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Designing Instrument Packages for the Low-Carbon Transition: An Evaluation Framework with an Application to Austria

Abstract

Limiting global warming to no more than 2°C requires global large-scale deployment of low-carbon and negative emissions technologies. This requires the development of new eco-innovations and the diffusion of new and existing ones. Existing portfolios of environmental and technology policy instruments, however, may not be up to this task. In this paper, we develop an evaluative framework for the assessment of existing and new policy instruments for the successful development and deployment of eco-innovations. Our evaluative framework considers focus, scope, strictness, coherence and timing as key criteria for the evaluation of policy instruments for the transition to a low-carbon economy. We apply our framework to the residential and commercial (buildings) sector in an ambitious country, Austria.

JEL-Codes: H230, Q540, Q580.

Keywords: climate change mitigation policy, policy instruments, eco-innovation.

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1 Introduction

Limiting global warming to no more than 2°C has become the *de facto* target for global climate policy (IPCC, 2018). For instance, the European Union has recently committed to a so called Climate Law that sets an EU's strengthened target of at least 55% emissions reductions by 2030 compared to 1990 and the its commitment to climate-neutrality by 2050. Such ambitious targets require countries to also introduce ambitious transition policies. Indeed, several countries have set domestic targets for a transition to a low-carbon economy. Also Austria, with its high share of renewable energy, aims at a reduction of its greenhouse gas emissions by 36% compared to 2005 and to cover 100% of total electricity consumption (national balance) from national renewable energy sources by 2030 (European Commission, 2018; BMNT and BMVIT, 2018). In its recent government declaration, Austria set itself the target of climate neutrality by 2040, currently the most ambitious target in the EU (Austrian Government, 2020).

Dramatic emission reductions require mass-deployment of low-, zero- and negative emission technologies in all sectors of the economy. This requires firms and sectors in these countries to adapt in ways that are likely to imply the end of currently profitable business models. For instance, leading international firms whose business models are based on the use of carbon-intensive technologies need to transform themselves into clean firms (Fankhauser et al., 2013). Eco-innovation plays a crucial role in the transition to a decarbonised economy. Indeed, invention, innovation and diffusion of low-carbon technologies (including zero- and negative emissions technologies) are crucial for the global community to meet the 2°C target (IPCC, 2018). Without government intervention, however, it is unlikely that emission reductions and eco-innovations will be supplied by the market at a level that matches those ambitions due to the underlying market failures (Jaffe et al., 2005; Popp et al., 2010; Acemoglu et al., 2012).

Government policies hence play an important role in the transition process. The objective of this paper is to develop an evaluative framework for policymakers to assess the potential of existing and new environmental and technology policy instruments to support the transition towards a decarbonised economy. The development and large-scale adoption of low-, zero- and negative emission eco-innovations are necessary to contribute to the reduction of greenhouse gas (GHG) emissions as agreed upon in the Paris Agreement.

Under which conditions would one expect a reduction in GHG emissions or an increase in the rate of development and diffusion of eco-innovations as a result of a change in the set of policy instruments? That is, how does (national) policy affect domestic emissions and eco-innovation, and which policy instrument (package) would be best to support this process in a specific country? We argue that the mechanism underlying this process is the change in behaviour by firms or other agents as a result of an (intended) policy change, for example a change in an (emission) price or a policy standard. This behavioural change reduces emissions and speeds up the process of directed technological change through new inventions or the diffusion of already known technologies (or both) which better match the new policy incentives. These additional eco-innovations, in turn, would reduce emissions at home but could also increase the potential of an economic sector to be(come) internationally competitive. While the existing potential for eco-innovation is likely to be the result of environmental and technology policy instruments applied in the past, new potentials may arise due to new or revised instruments that aim to reduce emissions.

In the next section, we first discuss the idea that environmental and technology policy instruments are key to inducing technological change towards a decarbonised economy. We also explain how policy instruments may correct for the set of market failures relevant for the current transition to a decarbonised economy. Section 3 introduces our evaluative framework to assess policy packages that aim to incentivize transitions to decarbonisation, in particular by stimulating eco-technologies in a specific country. Next, we present key information on the residential and commercial sector in Austria before applying make our framework. Section 5 applies our framework to this non-exposed sector that is key to the Austrian transition towards decarbonisation. Section 6 concludes.

2 Transitions, eco-innovation and market failures

2.1 The low-carbon transition as a process of inducing technological change

Our goal for the evaluative framework is to guide policymakers in their choice of a set of policy instruments or policy package that supports the transition towards an economy that should be decarbonised in, say, 2050. Our framework comprises a set of questions that provides guidance in choosing an appropriate set of policy instruments that reduces GHG emissions and induces technological change towards a decarbonised economy. To understand why properly designed policy changes would contribute to further development and implementation of technologies that direct the economy towards less carbon emissions, it is essential to understand how policy instruments (or their absence) affect technological change.

Technological change plays a driving role in capitalism and economic growth (Aghion and Howitt, 2009). Schumpeter (1942) distinguishes three phases in the process of technological change. The first two phases are invention and innovation, where an invention is the first idea for a new technology, product or process, and innovation is the development of inventions into new technologies, products or processes that can be sold on the market.

An important driver behind the efforts of inventors and innovators is to earn back their initial investment, e.g. by earning rents from their patented inventions. Indeed, when a patent gets granted to an invention, its owner obtains a temporary monopoly on the technology. As shown by Acemoglu (2002), such a monopoly will earn higher returns when the market for a technology is likely to be larger, i.e. when more products can potentially be sold, and when the relative price for the good that uses the technology is higher, i.e. higher profit margin per unit of product. These effects are called the market size and price effect, respectively.

Consequently, technological change will also be directed towards sectors where the market size effect and price effect are (expected to be) largest. This implies that large, monopolistic sectors attract more innovation than new technologies such as clean technologies in the case of climate change: not only is the market for clean technologies often smaller than that for dirty technologies (e.g. internal combustion engine vs. electric vehicles), there is also path dependency in the direction of technological change as firms that have innovated in dirty technologies in the past will find it profitable to continue to do so, rather than innovate in clean technologies (Acemoglu et al., 2012; Aghion et al., 2016).

The third phase in the process of technological change is diffusion, which is the process of adoption by multiple actors of the new innovations that have been proven at commercial scale. This relates to the market size effect mentioned above: the higher the adoption rate of a (clean) technology (e.g. the electric vehicle), the larger the potential market size for new inventions and innovations for this technology (e.g. improved batteries for electric vehicles).

This so-called path dependency of technological change is one explanation of the current lock-in into fossil fuel technologies and the slow transition towards a decarbonised society. The large existing markets for fossil-based technologies provide more incentives for invention, innovation and diffusion than the often much smaller markets for eco-innovations. In the next subsections we argue that these effects get exacerbated by failures in the markets for invention, innovation and diffusion as well as by environmental market failures, and that both technology policy and environmental policy instruments are needed to redirect technological change towards eco-innovations.

2.2 Market failures and motivation for policy instruments

As argued above, eco-innovations will be developed only when innovators deem it profitable to do so. However, the return on investment for *eco*-innovations is typically lower at the firm level than at the level of society, as such investments suffer from two types of market failures (Jaffe et al., 2005, Popp et al., 2010). The first type is the environmental market failure related to the production of emissions such as greenhouse gases that cause climate change. The second type of market failure is related to technological change.

If producers (or consumers) cause environmental damage through carbon emissions which is not reflected in their private decisions, they choose a production (or consumption) level that provides the greatest benefit to themselves but not to society. This negative externality is a market failure. To get closer to the social optimum, which is implicitly reflected in the policy goal of zero carbon emissions, damage costs should be included in the decisions of market participants to achieve this social optimum.[1] Relative to the initial situation, social welfare would then increase because polluters reduce emissions in response to these new incentives. In the absence of policies that reduce the level of emissions to the socially optimal level, dirty technologies prosper as their emissions are under-priced and therefore the market sizes for these technologies are larger than their socially optimal levels. This, in turn, provides larger incentives for dirty innovations than for eco-innovations and hampers a transition to a decarbonised society.

The second type of market failure is related to the process of technological change (see also Popp et al., 2010). First, new inventions typically generate *positive knowledge spillovers* from the inventor to society (Arrow, 1962). Due to its public good characteristic – if I invest in new knowledge, others are also likely to benefit from the new knowledge without paying for it – typically, too little invention would occur from existing market incentives only. Second, positive externalities exist related to *learning by using or doing* in the production or consumption of a new technology, which is typically related to the diffusion phase of a new technology. For example, it has been shown long ago that the production of a new type of airplane becomes cheaper as more units have been produced (Wright, 1936) and this effect has been demonstrated to be relevant often since (e.g. Popp, 2019). Third, *imperfect diffusion of knowledge about new technologies* may exist amongst actors in the market. Various studies show that the probability of adopting a new technology is positively affected by the proximity of agents that have already adopted the new technology (see Allan et al., 2013). Finally, new technologies may also suffer from *network externalities*. With network technologies, consumption benefits depend on the number of users of the same network (Katz and Shapiro, 1985, Gandal, 2002). They play a role for instance for the diffusion of plug-in electric and fuel cell electric vehicles: the benefit of owning such a vehicle increases in the number of other uses because the total number of users affects the incentives for providers to supply a network of charging stations (see e.g. Greaker and Midttømme, 2016).

2.3 Instruments to address externalities and their interactions

To incentivize the low-carbon transition properly, policies should be implemented to address these market failures (Popp et al., 2010). In doing so, they should also take into account the smaller current market size for eco-innovations as compared to dirty innovations. Indeed, a shift in current incentives is required to induce a shift in investment away from CO_2-emitting technologies towards zero- and even negative emission technologies.

