus uncertainty about the costs of quantity instruments. While this debate is more about instrument choice and incentives than about a policy mix, it has been connected – even in the context of climate policy – to hybrid instruments such as tradeable permits with a price floor (kind of a policy mix). Such hybrids are found to perform better than each instrument alone (Pizer, 1997). Considering a setting with multiple pollutants, Ambac and Coria (2013) find that the desirable policy mix depends on whether pollutants are complements or substitutes.

[9] We considered adding equity to the set of performance criteria. However, it has not received much attention in studies assessing synergy of policy instruments, while its assessment requires information about generally unknown factors, such as wealth and income distribution, prices, sector shifts and associated unemployment. In addition, it depends on how revenues of carbon pricing are used (Klenert et al., 2018; Hafstead, 2019).

using a lower carbon tax, which could be a wise strategy facing less political resistance than a high carbon tax in policy mix *A*. However, policy mix *B* also can suffer from negative synergy between the tax and standard (see Table 1), making it less effective than *A*. Note that renewable energy targets and adoption subsidies are excluded from policy mix *C* as they interact negatively with the carbon market (Sections 3.1 and 3.2). This means the long-term effectiveness of emissions reduction may be lower than that of policy mix *D*, which combines adoption subsidies with a carbon tax.[10]

Table 3. Possible policy mixes with complementarity or positive synergy

Policy mix	Instruments						*Performance*	
	Performance & technical standards	Carbon tax	Carbon market	Adoption subsidy	Innovation support	Information provision & nudges	*Effectiveness*	*Efficiency*
A	x			x	x	x	low	low
B	x	x		x	x	x	high	low
C			x		x	x	high	high
D		x		x	x	x	high	high

Finally, we discuss a neglected but relevant consideration in the literature on climate-policy mixes, namely the political feasibility of stringent climate policy. Since climate policy is an international challenge with the characteristics of a public good that invite free-riding by national governments, achieving stringent policies in all countries requires global upscaling, harmonization or integration of national policies (Jordan and Lenschow, 2010). This holds especially true for regulatory and pricing instruments, as these affect competitive positions (and thus exports) of countries. Motivations for this view are diverse – see, e.g., Fowlie (2009), Fischer and Fox (2012), and Al Khourdajiea and Finus (2020). For alternative, minority views see, e.g., Bernstein and Hoffmann (2019) and Jordan et al. (2018).

While international competitiveness effects of climate policies have been found to be rather weak overall (Aldy and Pizer, 2015), two comments are in order. First, national policies so far have been lax everywhere, meaning that differences in stringency among countries have not been pronounced. In a study focused on carbon pricing, Venmans et al. (2020) conclude that "When statistically significant results have been found, the magnitude of such effects tends to be small [...] These findings are in part because carbon price levels have been low." Indeed, a recent assessment of carbon pricing found that the average price of carbon in countries where it is implemented is about 7.90€ per ton CO_2 (Finch and van den Bergh, 2020). Hence, one cannot extrapolate empirical findings about competitiveness effects to carbon price ranges (or trajectories) recommended as needed to meet the Paris targets, i.e. US$50-100 by 2030 (HLCCP, 2017; IMF, 2019) or even US$245–14300 tCO2e (Masson-Delmotte et al., 2018). Second, perceptions matter: politicians fear for competitiveness effects and business lobby to strengthen

[10] One might, as a transition approach, combine a carbon tax for small emitters with a carbon market for large emitters, as already happens in various EU countries. This evidently complicates the policy mix while adding the challenge of multiple, incongruent carbon prices.

this. Note that the EU is seriously deliberating a border carbon tariff to protect its economy for competitiveness effects of its relatively stringent climate policy. Harmonization will take away politicians concerns and thus can encourage more stringent national policies.

Such a need for global policy harmonization can be seen as an argument for limiting the number of policy instruments, or striving towards a transparent and simple policy mix that can be more easily compared and integrated among countries. If, on the other hand, countries have very complex policy mixes, it might be difficult for them to judge, compare and match these (del Río, 2014; Howlett et al., 2017; Schmidt and Sewerin, 2019), in turn possibly discouraging them to implement strong regulation/pricing instruments (Weitzman, 2014). A rich policy mix, as is common worldwide, moreover can be used as an excuse for politicians to claim "we are doing a lot already", even when the overall effectiveness of the policy mix is disappointing. These considerations suggest limiting the number of regulatory/pricing instruments, which means a trade-off with reasons for additional policy instruments, such as positive instrument synergy.[11]

If we judge how the four policy mixes in Table 3 perform on capacity for global harmonization, then option *C* comes out best, given that harmonization so far has been more successful with carbon markets than carbon taxation (options *B* and *D*). Indeed, such markets have been integrated among regions or countries in North America and Europe, while the same has not happened with carbon taxes, possibly as governments are unlikely to hand over control over taxes to a supranational body (van den Bergh et al., 2020). Finally, achieving harmonization with options *A* and *B* seems also difficult given they involve a multidimensional challenge of harmonizing many performance and technical standards next to various subsidies, while the latter would also involve the problem of supranational financing.