As is well-known, emission reductions can be induced through various environmental policy instruments that address the environmental externality, such as emission standards or pricing of emissions. A tax on emissions for instance would require a payment by the emitter for every

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[1] Ideally, the optimum would be found exactly at the point where the benefit of further damage reduction no longer offsets the further loss of (net) private benefits. Here the emission level is ‘optimal’.

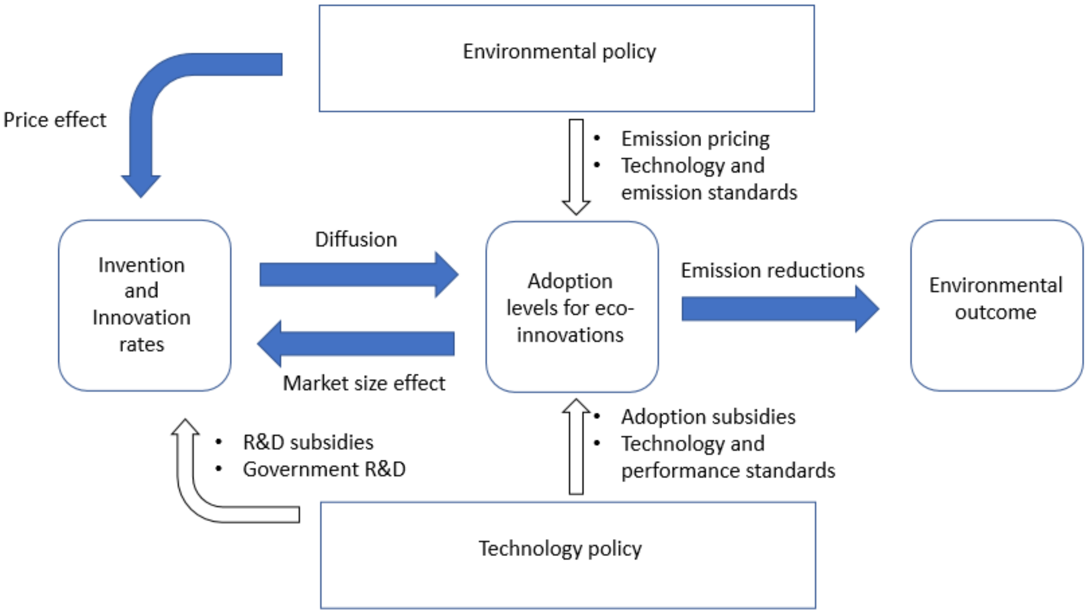
unit of emissions, while standards specify an amount of emission per unit of output to which the emitter should adapt. The level of stringency will determine whether the socially optimal level of emissions will be achieved, while the choice of the instrument itself will determine the social cost of achieving the resulting emission levels. The social optimum could indeed be achieved when producers or consumers react by reducing emissions to minimise their payment of emission taxes or comply with the standard. They can achieve this by cutting their emissions using the cheapest available abatement technologies or through behavioural options. Key to these changes, however, is a government intervention that imposes restrictions by pricing in the free use of environmental goods. Note that also standards restrict behaviour and therefore induce additional cost to firms and consumers.

Importantly, environmental policy instruments also affect the process of technological change (see Figure 1). This is true for all types of instruments. For instance, command-and-control instruments, such as technology mandates or emission standards, either encourage the adoption of eco-innovations or even make them compulsory. This increases the incentives for invention and innovation through the market size effect if a new eco-innovation becomes the technology that forms the basis of a new standard (Dekker et al., 2012). Also price instruments, such as an emission tax or cap and trade, provide an incentive to adopt eco-innovations (which increases the market size effect) and reduce the profit margin for dirty technologies, thereby reducing the price effect for these technologies and making investments in eco-invention and eco-innovation relatively more profitable. Environmental taxes and auctioned tradeable permits provide strong additional incentives for R&D because the polluter still has to pay for the remaining emissions, which is not the case for standards and grandfathered permits. Therefore, suppliers of eco-innovation face the option to expand their market by developing new technologies as long as their technologies may become accepted by more stringent (future) standards or permits (Vollebergh and Van der Werf, 2014).

Technology policy instruments affect the process of technological change itself by changing the incentives for invention, innovation and diffusion. Moreover, the different technology policy instruments also interact. For instance, subsidies that mitigate market failures related to the adoption or diffusion of a new eco-innovation also provide incentives for new inventions and eco-innovations. For example, an adoption subsidy for battery-electric vehicles increases the market size for inventors of improved batteries.

Technology policy instruments can either be generic or targeted. Generic instruments, such as patent laws and wage subsidies for R&D, typically focus at invention and innovation and support environmental policy objectives if the resulting innovations are indeed eco-innovations. Targeted technology policy instruments can be directed at the R&D phase (such as specific R&D subsidies) or at the diffusion phase (such as subsidies or tax expenditures for renewable energy technology adoption, or tradable renewable energy certificates combined with a renewable energy portfolio standard). If aimed specifically at eco-innovations, these instruments can also support the objectives of environmental policy (OECD, 2013).[2]

Figure 1. The interaction between environmental policy, technology policy, and the process of technological change.



Note: Dark arrows indicate processes; light arrows indicate policies.

Policymakers can also use standards as complements to these technology policy instruments (Vollebergh and Van der Werf, 2014). For network technologies, compatibility of devices is an important issue. When multiple specifications for plugs and sockets for plug-in electric vehicles are available, a consumer runs the risk of not being able to charge her car at a given charging station. This reduces the likelihood of adopting the technology. Government intervention in the standardization process for compatibility and interface standards may then be necessary to limit the number of available specifications, perhaps even to one, in order to prevent a potentially superior technology (vis-à-vis existing technologies) from failing (Katz and Shapiro, 1985, David, 1987).

Design of instrument (packages) is also related to the spatial dimension of the externalities, i.e. to what extent border crossing of both environmental and technology spillovers matters. On the one hand, climate change is notably insensitive to where GHGs are emitted, which complicates unilateral measures and is likely to give rise to carbon leakage (Hoel, 1991). On the other hand, countries could benefit from technology spillovers in various ways. For example, firms are likely to invest in new knowledge on eco-technology if a country imposes

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[2] Note that environmental gains from eco-innovations could be (partially) offset through behavioural responses such as the rebound effect (see e.g. Gillingham et al., 2016) and the green paradox (see e.g. Van der Werf and Di Maria, 2012).

more stringent measures. Next, other countries might benefit from those investments when they impose similar restrictions later on (Dekker et al., 2012).

We conclude that without government intervention, a transition to a decarbonised society would suffer from both environmental externalities (which implies a market price for emissions to be too low or even zero) and technology spillovers (positive externalities from the generation of new knowledge, learning by doing, network externalities, and the diffusion of technology knowledge). As eco-innovations suffer from multiple market failures (an environmental externality and at least one of the technology spillovers), multiple instruments are also required to correct for these externalities. Hence, a portfolio of instruments could be created in which the environmental policy instrument addresses the environmental externality and technology policy instruments address the relevant dynamic spillover(s). Indeed, such an instrument portfolio when properly designed could reduce emissions at lower costs than a single policy instrument (e.g. Fischer and Newell, 2008).

3 An evaluative framework for the selection of policy instruments: focus, scope, strictness, coherence and timing

3.1 Designing policy packages for the low-carbon transition

In an ideal world of economic policy, instruments could be designed in such a way that they fully address the environmental and technological externalities and their interactions as discussed in the previous section (see also Newell et al., 2005). In practice, however, many reasons exist why instruments or packages of instruments are difficult to implement. Practical design issues, such as who should pay what on which basis and when, are relevant to understand why large differences exist between optimal policy instruments in theory and instruments implemented in practice. Also, for newly designed packages or instrument (package) reform it matters whether environmental and technology policy instruments are already being used by policymakers to correct for these market failures (OECD, 2007, 2010). Indeed, first-best instruments are usually impossible to implement due to transaction costs, multiple externalities or overlapping impacts, industry lobbying and political compromise (Keohane et al., 1998; Hahn, 1995).

To help policymakers with the design of policy instruments for a decarbonised economy, we consider *five main design and context features* that are essential ingredients for providing relevant advice on new instruments or instrument packages. We use a standard goal-instrument perspective as we believe this is particularly helpful to keep track of a systematic representation of how effects or impacts are linked to which interventions, even in the case of complex interactions (Keeney and Raiffa, 1993).

The starting point of our framework is the extent to which the environmental or technology policy instrument is targeted towards its objective, i.e. its *focus* or ‘operational goal’. In the case of climate change, for instance, one would expect that an environmental policy instrument is targeted at the physical reduction of GHG emissions and not on carbon emissions alone. Such a policy instrument should be designed such that it targets those emissions as directly as possible, based on a proper *physical* relationship between emission and incentive. Although targeting may seem obvious in a simple world of one externality where information is available for free – the standard Pigovian case in economics – it is far from obvious in practice (Vollebergh, 2012).

For instance, GHG emissions from industry or energy generation can be priced directly (using a tax or a cap-and-trade system), as these emissions are relatively easy to monitor. However, in other sectors (e.g. agriculture or forestry), emissions are much harder to measure. The instrument could then address emissions indirectly, for example by focussing on inputs or production processes and using standards and other forms of direct regulation rather than a price instrument. Hence, an instrument with a very strong focus, such as a direct emission tax on all GHGs, is not always the first-best instrument (Cremer and Gahvari, 2002).