Considering all criteria together then, options *C* and *D* perform well on effectiveness, and *C* best on harmonization. *A* and *B* performs worst of the four options, and choosing between them is difficult in general as *A* may perform better on effectiveness (if *B* suffers seriously from negative synergy between the standard and tax) while *B* performs better on efficiency (so there is a trade-off then between effectiveness and efficiency to be made). This suggests that a ranking of options from most to least attractive is: *C, D, B, A*. However, a provision is needed, as we only consider two values for each criterion. Since it is possible that two "high" scores on effectiveness are not exactly the same, we cannot derive a definite ranking. This would require a trade-off between the exact performance in terms of each criterion (moving beyond the general instrument categories to specific instruments), as well as weights or priorities assigned to the different criteria. If one believes, for instance, that without harmonization significantly raising the carbon price over time to meet ambitious emissions reduction goals will be very difficult if not impossible, it would make sense to weight the final criterion more heavily. This then

[11] Among the various instruments, global carbon pricing enjoys the advantage that negotiating it is relatively simple as it means a one-dimensional negotiation challenge (Weitzman, 2014, 2017). Instead, negotiating national emission targets among 200 countries implies a 200-dimensional coordination problem, while negotiating technical standards for *n* products or technologies would mean an *n*-dimensional challenge (with *n* possibly being very large). In addition, a carbon market can harmonize national climate policies. Indeed, most current harmonized carbon prices are due to carbon markets (Haites, 2018).

would result in a preference for policy mix *C*. Although this is not a complete assessment, it indicates how one can integrate insights to decide about well-performing policy mixes.

5. Conclusions

It is important to seriously consider climate-policy mixes as recommended on the basis of insights about instrument interactions. The reason is that the practice of climate policy is strongly driven by political and stakeholder processes that easily result in what Bouma et al. (2018) call a "policy mess". As noted by Bennear and Stavins (2007), there is no evidence that implemented policy mixes are the most effective.

This study has collected insights and evidence from theoretical modelling and empirical and experimental studies to assess the negative or positive synergy of combining instruments in climate policy, aimed at achieving effective emissions reduction. This involved a more focused and concrete approach than in previous studies on climate policy mixes (listed in Section 1). We synthesized the findings on dual instrument synergies by formulating and comparing more complex policy mixes. We conclude that the most promising packages would be to combine innovation support and information provision with either a carbon tax and adoption subsidy, or with a carbon market and no adoption subsidy. We further argue that the latter could have stronger potential with respect to harmonization of international policy and thus the strengthening of mitigation policy over time.

Given its complexity, this topic merits further research. Quantification and weighting of policy-mix performance on multiple criteria, including notably equity, can help to provide more definitive advice. In addition, political feasibility of policy mixes deserves more attention in a dynamic setting of policy sequencing, transitions and coalition formation (Skovsgaard Aidta and Duttab, 2004; Gerlagh et al., 2009; Meckling et al., 2015; Herrmann and Savin, 2017; Edmondson et al., 2019). Finally, research is welcome beyond dual instrument interactions, namely on the magnitude of synergy between three or more instruments.

References

Abrahamse, W., L. Steg, C. Vlek and T. Rothengatter (2007). The effect of tailored information, goal setting, and tailored feedback on household energy use, energy-related behaviors, and behavioral antecedents. *Journal of environmental psychology* 27(4): 265-276.

Abrahamse, W., and L. Steg (2013). Social influence approaches to encourage resource conservation: A meta-analysis. *Global Environmental Change* 23(6): 1773–1785.

Aghion, P., Dechezleprêtre, A., Hémous, D., Martin, R., Van Reenen, J. (2016). Carbon taxes, path dependency, and directed technical change: evidence from the auto industry. *Journal of Political Economy* 124 (1): 1-51.

Al Khourdajiea, A., and M. Finus (2020). Measures to enhance the effectiveness of international climate agreements: The case of border carbon adjustments. *European Economic Review* 124, 103405

Aldy J., A. Krupnick, R. Newell, I. Parry, W. Pizer (2010). Designing climate mitigation policy. *Journal of Economic Literature* 48(4): 903-934.

Aldy, J. E., and W. A. Pizer. 2015. The competitiveness impacts of climate change mitigation policies. *Journal of the Association of Environment and Resource Economists* 2(4): 565–95.

Allcott, H., Knittel, C. and Taubinsky, D. (2015). Tagging and targeting of energy efficiency subsidies. *American Economic Review* 105: 187-191.

Ambac, S., and J. Coria (2013). Prices vs quantities with multiple pollutants. *Journal of Environmental Economics and Management* 66(1): 123-140.

Andor, M.A., Fels, K.M. (2018). Behavioral economics and energy conservation – A systematic review of non-price interventions and their causal effects. *Ecological Economics* 148, 178–210.
Arthur, B. (1989). Competing technologies, increasing returns, and lock-in by historical events. *Economic Journal* 99: 116–131.
Axsen, J., P. Plötz and M. Wolinetz (2020). Crafting strong, integrated policy mixes for deep CO2 mitigation in road transport. *Nature Climate Change* 10, 809–818.
Beckenbach, F., Daskalakis, M. and Hofmann, D. (2018). Agent-based analysis of industrial dynamics and paths of environmental policy: The case of non-renewable energy production in Germany. *Computational Economics* 52, 953–994.
Bernstein, S., and Hoffmann, M. (2019). Climate politics, metaphors and the fractal carbon trap. *Nature Climate Change* 9: 919-925.
Bennear, L.S., and Stavins, R.N. (2007). Second-best theory and the use of multiple policy instruments. *Environmental and Resource Economics* 37(1): 111-129.
Bollinger, B. and Gillingham, K. (2012). Peer effects in the diffusion of solar photovoltaic panels. *Marketing Science* 31(6): 900-912.
Boonekamp, P. (2006). Actual interaction effects between policy measures for energy efficiency – A qualitative matrix method and quantitative simulation results for households. *Energy* 31: 2848-2873.
Borrás, S., and C. Edquist (2013). The choice of innovation policy instruments. *Technological Forecasting and Social Change* 80(8): 1513-1522.
Bouma, J.A., Verbraak, M., Dietz, F., Brouwer, R. (2018). Policy mix: mess or merit? *Journal of Environmental Economics and Policy* 8(1): 1-16.
Böhringer, C., and K.E. Rosendahl (2011). Greening electricity more than necessary: on the cost implications of overlapping regulation in EU climate policy. *Schmollers Jahrbuch: Journal of Contextual Economics* 131: 469-492.
Bowles, S. (2016). *The Moral Economy: Why Good Incentives Are No Substitute for Good Citizens*. New Haven, Connecticut: Yale University Press.
Bozeman, B. (2000). Technology transfer and public policy: a review of research and theory. *Research policy* 29(4-5): 627-655.
Braathen, N.A. (2007). Instrument mixes for environmental policy: How many stones should be used to kill a bird? *International Review of Environmental and Resource Economics* 1: 185–235.
Brandon, A., List, J.A., Metcalfe, R.D., Price, M.K., Rundhammer, F. (2019). Testing for crowd out in social nudges: Evidence from a natural field experiment in the market for electricity. *PNAS* 116(12): 5293-5298.
Bulkeley, H., and K. Kern (2006). Local government and the governing of climate change in Germany and the UK. *Urban Studies* 43(12): 2237-2259.
Christiansen, V., and S. Smith (2012). Externality-correcting taxes and regulation. *Scandinavian Journal of Economics* 114(2): 358-383.
Christiansen, V., and S. Smith (2014). Emissions taxes and abatement regulation under uncertainty. *Environmental and Resource Economics* 60(1): 17-35.
Cowan, R., and S. Hulten (1996). Escaping lock-in: the case of the electric vehicle. *Technological Forecasting and Social Change* 53: 61-79
David, P. A. (1985). Clio and the economics of QWERTY. *American Economic Review* 75(2): 332–337.
del Río, P. (2011). Interactions between climate and energy policies: the case of Spain. *Climate Policy* 9(2): 119-138.
del Río, P. (2014). On evaluating success in complex policy mixes: the case of renewable energy support schemes. *Policy Sciences* 47: 267-287.
del Río, P. (2017). Why does the combination of the European Union Emissions Trading Scheme and a renewable energy target makes economic sense? *Renewable and Sustainable Energy Reviews* 74: 824-834.
Delarue, E., and K. Van den Bergh (2016). Carbon mitigation in the electric power sector under cap-and-trade and renewables policies. *Energy Policy* 92: 34-44.
Delmas, M., Fischlein, M., Asensio, O. (2013). Information strategies and energy conservation behavior: A meta-analysis of experimental studies from 1975-2011. *Energy Policy* 61(C): 729-739.
Di Stefano, G. A. Gambardella and G.Verona (2012). Technology push and demand pull perspectives in innovation studies: Current findings and future research directions. *Research Policy* 41(8): 1283-1295.
Dolan, P., and Metcalfe, R. (2015). Neighbors, knowledge, and nuggets: Two natural field experiments on the role of incentives on energy conservation. SSRN paper, doi:10.2139/ssrn.2589269
Dolfsma, W., and Dongback, S. (2013). Government policy and technological innovation—a suggested typology. *Technovation* 33: 173-179.
Drews, S., F. Exadaktylos and J.C.J.M. van den Bergh (2020). Assessing synergy of incentives and nudges in the energy policy mix. *Energy Policy* 144, 111605..
Duan, M., Z. Tian, Y. Zhao, and M. Li, 2017: Interactions and coordination between carbon emissions trading and other direct carbon mitigation policies in China. *Energy Research & Social Science*, 33, 59–69,