Similarly, a subsidy for eco-innovation could address the positive externalities from new knowledge through generic R&D support, or address the learning externality of a new technology through a focussed subsidy or policy standard (e.g. building codes) to support the diffusion of that specific technology. Furthermore, if the policymaker has a particular technology in mind, the technology readiness level of that technology and the presence or absence of network externalities also affect the focus of the instrument.

The second feature is the *scope* of the instrument: the extent to which an instrument covers the existing externalities. Ideally, the scope of an environmental policy instrument aimed at reducing GHG emissions would be all GHGs emitted by all actors (all sectors) in an economy. A general tax on all GHG emissions in an economy, expressed as a monetary amount per ton of CO_2-equivalent, has a much broader scope than the EU Emission Trading Scheme for GHGs (EU ETS), which covers only part of the EU economy and not all GHGs. Similarly, a general R&D subsidy has a much broader scope than a scientific research grant for, e.g., air carbon capture. In case of an emissions tax, the base of the tax determines its scope: the more exemptions are awarded to particular sectors or goods (e.g. a carbon tax that exempts coal for electricity production), the smaller the tax base and the narrower the scope of the instrument.

Third, the *strictness* of the instrument is an important design feature. In general, the level of a tax rate or a subsidy is likely to determine to a large extent how specific interventions influence the incentives for firms and households to reduce emissions or adopt a technology (OECD, 2010). Also, the strictness of an emission reduction standard determines how much action a firm is likely to undertake when implemented. Importantly, the actual enforcement of the policy will determine to what extent action will be undertaken. Strictness is also strongly related to the international dimension explained in section 2.3. Trade-offs exist when strict unilateral instruments – such as a high local carbon tax – are used in a small open economy setting: emissions might be reduced at home, but rise abroad. Such outcomes may be prevented by intelligent design of instruments such as a marginal carbon tax, i.e. a tax on the marginal emissions instead of on entire emission range or other compensating measures such as subsidies or carbon border adjustments (Cosbey et al., 2019).

The fourth feature is related to the context in which the instrument is implemented: existing or newly designed policy instruments may interact and require *coherent* implementation. Coherent implementation takes stock of potential complementarities and overlap of instruments to avoid inefficiencies. Since the transition towards decarbonisation faces multiple market failures (an environmental externality and the dynamic spillovers), multiple instruments are needed. If each instrument addresses a different externality, these instruments *complement* each other. For example, an eco-innovation with characteristics of a network technology will require environmental policies for competing polluting technologies and an adoption subsidy. In addition, non-environmental standards (such as compatibility and interface standards) are important for network technologies. Some polluting activities cause multiple pollutants, such as emissions from internal combustion engines, where damages can even be related to emissions in a non-linear way, e.g. when the location and timing of emissions matter (city centre, rush hour). In such cases, input (e.g. gasoline) pricing can be combined with technology standards to fine-tune regulation.

Using multiple instruments, however, is not always a guarantee for optimal policies, in particular if they directly or indirectly *overlap* with each other, which might reduce their combined impact in terms of effectiveness and efficiency. A well-known example related to the overlap of local and internationally enforced policy instruments is the waterbed effect resulting from the interaction between the (pre-2018) EU ETS and domestic policies like a subsidy for the adoption of renewable energy technologies (Böhringer et al., 2009).[3] Although the two instruments address different market failures (negative externalities from GHG emissions and positive externalities from technology adoption, respectively), their combined impact reduces demand for electricity from fossil fuels, which in turn is likely to lower the (expected) price in the cap and trade system without reducing additional emissions. Combining instruments might then call for a tighter cap (increased strictness) in the cap-and-trade system. Furthermore, adjusting or abolishing existing instruments may improve the effectiveness of a new instrument or make it redundant.

Finally, the *timing* of the instrument matters. In a dynamic environment with an explicit aim to stimulate the transition to decarbonisation, it is important to introduce instruments at the right

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[3] Another example in the context of EU ETS is the crowding out effect of an additional carbon tax within EU ETS (Brink et al., 2016). Currently, the interaction between local policies and the EU ETS is much more complicated due to the implementation of new rules that govern the Market Stability Reserve (see e.g. Perino, 2018).

moment in time and in a proper sequence. For instance, if one introduces a rather strict emission tax when abatement options are few, the social cost of such a policy might be quite high (e.g., Acemoglu et al., 2012). Such considerations are particularly relevant for coalitions of countries that aim to address global externalities such as climate change. Also, if an instrument is completely novel to policy makers and stakeholders, as was the case with emission trading for GHGs in the EU in 2005, a test phase might be indispensable. Phasing in of an instrument might also be necessary to obtain support from crucial stakeholders. Diffusion subsidies may need to decline over time, as the positive externalities they are supposed to correct become smaller with increased adoption of the technology (Bollinger and Gillingham, 2019; Nemet, 2012). A very strict instrument could be announced in advance with the explicit objective of triggering new innovations (technology forcing; Gerard and Lave, 2005). The timing of instruments at home should also consider which policy instruments other countries, within or outside a common coalition, implement at what date.

3.2 A set of evaluative questions for the design or reform of instruments

Based on these five design and context features, we define our evaluative framework for policymakers to guide their decisions regarding the implementation of new or reformed policy instrument packages for decarbonisation, taking stock of the existing policies and their impacts. Our evaluative framework consists of five questions that explicitly refer to each of the design and context features discussed above:

1. Is the *focus* of the instrument (package) appropriately targeted?

That is, which operational goal is the target of the instrument(s), and to what extent do(es) the instrument(s) address this goal directly? The question serves to assess whether a particular environmental or technology policy instrument (or policy package) is appropriately targeted towards its objective, in this case decarbonisation or the reduction of all relevant GHG emissions.

2. To what extent does the *scope* of the instrument (package) cover the operational goal?

Here we distinguish between (a) the *environmental scope* and (b) the *technological scope*. For the environmental scope the question is: to what extent is the environmental externality properly covered by the instrument(s) in terms of the regulatory base? For the technological scope, the question to be answered is to what extent do the instruments cover the technological spillovers? Unilateral action, international value chains and networks should also be considered.

3. Is the *strictness* of the instrument (package) in line with the operational ambition?

What degree of strictness does the instrument provide, i.e. what is the level of the tax rate, subsidy level or standard relative to the status quo? To what extent does this strictness provide incentives that are in line with political and social ambitions towards the operational goal of the instrument (package)? Cross-border impacts are relevant here too.

4. Is the instrument a *coherent* addition to existing and other instruments of the overall package?

The question is whether the proposed instrument(s) and the existing instruments can form a portfolio of *complementary* instruments without inefficient *overlap*. Indeed, answering this question should also answer the question whether a new policy instrument is necessary in the first place or whether existing instruments should be adjusted. This question also considers existing instruments implemented by multi-level government units such as a federation or a group of coordinating countries such as the European Union.

5. Is the *timing* of the instrument (package) appropriate?

Finally, the question of choosing a proper time path should be assessed as well. To what extent is it necessary and possible to phase in a particular instrument? In case of an instrument that interacts or overlaps with an international policy instrument: is it possible to coordinate with other countries as to when to implement particular instruments? Should a particular instrument have a testing phase, or should it be implemented as soon as possible? And should the instrument be assessed on a regular basis (because the positive spillover it is supposed to correct becomes smaller over time, e.g. due to increased adoption), or, in the extreme: should the law that introduces the instrument have a sunset clause?

Answering these questions simultaneously would allow policymakers to design a policy package that is both effective and (dynamically) efficient. Instead of only focusing on carbon pricing to take stock of the environmental failures, such a package should also incentivize the transition to decarbonisation in a specific country by exploiting eco-innovation options of that country as effectively as possible.

4 An application to Austria: key descriptive indicators for decarbonisation in the residential and commercial sector

We apply our evaluative framework to a case study of the residential and commercial sector (homes and other buildings) in Austria. The country has set itself the target of climate neutrality by 2040, currently the most ambitious target in the EU (Austrian Government, 2020). At the same time, Austria is one of the few EU countries whose total GHG emissions have increased rather than decreased since 1990 (European Environment Agency, 2020). Further action is therefore necessary, also considering the European Commission’s ambition to raise the 2030 climate target (European Commission, 2020). Moreover, the residential and commercial sector is considered one of the key sectors in terms of emission reductions for a low-carbon transition by policymakers in Austria (BMNT, 2019a).

Before being able to provide context-specific answers to the five questions of the evaluative framework described above in the Austrian case, it is essential to take stock of three key indicators of the potential transition. Together these indicators provide a comprehensive description of the status quo (see Appendix). First, it is important to identify which sectors are responsible for which part of current emissions and are most likely able to contribute to emission reductions. Second, sectoral innovation rates should be identified. Sectors within a country differ in their current innovation intensity because countries tend to specialize in certain areas, particularly in response to past policies (or their absence). Finally, an overview of the focus, scope and strictness of existing environmental and technology policy instruments is necessary. This section explains this descriptive information for Austria in more detail.

4.1 Greenhouse gas emissions and fossil fuel use in Austria

As shown in Figure 2, the sectors responsible for most GHG emissions in Austria are energy generation and industry, followed by transport and the residential and commercial sector. Energy and industry are mainly covered by the EU Emission Trading System (ETS). Outside the EU ETS, the residential and commercial sector is Austria's second largest in terms of GHG emissions and therefore plays a major role in the current national policy debate.[4] The sector emitted 16.1% of the country's greenhouse gases outside the ETS in 2017 (Anderl et al., 2019). Although emissions from the sector declined by about 33% in Austria since 2005, the trend has been upwards again since 2014. According to Austria's National Energy and Climate Plan submitted to the European Commission in 2019, national policymakers see potential for reducing emissions in the sector by a further 37% until 2030 to help achieve the country's current emission reduction target for the sectors outside the EU ETS (BMNT, 2019a). The recent declaration of the Austrian Government (2020) contains a range of measures to reduce emissions in the sector, primarily by increasing the renovation rate, phasing out fossil-fuelled heating systems and making zero-emission buildings the standard in building codes.

The main sources of final energy use in the residential and commercial sector in Austria are, according to Sporer (2019), electricity (30%), biomass (19%), natural gas (18%), district heating (16%) mineral oil (13%) and geothermal/solar/ambient heat (4%). Note that energy from electricity and district heating does not cause emissions in the residential sector, but rather in the energy sector and industry, respectively. Consumption of electricity, district heating, biomass and geothermal/ solar/ambient heat has increased since 2005, while consumption of natural gas and mineral oil has declined.

Besides fossil-fuelled space heating systems, low-quality thermal insulation of buildings is a key driver of (fossil) energy use in the residential and commercial sector. Currently, the thermal

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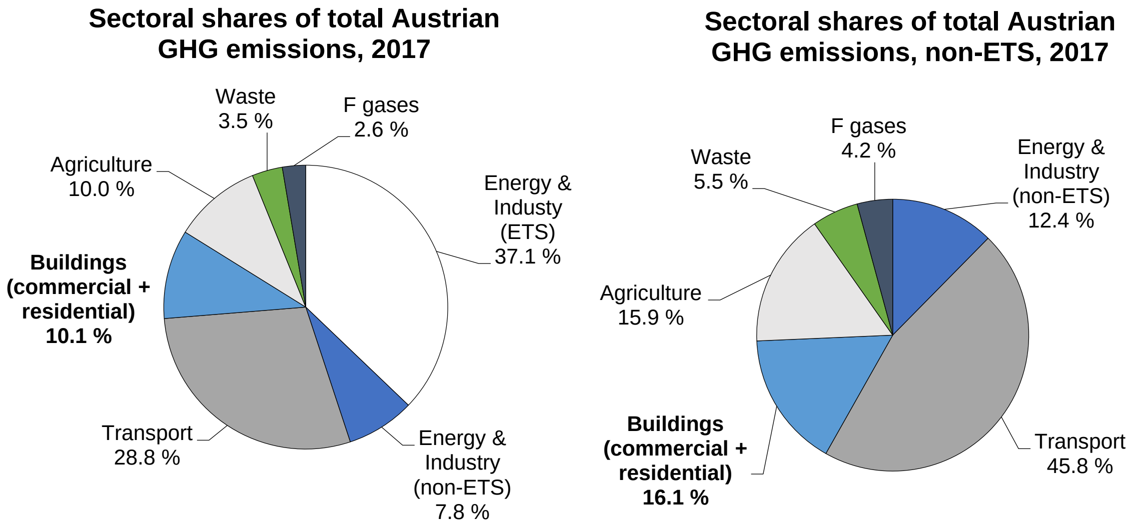
[4] The sector classification for reporting GHG emissions under the UNFCCC is defined in IPCC (2006).

standard of roughly 40% of residential buildings is considered insufficient. Therefore, in addition to exchanging heating systems for renewables, at least a doubling of the renovation rate is recommended in order to decarbonise the Austrian building stock by 2040 (Amann et al., 2020).

Figure 2. Key GHG emission sectors in Austria in 2017 (%).



Source: Adapted from Anderl et al. (2019)

4.2 Eco-innovation performance of Austrian emission sectors

To gain insight into Austria's eco-innovation performance in different emission sectors, we compute indices of revealed comparative advantage (RTA). This index captures one country's specialisation in a particular technology compared to all other countries and can therefore be used to measure countries' relative technological specialisation (see Appendix for details). To construct the RTA index, we use data on patent applications by climate change mitigation technologies in different emission sectors from the OECD environment statistics database (OECD, 2016, 2020; see Table A1 in the Appendix for the list of technologies).[5] We present time-averaged RTA indices over the period from 2010 to 2016, the latest year for which data are available. Using averages helps smooth out the jumpiness of data on patent applications (e.g. two in one year, zero in the next two).

Figure 3 shows RTA indices by emission sectors for Austria, Germany and the Netherlands. For all emission sectors considered together (top bars), Austria's RTA equals 0.95 on average between 2010 and 2016, indicating a revealed technological disadvantage in climate change mitigation technologies compared to the rest of the world. From the RTA indices for individual

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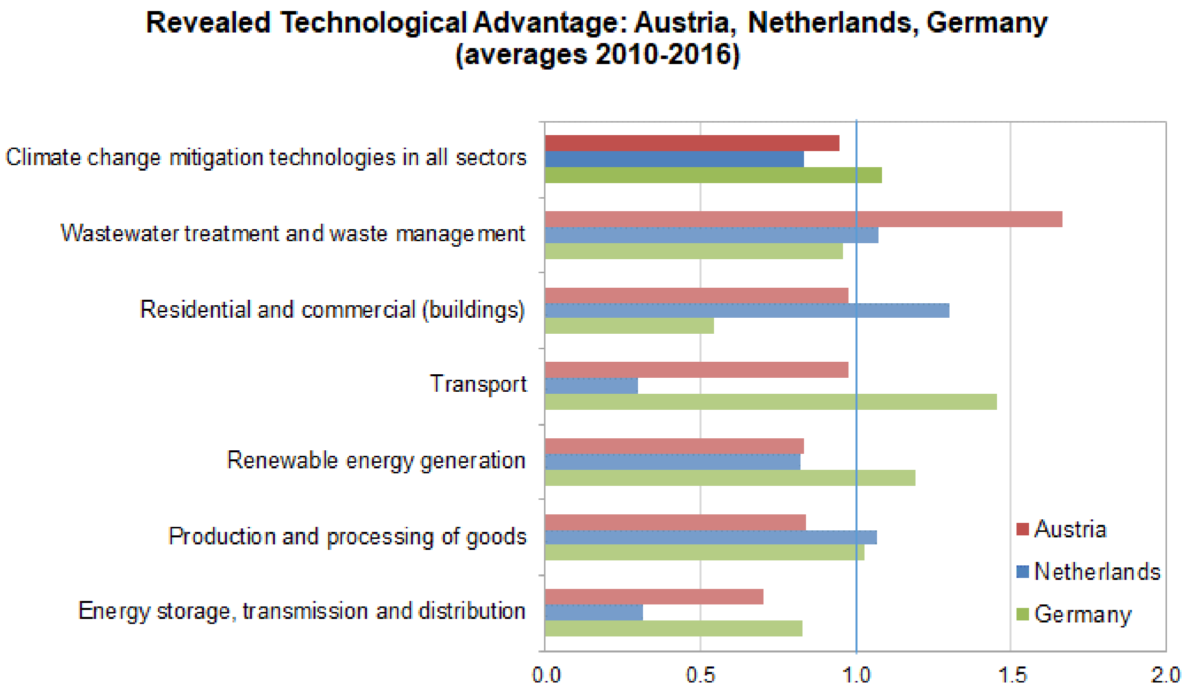
[5] The data refer to the number of patents applied for by a country's inventors, independent of where patent protection is sought (i.e. all jurisdictions worldwide). The patents are presented by country of inventor, priority date and patent family size, which refers to the number of patent applications protecting the same priority filing worldwide. In this paper, a patent family size of three or greater is chosen, covering only those inventions for which patent protection is sought in at least three jurisdictions worldwide, to capture higher-quality patents.

emission sectors (lighter bars), it is apparent that the country's main strength lies in technologies related to the waste sector, where the RTA value of 1.7 indicates a strong technological specialization. This is largely driven by reuse, recycling and recovery technologies, particularly of plastics and paper.

Figure 3. RTA indices in climate change mitigation technologies by emission sectors according to the OECD ENV-TECH classification (OECD, 2016), averages 2010-2016.



Note: Index values above 1 indicate a revealed technological advantage in technologies related to a given emission sector. Darker shades (top bars) represent all emission sectors on aggregate, lighter shades (bars below) indicate technologies related to individual emission sectors.

In climate change mitigation technologies related to the emission sectors residential and commercial buildings, transport, energy[6] and the production and processing of goods – which includes industry and agriculture – Austria's average RTA indices take on values equal to or less than 1. This indicates that on aggregate, the country either enjoys no technological advantage in these fields or is even at a technological disadvantage compared to the rest of the world. However, sub-fields with RTA values above 1 exist in all sectors (not shown).

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[6] For illustrative purposes, energy technologies are split into their two main components in the figures, namely those related to renewable energy generation and those related to energy storage, transmission and distribution.