Durrmeyer, I. (2018). Winners and Losers: The Distributional Effects of the French Feebate on the Automobile Market. TSE Working Papers 18-950, Toulouse School of Economics (TSE).

Edmondson, D.L., F. Kern and K. Rogge (2019). The co-evolution of policy mixes and socio-technical systems: Towards a conceptual framework of policy mix feedback in sustainability transitions. *Research Policy* 48(10), 103555.

Ergas, H., (1987). The importance of technology policy. In: P. Dasgupta and P. Stoneman (Eds.), *Economic Policy and Technological Performance*. Cambridge University Press, Cambridge, pp. 51-96.

Fagiani, R., J.C. Richstein, R. Hakvoort and L. De Vries (2014). The dynamic impact of carbon reduction and renewable support policies on the electricity sector. *Utilities Policy* 28: 28-41.

Fais, B., M. Blesl, U. Fahl and A. Voß (2015). Analysing the interaction between emission trading and renewable electricity support in TIMES. *Climate Policy* 15(3): 355-373.

Fankhauser, S., Hepburn, C. and Park, J. (2010). Combining multiple climate policy instruments: How not to do it. *Climate Change Economics*, 1(3), pp. 209-225.

Finch, A., and J. van den Bergh (2020). Assessing the authenticity of national carbon prices. Unpublished working paper, ICTA-UAB.

Fischer C., and Fox A.K. (2012). Comparing policies to combat emissions leakage: border carbon adjustments versus rebates. *Journal of Environmental Economics and Management* 64:199-216.

Flachsland, C., M. Pahle, D. Burtraw, O. Edenhofer, M. Elkerbout, C. Fischer, O. Tietjen and L. Zetterberg (2019). How to avoid history repeating itself: the case for an EU Emissions Trading System (EU ETS) price floor revisited. *Climate Policy* 20(1): 133-142.

Font Vivanco, D., R. Kemp and E. van der Voet (2016). How to deal with the rebound effect? A policy-oriented approach. *Energy Policy* 94: 114-125.

Foramitti, J., Savin, I., and van den Bergh, J. (2021). Emission tax vs. permit trading under bounded rationality and dynamic markets. *Energy Policy*, 148, 112009.

Fowlie, M. (2009). Incomplete environmental regulation, imperfect competition, and emissions leakage. *American Economic Journal: Economic Policy* 1(2): 72-112.

Freire-González, J. (2018). Environmental taxation and the double dividend hypothesis in CGE modelling literature: A critical review. *Journal of Policy Modeling* 40(1): 194–223.

Freire-González, J. (2020). Energy taxation policies can counteract the rebound effect: analysis within a general equilibrium framework. *Energy Efficiency* 13: 69-78.

Geels, F., Sovacool, B. K., Schwanen, T., and Sorrell, S. (2017). Sociotechnical transitions for deep decarbonization. *Science* 357(6357), 1242-1244.

Gerlagh, R., S. Kverndokk and K.E. Rosendahl (2009). Optimal timing of climate change policy: Interaction between carbon taxes and innovation externalities. *Environment and Resource Economics* 43: 369-390.

Glaeser, E., and Ujhelyi, G. (2010). Regulating misinformation. *Journal of Public Economics* 94(3-4): 247–257.

Görlach, B. (2014). Emissions trading in the climate policy mix – understanding and managing interactions with other policy. *Energy & Environment* 25: 733-749

Goulder, L.H., and Schein, A.R. (2013). Carbon taxes versus cap and trade: A critical review. *Climate Change Economics* 04(03), 1350010.

Goulder, L.H. and Parry, I.W. (2008). Instrument choice in environmental policy. *Review of Environmental Economics and Policy* 2(2): 152–174.

Grülla, G., and L. Taschinibc (2011). Cap-and-trade properties under different hybrid scheme designs. *Journal of Environmental Economics and Management* 61(1): 107-118.

Gsottbauer, E., and J.C.J.M. van den Bergh (2014). Environmental policy when pollutive consumption is sensitive to advertising: Norms versus status. *Ecological Economics* 107: 39-50.

Hafstead, M. (2019). Carbon pricing 102: Revenue use options. Resources for the Future, September 26, 2019. https://media.rff.org/documents/Carbon_Pricing_Explainer_102.pdf

Haites, E. (2018). Carbon taxes and greenhouse gas emissions trading systems: what have we learned? *Climate Policy* 18(8): 955-966.

Handgraaf, M.J.J., Van Lidth de Jeude, M.A. and Appelt, K.C. (2013). Public praise vs. private pay: Effects of rewards on energy conservation in the workplace. *Ecological Economics* 86, 86–92.

Haultfœuille, X., Givord, P. and Boutin, X (2014). The environmental effect of green taxation: The case of the French bonus/malus. *The Economic Journal* 124: F444–F480.

Hepburn, C. (2006). Regulating by prices, quantities or both: an update and an overview. *Oxford Review of Economic Policy* 22(2): 226-247.

Herrmann, J.K., and Savin, I. (2017). Optimal policy identification: Insights from the German electricity market. *Technological Forecasting and Social Change* 122(C): 71-90.

Hilton, D., Charalambides, L., Demarque, C., Waroquier, L. & Raux, C. (2014). A tax can nudge: The impact of an environmentally motivated bonus/malus fiscal system on transport preferences. *Journal of Economic Psychology* 42, 17–27.

HLCCP (2017). *Report of the High-Level Commission on Carbon Prices*. World Bank, Washington D.C.

Hood, C., 2013: Managing interactions between carbon pricing and existing energy policies: Guidance for policymakers. http://www.indiaenvironmentportal.org.in/files/file/ManagingInteractionsCarbonPricing_FINAL.pdf

Hoppmann J., Peters M., Schneider M., Hoffmann V.H. (2013) The two faces of market support—how deployment policies affect technological exploration and exploitation in the solar photovoltaic industry. *Research Policy* 42(4): 989-1003

Howlett, M., and Rayner, J. (2007). Design principles for policy mixes: Cohesion and coherence in 'new governance arrangements. *Policy and Society* 26(4): 1-18.

Howlett, M., J. Vince and P. del Rio (2017). Policy integration and multi-level governance: dealing with the vertical dimension of policy mix designs, *Politics and Governance* 5(2): 69-78.

IMF (2019). Fiscal Policies for Paris Climate Strategies—from Principle to Practice. Fiscal Affairs Department, International Monetary Fund, Washington D.C.

Jacobsson, S., A. Bergek and B. Sandén (2017). Improving the European Commission's analytical base for designing instrument mixes in the energy sector: Market failures versus system weaknesses. *Energy Research & Social Science* 33: 11-20.

Jacoby, H. D. and Ellerman, A. D. (2004). The safety valve and climate policy. *Energy Policy* 32: 481-491.

Jaffe, A., R.G. Newell and R.N. Stavins (2005). A tale of two market failures: Technology and environmental policy. *Ecological Economics* 54(2): 164-174.

Jenn, A., I.L. Azevedo and J.J. Michalek (2016). Alternative fuel vehicle adoption increases fleet gasoline consumption and greenhouse gas emissions under United States corporate average fuel economy policy and greenhouse gas emission standards. *Environmental Science & Technology* 50 (5), 2165-2174.

Jenn, A., I.L. Azevedo and J.J. Michalek (2019). Alternative-fuel-vehicle policy interactions increase U.S. greenhouse gas emissions. *Transportation Research Part A: Policy and Practice* 124: 396-407.

Jordan, A., and A. Lenschow (2010). Environmental policy integration: A state of the art review. *Environmental Policy and Governance* 20(3): 147-158.

Jordan, A., D. Huitema, H. van Asselt and J. Forster (2018, eds.). *Governing Climate Change: Polycentricity in Action?* Cambridge University Press, Cambridge, UK.

Klenert, D., Mattauch, L., Combet, E., Edenhofer, O., Hepburn, C., Rafaty, R., & Stern, N. (2018). Making carbon pricing work for citizens. *Nature Climate Change* 8: 669–677.

Konc, T., I. Savin and J. van den Bergh (2021). The social multiplier of environmental policy: Application to carbon taxation. *Journal of Environmental Economics and Management* 105, 103396.

Lehmann, P. (2012). Justifying a policy mix for pollution control: A review of economic literature. *Journal of Economic Surveys* 26(1): pp. 71–97.