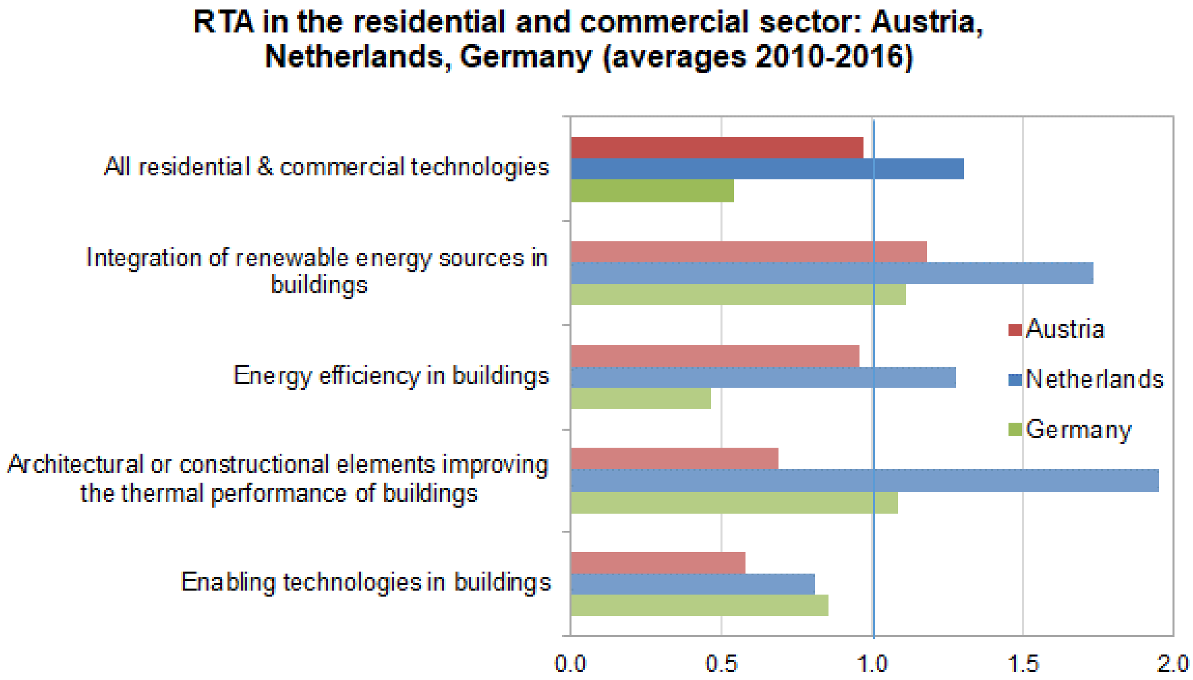


Figure 4. RTA indices in climate change mitigation technologies related to the residential and commercial sector, averages 2010-2016. Note: Index values above 1 indicate a revealed technological advantage. Lighter shades indicate technology sub-fields.

In the residential and commercial sector, Austria registers an average RTA of 0.98 between 2010 and 2016, indicating a marginal technological disadvantage compared to the rest of the world. However, as Figure 4 shows, there is considerable heterogeneity across technological sub-fields within the sector. For example, Austria has a technological advantage (RTA of 1.2) in technologies relating to the integration of renewable energy sources in buildings, including photovoltaic, solar thermal energy or wind power systems and heat pumps. On the other hand, the country’s average RTA in energy efficiency technologies for applications inside buildings is just below 1 at 0.96; and the RTA for elements that improve the thermal performance of buildings (insulation materials and specialized windows, doors, floors and roofs) and for so-called enabling technologies are considerably below 1 (at 0.69 and 0.58, respectively). The latter field includes applications of fuel cells and smart grid technologies in buildings.

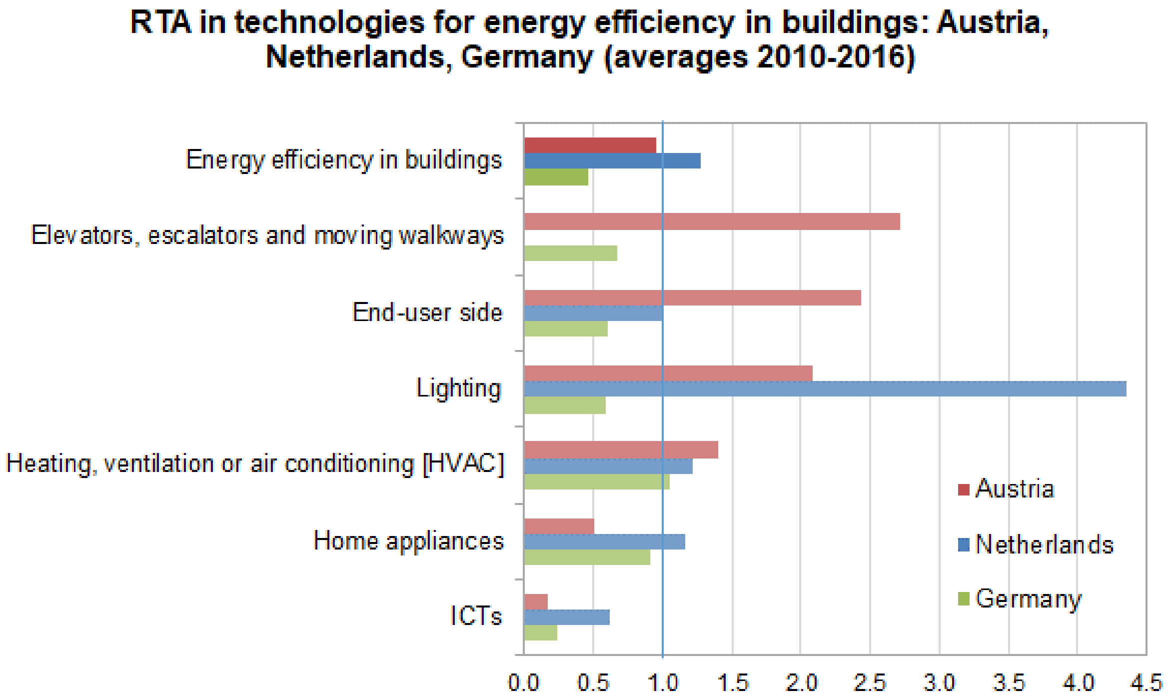


Figure 5. RTA indices in climate change mitigation technologies related to the residential and commercial sector, energy efficiency sub-field only, averages 2010-2016. Note: Index values above 1 indicate a revealed technological advantage. Lighter shades indicate technology sub-fields.

Among the further sub-fields of energy efficiency technologies, shown in Figure 5, Austria's specialisation in technologies for energy-efficient heating, ventilation or air conditioning systems is particularly relevant to decarbonising the buildings stock. This field includes central heating or hot-water supply systems using heat pumps, district heating and waste heat, heat recovery systems and passive house technology. Other areas of technological advantage are energy-efficient elevators, escalators and moving walkways; lighting technologies; and efficient end-user side electric power management and consumption (demand response systems, smart metering and switched-mode power supplies, e.g. energy-saving modes). Areas of technological disadvantage are home appliances and information and communication technologies (ICTs) aiming at the reduction of their own energy use, such as energy-efficient computing technologies and techniques for reducing network energy consumption.

Emission reductions from the residential and commercial sector come from reduced use of fossil fuel-based heating systems and improved thermal insulation. Overall, the evidence presented in this section indicates that Austria is at a disadvantage in technologies related to the latter. In fact, the RTA in the category architectural or constructional elements improving the thermal performance of buildings takes the value zero in all years from 2011 to 2016, following a relatively high value of 4.8 in 2010. Further relevant areas of disadvantage include enabling technologies like fuel cells, smart grids and efficiency technologies in ICTs.

Regarding the second key driver of emissions in the residential and commercial sector, fossil-fuelled heating systems, Figures 4 and 5 indicate that Austria enjoys an advantage in technologies that relate to the integration of renewable energy sources in buildings as well as in heating, ventilation and air conditioning technologies. The RTA values for both categories are rather stable over the years between 2010 and 2016. Therefore, domestic technologies for zero-emissions energy and heating systems for buildings are already available in Austria.

4.3 Existing policy instruments in the Austrian residential and commercial sector

This section provides a short overview of the main instruments currently exploited in the Austrian residential and commercial sector that contribute directly or indirectly to the development or diffusion of eco-innovations in this sector.

4.3.1 Direct and indirect carbon pricing

The Austrian residential and commercial sector is not part of the EU ETS. Its emissions are not taxed directly under Austrian law, but energy use is taxed through a variety of energy taxes (see also OECD, 2018). Table 1 presents the existing tax rates. All electricity use, which is the most common energy product used within this sector in Austria, is taxed at 0.015 Euro per kWh. The electricity tax incentivises consumers to reduce their electricity consumption but does not discriminate with respect to the emission profile of its generation. In other words, the same tax rate applies to electricity produced from renewables and fossil fuels. Other energy products for heating are taxed as well, notably natural gas, heating oil and coal, although the share of coal and coke in energy consumption in Austria is negligible.

Table 1. Energy taxes relevant for the residential and commercial sector in Austria

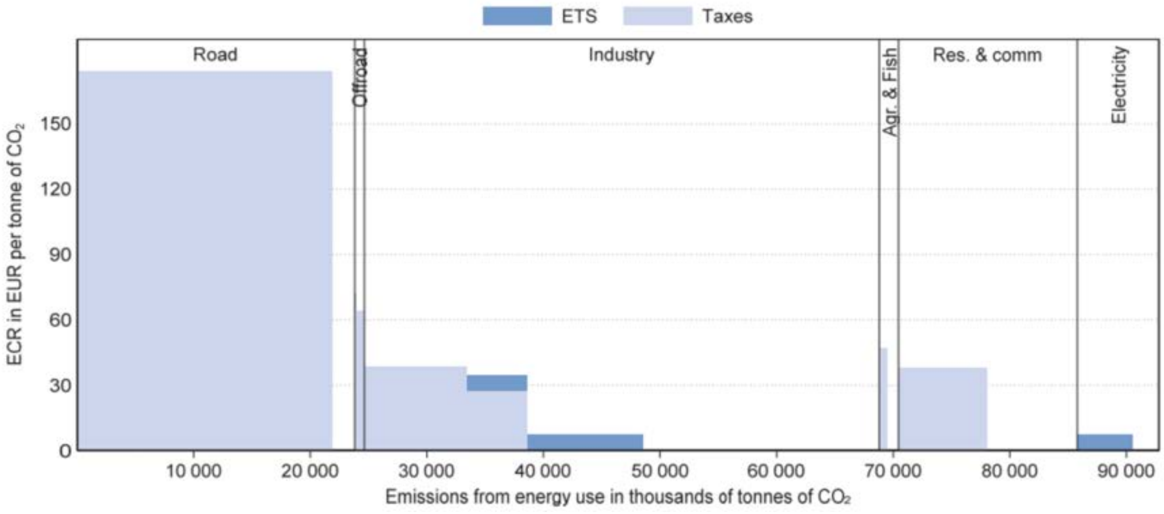
Energy carrier	Tax rate	Rate per GJ	Rate per tonne of CO_2-eq.
Electricity	€ 0.015 per kWh	€ 4.17	€ 99.24
Natural gas	€ 0.066 per m^3	€ 1.66	€ 30.74
Heating oil	€ 0.098 per litre	€ 3.14	€ 40.30
Coal and coke	€ 0.05 per kg	€ 1.70	€ 18.09