Lehmann, P., and E. Gawel (2013). Why should support schemes for renewable electricity complement the EU emissions trading scheme? *Energy Policy* 52: 597-607

Li, S., J. Linn and E. Muehlegger (2014). Gasoline taxes and consumer behavior. *American Economic Journal: Economic Policy* 6: 302-342.

Lindman, Å., and P. Söderholm (2016). Wind energy and green economy in Europe: Measuring policy-induced innovation using patent data. *Applied Energy* 179: 1351-1359.

List, J.A., Metcalfe, R.D., Price, M.K. & Rundhammer, F. (2017). Harnessing policy complementarities to conserve energy: evidence from a natural field experiment. NBER Working Paper No. 23355. doi:10.3386/w23355

Martin, B.R. (2012). The evolution of science policy and innovation studies. *Research Policy* 41(7): 1219-1239.

Masson-Delmotte, V., P. Zhai, H.-O. Pörtner, D. Roberts, J. Skea, P.R. Shukla, A. Pirani, W. Moufouma-Okia, C. Péan, R. Pidcock, S. Connors, J.B.R. Matthews, Y. Chen, X. Zhou, M.I. Gomis, E. Lonnoy, T. Maycock, M. Tignor, and T. Waterfield (2018, eds.). *Global Warming of 1.5°C.* An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels. IPCC, Geneva.

Matthies, E., Kastner, I., Klesse, A. and Wagner, H.J. (2011). High reduction potentials for energy user behavior in public buildings: How much can psychology-based interventions achieve? *Journal of Environmental Studies and Sciences* 1: 241-255.

Meckling,J., N. Kelsey, E. Biber, E. J. Zysman (2015). Winning coalitions for climate policy. *Science* 349: 1170-1171.

Mercure, J.-F., H. Pollitt, U. Chewpreecha, P. Salas, A.M. Foley, P.B. Holden, N.R. Edwards (2014). The dynamics of technology diffusion and the impacts of climate policy instruments in the decarbonisation of the global electricity sector. *Energy Policy* 73: 686-700.

Mizobuchi, K., and Takeuchi, K. (2013). The influences of financial and non-financial factors on energy-saving behaviour: A field experiment in Japan. *Energy Policy* 63, 775–787.

Mundaca, L., Sonnenschein, J., Steg, L., Höhne, N., Ürge-Vorsatz, D. (2019). The global expansion of climate mitigation policy interventions, the Talanoa Dialogue and the role of behavioural insights. *Environmental Research Communications* 1, 061001.

Murray, B.C., M.L. Cropper, F.C. de la Chesnaye, and J.M. Reilly (2014). How effective are US renewable energy subsidies in cutting greenhouse gases? *American Economic Review* 104 (5): 569-74.
Nisa, C. F., Bélanger, J. J., Schumpe, B. M., and Faller, D. G. (2019). Meta-analysis of randomised controlled trials testing behavioural interventions to promote household action on climate change. *Nature Communications* 10(1): 1-13.
Nyborg, K., R.B. Howarth and A. Brekke (2006). Green consumers and public policy: On socially contingent moral motivation. *Resource and Energy Economics* 28(4): 351-366.
OECD (2011). Interactions between emission trading systems and other overlapping policy instruments. General Distribution Document, Environment Directorate, OECD, Paris, www.oecd.org/env/taxes.
Oikonomou, V., and C. Jepma (2008). A framework on interactions of climate and energy policy instruments. *Mitigation and Adaptation Strategies for Global Change* 13(2): 131-156.
Oikonomou, V., A. Flamos, S. Grafakos (2010). Is blending of energy and climate policy instruments always desirable? *Energy Policy* 38 (2010) 4186-4195.
Osorio, S., R.C. Pietzcker, M. Pahle and O. Edenhofer (2020). How to deal with the risks of phasing out coal in Germany. *Energy Economics* 87, 104730
Palage, K., Lundmark, R. & Söderholm, P. (2019). The innovation effects of renewable energy policies and their interaction: the case of solar photovoltaics. *Environmental Economics and Policy Studies* 21: 217-254.
Panzone, L.A., Ulph, A., Zizzo, D.J., Hilton, D., Clear, A. (2018). The impact of environmental recall and carbon taxation on the carbon footprint of supermarket shopping. *Journal of Environmental Economics and Management*.
Pellerano, J.A., Price, M.K., Puller, S.L. and Sánchez, G.E. (2017). Do extrinsic incentives undermine social norms? evidence from a field experiment in energy conservation. *Environmental and. Resource Economics* 67, 413–428.
Perino, G., Panzone, L.A. and Swanson, T. (2014). Motivation crowding in real consumption decisions: Who is messing with my groceries? *Economic Inquiry* 52, 592-607.
Perino, G. (2018). New EU ETS Phase 4 rules temporarily puncture waterbed. *Nature Climate Change*, 8, 20: 262–264.
Perino, G., R.A. Ritz, and A. van Benthem (2019). Understanding overlapping policies: Internal carbon leakage and the punctured waterbed. NBER Working Paper No. 25643.
Philibert, C. (2009). Assessing the value of price caps and floors. *Climate Policy* 9: 612-633.
Pitelis, A.T. (2018). Industrial policy for renewable energy: The innovation impact of European policy instruments and their interactions. *Competition and Change* 22(3): 227-254.
Pizer, W.A. (1997). Prices vs. quantities revisited: The case of climate change. Discussion paper 98-02, Resources for the Future, Washington D.C.
Popp, D. (2002). Induced innovation and energy prices. *The American Economic Review* 92(1): 160-180.
Richstein, J.C., Chappin, É.J.L. and de Vries, L.J. (2015). Adjusting the CO_2 cap to subsidised RES generation: Can CO_2 prices be decoupled from renewable policy? *Applied Energy* 156, 693–702.
Roberts, M.J. and Spence, M. (1976) Effluent charges and licenses under uncertainty. *Journal of Public Economics* 5, 193-208.
Rogge, K.S. and K. Reichardt (2016). Policy mixes for sustainability transitions: An extended concept and framework for analysis. *Research Policy* 45(8): 1620-1635.
Rogge, K.S., Kern, F., Howlett, M. (2017). Conceptual and empirical advances in analysing policy mixes for energy transitions. *Energy Research & Social Science* 33, 1–10.
Rosenow, J., F. Kern and K. Rogge (2017). The need for comprehensive and well targeted instrument mixes to stimulate energy transitions: The case of energy efficiency policy. *Energy Research & Social Science* 33: 95-104.
Schall, D. L., Wolf, M. and Mohnen, A. (2016). Do effects of theoretical training and rewards for energy-efficient behavior persist over time and interact? A natural field experiment on eco-driving in a company fleet. *Energy Policy* 97, 291–300.
Schatzki, T., and R. N. Stavins, 2012: Implications of policy interactions for California's climate policy. 23 pp. https://www.analysisgroup.com/globalassets/content/insights/publishing/implications_policy_interactions_california_climate_policy.pdf
Schmidt, T.S. and S. Sewerin (2019). Measuring the temporal dynamics of policy mixes – An empirical analysis of renewable energy policy mixes' balance and design features in nine countries. *Research Policy* 48(10): 103557.
Schubert, C. (2017). Green nudges: Do they work? Are they ethical? *Ecological Economics* 132: 329-342.
Seto, K.C., S.J. Davis, R.B. Mitchell, E.C. Stokes, G. Unruh, and D. Ürge-Vorsatz (2016). Carbon lock-in: Types, causes, and policy implications. *Annual Review of Environment and Resources* 41: 425-452.
Sijm, J. (2005). The interaction between the EU emission trading scheme and national energy policy schemes. *Climate Policy* 5: 79–96.