Sources: Sporer (2019), Kettner-Marx and Kletzan-Slamanig (2018)

Figure 6 shows the share of carbon emissions of key Austrian emission sectors covered by an effective carbon price (e.g. EU ETS or energy tax) on the horizontal axis (OECD, 2018). On the vertical axis, it presents effective tax rates, i.e. energy taxes expressed in their underlying carbon tax base using emission factors. In 2015, which is the most recent year for which data are available, Austria an effective carbon price applies to 49% of emissions from the residential and commercial sector (the width of the light blue bar under ‘Res. & comm’) due to the use and taxation of heating fuel. The remaining, unpriced half of the emissions in this sector stems from the combustion of biomass as an energy source. This biomass consists of about 33% wood pellets, and the remainder comes from wood logs and wood chips (Landwirtschaftskammer Niederösterreich, 2020).[7]

As can be seen from Figure 6, effective tax rates in the Austrian residential and commercial sector are much lower than emissions from road transport and slightly lower than industry and agriculture. Also, Austrian rates tax rates are considerably lower compared to the residential and commercial sectors in Denmark and the Netherlands but slightly higher than the rates in Germany (OECD, 2018). Currently, Austrian rates are well below the rates that are generally considered to be necessary for a transition to decarbonisation in 2050 (at least US$40-80, or €36-72, by 2020 and US$50-100 by 2030; Carbon Pricing Leadership Coalition, 2017).

Figure 6. Average effective carbon rates in Austria by emission sector, 2015.



Source: OECD (2018)

4.3.2 Standards

Perhaps the most important policy instruments directed at environmental externalities in the residential and commercial sector are building codes (Sporer, 2019). Part of these building codes aim at energy savings and thermal insulation and are emission reduction standards. Building codes (and other direct regulations) affect emissions and thereby the width of the base in Figure 6, either for the residential and commercial sector (if they directly affect emissions from buildings) or for the energy sector (if they affect electricity consumption).

In Austria, building codes are the responsibility of the federal states. However, state-level thermal insulation standards, which define minimum standards for the level of insulation of building components, have been surpassed by the national OIB (Österreichisches Institut für Bautechnik) guideline 6 since 2007. Since, state-level building codes have been reformulated

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[7] Whether emissions from biomass combustion should be taxed depends on many factors, including the sustainability of the biomass used. According to current EU rules biomass does not imply net additions to the flow of carbon emissions due to carbon capture.

as energy performance standards, which offer more flexibility to architects and reduce the risk of lock-in (IEA and UNDP, 2013). These performance standards define maximum values for energy demand of an entire building for new buildings and buildings that are subject to comprehensive renovation. It should be noted that OIB guideline 6 primarily takes care of implementing the requirements of EU directives into national law, such as those on the energy performance of buildings (directives 2010/31/EU and (EU) 2018/844).[8] Federal states, however, can issue their own, more stringent ones.

4.3.3 Generic technology policies

Austria offers various incentives for R&D, for example through a tax credit of currently 14% (OECD, 2019), the Forschungsprämie, which Austrian companies can apply for annually on their R&D expenditures. The Forschungsprämie applies to all R&D and does not target any specific technologies. Regarding energy technology R&D in particular, IEA data indicate that Austria provides generous public funding by European comparison. While on average over the period from 2010 to 2018, 48 million Euro were spent across the EU-28, Austria spent 123 million Euro. Germany, which is ten times larger in terms of population, spent 830 million Euro, and the Netherlands, with almost twice Austria's population, spent 150 million Euro. Of Austria's total, about 12% were allocated to energy efficiency in buildings, while the corresponding figures for the Netherlands and Germany were 5% and 3% respectively (IEA, 2020).

Non-price instruments also play a role in technology policy. To support the diffusion of Austrian technology abroad, the Austrian Federal Economic Chamber and the Federal Ministry for Climate Action run two export promotion initiatives. Firstly, the Export Initiative Environmental Technologies organizes networking missions abroad for company representatives, with a focus on small and medium-sized companies. Secondly, TECXPORT provides an online platform for networking with potential clients and subsidizes travel to a technology promotion event abroad. Of the nine program areas, five could be regarded as at least party climate-related (environment, energy, mobility, transport & infrastructure and smart cities).

4.3.4 Specific technology policies for the residential and commercial sector

The Housing Support Scheme (Wohnbauförderung) is a state-level policy that subsidises the construction of new buildings as well as the renovation of existing buildings. In the early 2000s, it co-funded about 75% of housing permitted for construction. The Scheme combines the subsidy with a standard as the subsidy is conditional on (among other things) minimum energy performance or thermal insulation standards in all states. The emission reductions achieved by

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[8] These require that all new buildings be nearly zero-energy buildings by the end of 2020 and that EU member states submit long-term renovation strategies outlining how existing buildings can be transformed into nearly zero-energy buildings by 2050.

this policy peaked around 2010 and have declined since then, as subsidized gross floor space has declined (Sporer, 2019). Like OIB guideline 6, the Housing Support Scheme supports the diffusion of existing technologies, while the extent to which it supports innovations depends on the dynamics of standards-setting within the Scheme, which varies across states.

The Domestic Environmental Support (Umweltförderung im Inland) aims at increasing energy efficiency and reducing emissions primarily in buildings and transport. In the residential and commercial sector, it provides investment subsidies to private households, companies and municipalities for improving energy efficiency and replacing fossil-fuelled heating systems with renewable ones (including biomass). A specific instrument for private households and companies is the Renovation Campaign, introduced in 2009, which includes for the former group the ‘renovation cheque’ for thermal renovations as well as a bonus for renewable replacements of fossil heating systems. In 2018, a total of approximately 100 million Euro in subsidies was granted for all initiatives under the Domestic Environmental Support scheme, triggering close to 1 billion Euro in environmentally relevant investments (BMNT, 2019b). The Domestic Environmental Support supports the diffusion of eco-innovations.

The Green Electricity Subsidy aims at increasing the share of electricity from renewable sources. Most relevant for the residential and commercial sector are investment subsidies for green electricity plants (except for large hydro-power plants) and subsidies for CHP plants that provide public district heating (and ensure energy savings and emission reductions as compared to separate heat and electricity production). The subsidy has an environmental objective and effectively supports the diffusion of existing technologies.

The Climate and Energy Fund is a subsidy instrument of the federal government, which funds a broad range of innovative projects on renewable energy systems, energy efficiency and sustainable transport technologies as well as awareness-raising and knowledge transfer programs. Its aims are to improve Austria’s performance regarding its energy and climate policy targets and to promote the development and diffusion of Austrian environmental and energy technology. Funding is available for projects at various stages of technological development, from basic R&D to support for demonstration projects, technology adoption and funding for green start-ups. Concerning buildings, the programs funded since the Fund’s establishment in 2007 have included research and investment subsidies for solar thermal and photovoltaic energy systems as well as associated energy storage and network infrastructure for private households, municipalities and companies. In addition, high-standard building renovations, building technologies like thermal component activation and planning concepts such as “smart cities” have received funding, partly also under the funding track addressing natural and social science research, the Austrian Climate Research Programme (ACRP). Since 2007, the Climate and Energy Fund has disbursed 1.4 billion Euro in subsidies on 144,000 projects, which triggered close to 5 billion Euro in total investments (Climate and Energy Fund, 2020).

4.3.5 Information policies

klimaaktiv, a climate action initiative of the Federal Ministry, is an information instrument that provides consulting and networking services, training programs and quality assurance for and in cooperation with companies, municipalities, households and public institutions like universities. The aim of the initiative is to support the diffusion of climate-friendly technologies in the sectors buildings, transport and energy (efficiency and renewables). In buildings, the initiative has been developing quality standards for renovations and new constructions since its inception in 2004. These standards – klimaaktiv gold, silver and bronze – contain criteria on energy efficiency and renewable heating systems, among others. They are also increasingly integrated into other instruments, such as the state-level Housing Support Schemes, the Domestic Environmental Support and the Climate and Energy Fund, with extra funding available for buildings certified according to the klimaaktiv building standards.

5 An application to Austria: policy packages for decarbonisation in the residential and commercial sector

With the descriptive information on the three key indicators above, we are able to answer the questions posed in the evaluative framework in section 3 for the Austrian residential and commercial sector. Note that this section does not aim to provide a complete and exhaustive analysis but aims to illustrate how our framework would work in practice.

1. Is the *focus* of the instrument (package) appropriately targeted?

Austria has set itself the target of climate neutrality by 2040 (Austrian Government, 2020). The operational goal, then, is GHG emission reductions from the residential and commercial sector, via behavioral changes and the adoption of technologies that reduce emissions (i.e. a switch towards renewable energy or electricity, or improved thermal insulation). Clearly, the focus of policy instruments should be in line with those ambitions. For instance, the operational goal of the instruments should be pointing in the direction of fewer GHG emissions, i.e. tax or subsidy bases and rates should be such that they punish current dirty, GHG intensive technologies and support GHG free innovations.