Silvia, C. and Krause, R.M. (2016). Assessing the impact of policy interventions on the adoption of plug-in electric vehicles: An agent-based model. *Energy Policy* 96, 105–118.
Sinn, H.W. (2015). The Green Paradox: A supply-side view of the the climate problem. *Review of Environmental Economics and Policy* 9(2): 239-245.
Skovsgaard Aidta, T., and J. Duttab (2004). Transitional politics: emerging incentive-based instruments in environmental regulation. *Journal of Environmental Economics and Management* 47(3): 458-479.
Somanathan E., T. Sterner, T. Sugiyama, D. Chimanikire, N. K. Dubash, J. Essandoh-Yeddu, S. Fifita, L. Goulder, A. Jaffe, X. Labandeira, S. Managi, C. Mitchell, J. P. Montero, F. Teng, and T. Zylicz (2014). National and Subnational Policies and Institutions. Chapter 15 In: *Climate Change 2014: Mitigation of Climate Change.* Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Edenhofer, O., R. Pichs-Madruga, Y. Sokona, E. Farahani, S. Kadner, K. Seyboth, A. Adler, I. Baum, S. Brunner, P. Eickemeier, B. Kriemann, J. Savolainen, S. Schlömer, C. von Stechow, T. Zwickel and J.C. Minx (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.
Sorrell, S., and J. Sijm (2003). Carbon trading in the policy mix. *Oxford Review of Economic Policy* 19(3): 420-437.
Sorrell, S., D. Harrison, D. Radov, P. Klevnas and A. Foss (2009). White certificate schemes: Economic analysis and interactions with the EU ETS. *Energy Policy* 37(1): 29-42.
Stern, P.C. (1999). Information, incentives, and proenvironmental consumer behavior. *Journal of Consumer Policy* 22: 461-478.
Stern, P.C. (2020). A reexamination on how behavioral interventions can promote household action to limit climate change. *Nature Communications* 11(1): 1-3.
Sterner, T. (2002). *Policy Instruments for Environmental and Natural Resource Management*. RFF Press, Washington.
Sterner et al. (2019). Policy design for the Anthropocene. *Nature Sustainability* 2: 14-21.
Stiglitz, J.E. (2019). Addressing climate change through price and non-price interventions. *European Economic Review* 119: 594-612.
Sudarshan, A. (2017). Nudges in the marketplace: The response of household electricity consumption to information and monetary incentives. *Journal of Economic Behavior and Organization* 134, 320–335.
Thurber, M. C., T. L. Davis, and F. A. Wolak, 2015: Simulating the Interaction of a Renewable Portfolio Standard with Electricity and Carbon Markets. *The Electricity Journal* 28: 51–65.
Tinbergen, J. (1952). *On the theory of economic policy.* North-Holland Publishing Company, Dordrecht.
Tørnblad, S.H., Kallbekken, S., Korneliussen, K. & Mideksa, T.K. (2014). Using mobility management to reduce private car use: Results from a natural field experiment in Norway. *Transport Policy* 32, 9–15.
Trencher, G., and J. van der Heijden (2019). Instrument interactions and relationships in policy mixes: Achieving complementarity in building energy efficiency policies in New York, Sydney and Tokyo. *Energy Research & Social Science* 54 (2019): 34-45.
Tu, Q., and J.-L. Mo (2017). Coordinating carbon pricing policy and renewable energy policy with a case study in China. *Computers & Industrial Engineering* 113: 294-304.
Twomey (2012). Rationales for additional climate policy instruments under a carbon price. *The Economic and Labour Relations Review* 23(1): 7-31.
van den Bergh, J.C.J.M. (2011). Energy conservation more effective with rebound policy. *Environmental and Resource Economics* 48(1): 43-58.
van den Bergh, J.C.J.M. (2013a). Policies to enhance economic feasibility of a sustainable energy transition. *PNAS* 110(7): 2436-2437.
van den Bergh, J.C.J.M. (2013b). Environmental and climate innovation: Limitations, policies and prices. *Technological Forecasting and Social Change* 80(1):11-23.
van den Bergh. J.C.J.M., A. Angelsen, A. Baranzini, W.J.W. Botzen, S. Carattini, S. Drews, T. Dunlop, E. Galbraith, E. Gsottbauer, R.B. Howarth, E. Padilla, J. Roca, R.C. Schmidt (2020). A dual-track transition to global carbon pricing. *Climate Policy* 20(9): 1057-1069.
van der Ploeg, R., and C. Withagen (2015). Global warming and the green paradox: A review of adverse effects of climate policies. *Review of Environmental Economics and Policy* 9(2): 285-303.
Venmans, F., J. Ellis and D. Nachtigall (2020). Carbon pricing and competitiveness: are they at odds? *Climate Policy* 20(9): 1070-1091.
Vilchez, J.J., P. Jochem, W. Fichtnera (2020). Interlinking major markets to explore electric car uptake. *Energy Policy* 144, 111588
Way, R., F. Lafond, F. Lillo, V. Panchenko, D. Farmer (2019). Wright meets Markowitz: How standard portfolio theory changes when assets are technologies following experience curves. *Journal of Economic Dynamics and Control* 101: 211-238.
Weitzman, M. L. (1974). Prices vs. quantities. *Review of Economic Studies* 41(4): 477-491.

Weitzman M.L. (2014). Can negotiating a uniform carbon price help to internalize the global warming externality? *Journal of the Association of Environmental and Resource Economists* 1: 29-49.

Weitzman, M. L. (2017). On a world climate assembly and the social cost of carbon. *Economica* 84(336): 559-586.

Whistance, J., W. Thompson, and S. Meyer (2017). Interactions between California's Low Carbon Fuel Standard and the National Renewable Fuel Standard. *Energy Policy* 101: 447–455.

Wiese, C., A. Larsen and L.L. Pade (2018). Interaction effects of energy efficiency policies: a review. *Energy Efficiency* 11: 2137–2156.

Wynes, S., Nicholas, K.A., Zhao, J., Donner, S.D. (2018). Measuring what works: quantifying greenhouse gas emission reductions of behavioural interventions to reduce driving, meat consumption, and household energy use. *Environmental Research Letters* 13, 113002.

Zeppini, P., and J. van den Bergh (2020). Global competition dynamics of fossil fuels and renewable energy under climate policies and peak-oil: A behavioural model. *Energy Policy* 136, 110907.