GHG emissions in the residential and commercial sector can be reduced along two lines: reduction of fossil fuel use for heating of water and space, and improvement of the thermal performance of the buildings stock. Currently the residential and commercial sector is not part of the EU Emissions Trading System (ETS). Current energy taxes do not directly address carbon emissions: the tax rate per tonne of CO_2 for heating oil is about a third higher than the rate for natural gas. The rate for coal is lowest, but this fuel has a negligible share in energy consumption by buildings.

Importantly, the tax rate per GJ and per tonne of CO_2 is highest for electricity, which does not support substitution from gas and heating oil to electricity-based technologies. Introducing differentiated electricity tax rates according to the fuel source (fossil or renewable) could improve its focus. Still, Austria's energy taxes do support the adoption of technologies for thermal insulation that contribute to reduced (fossil) energy consumption for heating. By pricing energy consumption and supporting the adoption of insulation technologies, the energy taxes indirectly increase the potential market size for eco-innovations (both for low- and zero-emission heating technologies and for insulation technologies).

Building codes (state-level and OIB guideline 6) reduce demand for energy for space heating (insulation standards) and for other uses. In this way, they only indirectly contribute to the operational goal of carbon emission reductions. However, building codes also directly support the adoption of insulation technologies and indirectly increase the potential market size for new eco-innovations.

As noted above, Austria's public funding for energy technology R&D is relatively generous as compared to the EU as a whole, and a relatively large share of it is aimed at energy efficiency in buildings, thereby contributing to reduced (fossil) energy demand. It is unclear what share is aimed at zero-emission technologies for heating of space and water. The existing R&D tax credit (Forschungsprämie) has no specific technological focus, so a specific programme targeted at emissions reduction technologies could be introduced to improve the focus of supporting decarbonisation. The existing portfolio of adoption subsidies (e.g. Domestic Environmental Support, Climate and Energy Fund) provides incentives for the adoption of insulation technologies and renewable energy systems. They thereby contribute to the objective of reducing emissions and increase the potential market size for new eco-innovations.

2. To what extent does the *scope* of the instrument (package) cover the operational goal?

Regarding the environmental scope of existing instruments in Austria's residential and commercial sector, Figure 6 shows that existing energy taxes in Austria do not cover all GHG emissions from this sector, as emissions from biomass are untaxed following EU regulations. Emissions from gas and heating oil are covered by the respective energy taxes, which shows that the environmental scope of the current instrument package is sufficient.[9]

Regarding the scope of the existing technology instrument package in buildings, Austria has a diverse set of instruments supporting invention, innovation and diffusion of eco-innovations. The Forschungsprämie supports R&D but could be focused more strongly on emission reductions technologies. We observe that Austria has a revealed technological disadvantage for several relevant technology fields, notably enabling technologies in buildings (RTA equal to

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[9] This conclusion would change if other externalities were also considered, such as air pollution impacts. The same holds for other aspects such as the sustainability of the wood used to produce pellets and logs. This evaluation, however, is beyond the scope of this paper.

0.58), and architectural or constructional elements improving the thermal performance of buildings (RTA 0.69). Hence additional policy support, such as specific R&D subsidies or research grants, can contribute to new eco-innovations in these technology fields, which in turn contribute to the reduction of emissions from the residential and commercial sector.

Federal and state-level building codes support the diffusion of eco-innovations, as do other adoption subsidies. Austria has a technological advantage (RTA of 1.2) in technologies relating to the integration of renewable energy sources in buildings, including photovoltaic, solar thermal energy or wind power systems and heat pumps. The country also has a technological advantage in energy-efficient heating, ventilation or air conditioning systems, which include central heating or hot-water supply systems using heat pumps, district heating and waste heat, heat recovery systems and passive house technology. To foster the further diffusion of these technologies, existing building codes and support schemes need to be checked as to whether they support them properly, and, if not, could be adapted accordingly.

Related to whether existing taxes and subsidies properly provide incentives to those willing to invest in renewable energy heating systems or insulation, there are several principal/agent problems. For example, if the buyer of a new house underestimates the value of low- or zero-energy investments by the builder in terms of reduced energy expenses, the latter may not be able to cover his investment through the sales price (Levinson and Niemann, 2004). Similarly, if a landlord who invests in low- or zero-energy technologies cannot raise the rent (e.g. due to social housing regulations), while the tenants pay the electricity bill, the landlord will not be able to earn back her/his investment. Also other design aspects are particularly relevant to make such subsidies work in practice while not inducing high levels of free riding (Ruijs and Vollebergh, 2013).

3. Is the *strictness* of the instrument (package) in line with the operational ambition?

Austria’s current energy tax rates for natural gas and heating oil are €30.74 and €40.30 per tonne of CO_2-eq. respectively. Not only is the structure of both taxes not aligned with the carbon intensity of the fuels, also the current rates are below what is estimated to be the necessary global tax rate to induce investments towards decarbonisation. According to the Carbon Pricing Leadership Coalition (2017), global carbon tax rates of €36-72 by 2020, and rising afterwards, are necessary for a transition to decarbonisation in 2050, while Austria’s ambition to be climate neutral by 2040 is even stricter.[10] In other words, existing energy tax rates need to be raised to provide the right level of incentives to adopt renewable energy heating and improved thermal insulation technologies in the residential and commercial sector.

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[10] Note that these taxes implicitly cover multiple environmental externalities (such as emissions of local air pollutants) that differ per energy carrier. Hence, their rates should reflect the environmental damages that come from the respective energy carrier.

Since higher energy taxes may lead to increased energy poverty – i.e. a higher number of households spending a very large share of their housing costs on energy – they may require complementary social policies including (adoption) subsidies for clean technologies. Also, the tax rate on electricity could be reduced (in addition to its differentiation by fuel source suggested above). This lowers the tax burden and provides incentives in the residential and commercial sector to substitute from fossil fuel technologies to (renewable) electricity-based technologies.

With the arrival of new, relevant technologies, building codes should be updated (increased strictness) to support the diffusion of these new technologies, in particular if emissions from the residential and commercial sector do not decline sufficiently fast. Similarly, adoption subsidies may need to be increased if existing rates are too low to induce climate neutrality by 2040. Importantly, the prospect for innovators that their technology might induce policymakers to increase the strictness of building codes and diffusion support is an incentive in itself for innovators to further develop and diffuse new eco-innovations.

4. Is the instrument a *coherent* addition to existing and other instruments of the overall package?

Because the residential and commercial sector is not part of EU ETS, direct overlap of CO_2 emissions pricing through multiple pricing instruments is limited. Still, there are relevant interactions. For instance, a high energy tax rate on electricity might exacerbate the potential waterbed effect described earlier, and requires proper adaptation of the EU ETS cap. Worse, since the tax rate per GJ is higher for electricity than for natural gas and heating oil, it impedes the adoption of electricity-based (water) heating technologies. Austria’s high energy tax rate for electricity hence interacts with other instruments in a way that hinders emission reductions in the residential and commercial sector.

Austria has a broad policy package aimed at the adoption of zero-emission heating and thermal insulation technologies. Building codes ensure that new buildings and construction elements used in renovation meet minimum requirements. The Housing Support Scheme and Domestic Environmental Support both provide incentives to adopt eco-innovations. Only a much more detailed analysis of the various instruments aimed at technology adoption should reveal to what extent these support schemes do or do not (partially) overlap with each other. At face value there do not seem to be clear interactions that might reduce the effectiveness of a particular instrument. Still, the instruments could be scanned in further detail for their complementarity and overlap.

5. Is the *timing* of the instrument (package) appropriate?

Regarding the existing policy package, one of the issues of timing concerns the termination of a policy. As long as the objective of climate neutrality has not been met, there is no reason to terminate one of the existing instruments. Regular assessment of existing instruments, however, for example by applying the evaluative framework presented in this paper, could improve both effectiveness and efficiency of the package by mitigating inefficient overlap and elimination of subsidy rates for technologies that are already widely adopted.

One example is the importance to frequently review existing building codes to ensure that redundant technology requirements are replaced by new ones, based on novel heating or insulation technologies. And, closely related, also existing subsidy schemes for diffusion of particular technologies should be updated on a regular basis as well. It has been shown for the Netherlands in detail how important it is to update technologies for which such subsidies are usually provided, in particular also for firms (Ruijs and Vollebergh, 2013). A key feature of subsidies that use a (dynamic) technology list is that this makes the regulation flexible, allowing policy makers to adapt the program to a changing policy environment. The list also reduces information asymmetry between supply of and demand for new technologies which is important to also reduce the likelihood of free riding.

Another related issue is that the timing of the instrument reform should be related to the availability of a proper infrastructure that is key to decarbonisation in the long run. For instance, if the use of gas and oil is substituted by electricity-based equipment, this might require adaptation of the existing electricity network. Some combination of new electricity-based technologies such as electric cars or heat pumps may require proper and timely adaptations of the electricity or other grids. So if a particular instrument or package stimulates a switch too early, that might induce excessive costs to users and even backfire through lowering support for the policy change.

6 Conclusion

This paper develops and applies an evaluative framework for the assessment of existing and potential new policy instruments that aim at decarbonisation of the economy. Our framework borrows from the theory of environmental and technology externalities with a strong eye on policy design issues. From this perspective, we know that not only proper individual incentives are key to behavioral change that should bring about the switch to decarbonisation, but also a proper assessment of context and practical policy design features. Our evaluative framework therefore captures five design and context features: focus, scope, strictness, coherence and timing. Moreover, we show that adapting or developing a policy instrument or package benefits from a proper assessment of the status quo regarding emissions (who emits how much?), innovation intensity (to what extent is the country strong in relevant technology fields?) and existing environmental and technology policy instruments.

Our paper justifies the following conclusions as to why our framework is important. First of all, a critical evaluation of (portfolios of) environmental and technology policy instruments and their interactions is essential to meet a given policy objective such as decarbonisation. Instruments often not only have direct but also indirect impacts that might go far beyond their original intention and could therefore even backfire if they are not well-designed. This is why scrutinizing each existing instrument for key design elements such as focus, scope and strictness is essential for better-targeted instruments and instrument packages.

Second, the specific context of instrument choice matters a lot. For instance, the residential and commercial sector is substantially different from other sectors because it is non-exposed and does not suffer from intense international competition. Therefore is it important to also have a thorough understanding of the current emissions and innovative performance of sectors in order to find loopholes and provide better-targeted incentives. This understanding allows policy makers to develop technology niches within their own country and, when successful, with some eco-innovation potential abroad as well.

Our application to the Austrian residential and commercial sector illustrates these more general conclusions. We have proposed several changes to the existing policy package aimed at the transition towards a decarbonisation of the residential and commercial sector via the adoption of zero-emission heating as well as insulation technologies. Reducing the energy tax rate for electricity and differentiating it by fuel source is a relatively easy option and could be done comparatively quickly. Furthermore, an increase in the tax rates for natural gas and heating oil and a harmonization of their rates per tonne of CO_2 emissions is another relatively simple option but might require complementary policies to mitigate their potential negative effects on energy poverty.

New instruments that contribute to R&D for technology fields in which Austria has a low RTA (notably enabling technologies, and architectural or constructional elements improving the thermal performance of buildings) could also be easily developed and implemented without delay. From the perspective of efficiency, these would need to be updated regularly or come with a sunset clause. Finally, existing building codes and adoption subsidy schemes should be checked for their support for technology fields in which Austria has a high RTA (integration of renewable energy sources in buildings; energy-efficient heating, ventilation and air conditioning systems).

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Appendix: Taking stock of emissions, innovations, and policies

A.1 Emission performance of emission sectors

The first descriptive indicator to be taken stock of before applying the evaluative framework in practice is which key polluting activities are responsible for the environmental externalities in the context of a country's transition towards decarbonisation. Various forms and roles of energy use in different parts of the economic system are responsible for those GHG emissions in the status quo.[11] Moreover, these existing quantities of energy use and emissions by specific sectors also reflect the outcomes of market conditions and past policies. Indeed, the amount of emissions at a given date reflects the (revealed equilibrium) impact of existing price and non-price instruments.

When countries record their GHG emissions in national inventories to be reported annually under the United Nations Framework Convention on Climate Change (UNFCCC), they use a sectoral classification system laid down in IPCC (2006), which allows distinguishing the following broad emission sectors and sources:

- Industry (fuel combustion, industrial processes and product use);
- Energy generation (mostly fuel combustion for electricity and heat production, petroleum refining and manufacture of solid fuels);
- Transport (combustion of motor fuels);
- Commercial and residential buildings (combustion of heating fuels by households, businesses and other institutions).

An inventory of emission sources is important for determining the focus and scope of environmental and innovation policy.

A.2 Eco-innovation performance of emission sectors

A second important descriptive indicator is an assessment of sectoral innovation rates. Eco-innovation enables a switch from currently used carbon-intensive technologies towards cleaner, less carbon-intensive substitutes. Depending on the country's performance in different environmental technology fields, policy instruments can then be developed to foster innovation and/or diffusion in targeted areas.

To examine the eco-innovation performance of emission sectors, patent applications can provide insight. Patent applications are standardized documents classified by technology field according to the International Patent Classification of the World Intellectual Property Organization. Specialized classifications of environmental technologies have been developed, such as the OECD ENV-TECH classification (OECD, 2016), which records pollution

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[11] Eco-innovations may also be linked to other emissions affecting air quality, water and soil systems and biodiversity. Given our focus on decarbonization, these are beyond the scope of this article, however.

abatement technologies and climate change mitigation technologies related to different emission sectors (see Table A1 below). Patent applications are published and are thus readily available and comparable across countries. They are often used as a proxy for innovation in the empirical literature (Popp, 2002; Popp et al., 2010), although not all innovations are patented and not all patents represent innovations (i.e. commercially successful inventions).

Table A1: OECD ENV-TECH climate change mitigation technologies by emission sectors

Transportation:
Road transport (conventional, hybrid or electric vehicles) Rail transport Air transport Maritime or waterways transport Enabling technologies in transport (electric vehicle charging, application of fuel cell and hydrogen technology to transportation)
Buildings:
Integration of renewable energy sources in buildings Energy efficiency in buildings (Lighting, heating, home appliances, elevators, ICT) Architectural or constructional elements improving the thermal performance of buildings Enabling technologies in buildings
Production or processing of goods:
Metal processing Chemical industry Oil refining and petrochemical industry Processing of minerals Agriculture, livestock and agroalimentary industries Final industrial or consumer products Sector-wide applications Enabling technologies with a potential contribution to greenhouse gas emissions mitigation
Energy generation, transmission or distribution:
Renewable energy generation (wind, solar, hydro etc.) Energy generation from fuels of non-fossil origin (e.g. biofuels) Combustion technologies with mitigation potential Efficiency in electrical power generation, transmission or distribution Enabling technologies in the energy sector (batteries, hydrogen technology, fuel cells, smart grids in the energy sector)
Wastewater treatment or waste management:
Wastewater treatment Solid waste management (waste collection, processing or separation, and reuse, recycling or recovery technologies)

Enabling technologies or technologies with a potential or indirect contribution to greenhouse gas emissions mitigation
Capture, storage, sequestration or disposal of greenhouse gases:
CO_2 capture and storage Capture or disposal of greenhouse gases other than CO_2 (N_2O, CH_4, PFC, HFC, SF6).

Source: (OECD, 2016)

The index of revealed technological advantage (RTA) is computed to gauge Austria's relative eco-innovation performance in comparison to other countries, using data on the number of patent applications in climate change mitigation technologies related to different emission sectors. The RTA index for country *i* and technology field *d* can be written mathematically as follows: [12]

$$\mathrm{RTA}_{d,i} = \frac{P_{d,i} \Big/ \sum_i P_{d,i}}{\sum_d P_{d,i} \Big/ \sum_{d,i} P_{d,i}}$$

where *P* refers to the number of patent applications as a measure of innovation activity. The RTA expresses country *i*'s share of all countries' patent applications in technology field *d* relative to its share of all countries' patent applications in all technology fields.

For our indicator of eco-innovation performance, we select technology field *d* in the numerator to be an environmental technology field, specifically a climate change mitigation technology in a particular emission sector. The index then takes the value 0 when the country holds no patent in that given climate change mitigation technology field; the value 1 when the country's share of patent applications in the given climate change mitigation technology field is equal to its share of patent applications in all fields (no specialization); and a value greater 1 when its share in the given climate change mitigation technology field is greater than its share in all technology fields (positive specialization or revealed technological advantage).

A.3 Existing policy instruments by emission sectors

The final step towards designing policy packages is to understand the role of existing (implicit) policy instruments in the different emission sectors in a country. In almost all (developed) countries, some environmental and technology policy instruments already exist. They are likely to be responsible for both the amounts and sources of energy used in the country – and hence for carbon emissions per emission sector – as well as for existing eco-innovation activities (as measured for instance by patent applications for eco-innovations; OECD, 2010). For a full picture, also with an eye on the scope and strictness of new policies necessary for the zero-

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[12] The RTA is identical in structure to the more commonly known index of revealed comparative advantage (RCA) used to measure relative specialization in international trade (Balassa, 1965). See OECD (2013) for a description of the RTA.

carbon transition, it is crucial to take stock of the existing portfolio of policy instruments that support the development and deployment of eco-innovations. As noted in section 3.1, a combination of new and existing instruments can be useful if they complement each other, but they can also lead to inefficiencies if they overlap.

A useful starting point for checking whether externalities from GHG emissions are properly priced are effective carbon rates (OECD, 2018). Using a highly disaggregated database of energy use and both explicit and implicit carbon prices, the OECD presents a concise evaluation of how well the carbon emission base is actually priced in each emission sector. The analysis presents effective tax rates on (fossil fuel) energy use in terms of carbon emissions as well as the share of emissions that is priced at various levels. These effective rates account for actual carbon taxes, specific taxes on energy use and fuel consumption, and tradable emission permit prices in the various countries. Emissions for which tax rates are zero are also included in the calculation.

In addition to an overview of existing pricing instruments, non-pricing environmental policy instruments are relevant as well. Policy standards come in a wide range of shapes and sizes (Vollebergh and Van der Werf, 2014). Well-known environmental policy standards, for instance, include insulation norms for buildings and emission norms for new vehicles. However, relevant policy standards go beyond environmental policy standards. For example, compatibility standards for charging systems are indispensable for the widespread adoption of electric vehicles.

Technology policy instruments support the development and diffusion of eco-innovations. Explicit diffusion policies are often implemented as adoption subsidies, such as subsidies for renewable energy production (i.e. subsidies for the adoption of wind and solar energy technologies) and subsidies for the purchase of specific clean(er) technologies like energy efficient appliances, electric vehicles and charging systems.

It is important to note that an inventory of existing policy instruments might also include international policies. This is especially relevant in a policy environment with some degree of federalism, as illustrated before for the case of the EU ETS.