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DECARB

Mixes of policy instruments for full decarbonisation by 2050

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Summary

The goal of the DECARB research project is to investigate mixes of policy instruments that would allow Switzerland to respect its climate commitments and reach the net-zero emissions target by 2050. In this context, we focus on energy-related emissions which stem from four sectors, namely: power generation, transport, buildings and industry. We evaluate various policy measures, as well as combinations thereof, along several dimensions relevant to policymakers, including environmental effectiveness, economic efficiency, and political feasibility. We adopt complementary methods to perform our analyses in this regard. First, we derive lessons on climate policy design from the existing scientific literature. Second, we employ an augmented numerical simulation model to quantify the economic effects of full-decarbonization pathways for Switzerland. Third, we investigate public support for various policy measures by Swiss residents thanks to a stated-preference survey.

Our analyses reveal that a strong case can be made for mixes of policy instruments if Switzerland is to reach climate neutrality by 2050. Indeed, once real-world complexities are taken into account, the superiority once granted to carbon pricing as a stand-alone measure to abate greenhouse gas emissions is compromised. Indeed, carefully combining policy instruments has the potential for substantial positive synergies in a number of respects, thereby offering an opportunity to improve climate policy. Importantly, desirable mixes of policy instruments are found to differ across sectors, given the distinct targeted technologies and agents. The corresponding results have been presented at international conferences and resulted in four working papers, to be submitted and eventually published in peer-reviewed journals. The key findings and policy recommendations ensuing from the DECARB research project are provided in the form of three policy briefs.

Zusammenfassung

Das DECARB-Forschungsprojekt untersucht Massnahmenkombinationen, die es der Schweiz ermöglichen, ihre Klimaverpflichtungen einzuhalten und das Netto-Null-Emissionsziel bis 2050 zu erreichen. Wir konzentrieren uns dabei auf die energiebedingten Emissionen aus den vier Sektoren Stromerzeugung, Verkehr, Gebäude und Industrie. Massnahmen und Massnahmenkombinationen werden anhand politisch relevanter Kriterien beurteilt. Dazu gehören die Wirksamkeit zur Treibhausgasminderung, die wirtschaftliche Effizienz und die politische Machbarkeit. Für die Analysen verwenden wir einander ergänzende Methoden: Erstens leiten wir aus der bestehenden wissenschaftlichen Literatur Lehren für die Gestaltung der Klimapolitik ab. Zweitens haben wir ein numerisches Simulationsmodell weiterentwickelt, mit dem wir die wirtschaftlichen Auswirkungen klimaneutraler Pfade in der Schweiz quantifizieren. Drittens untersuchen wir die Unterstützung der Schweizer Bevölkerung für verschiedene Massnahmen mit einer Umfrage.

Unsere Analysen zeigen, dass ein Mix aus verschiedenen Massnahmen sinnvoll ist, um die Schweizer Klimaneutralität bis 2050 zu erreichen. Zwar wurde ein einheitlicher CO_2-Preis als alleinige Massnahme schon häufig als überlegenes klimapolitisches Instrument präsentiert. Dessen vermutete Überlegenheit hält einer Prüfung jedoch nicht Stand, wenn sie die tatsächliche Vielschichtigkeit der Wirklichkeit berücksichtigt. Sorgfältig konzipiert bergen Massnahmenkombinationen in vielerlei Hinsicht erhebliche Synergien und können so die Klimapolitik voranbringen. Entscheidend ist dabei, dass die Massnahmenkombinationen jeweils unterschiedlich auf die einzelnen Sektoren zugeschnitten werden, um die sektoralen Besonderheiten bei Technologien und Akteuren zu berücksichtigen. Unsere Ergebnisse wurden auf internationalen Konferenzen vorgestellt und führten zu vier Arbeitspapieren, die in Fachzeitschriften mit Peer Review eingereicht und veröffentlicht werden sollen. Wir stellen die wichtigsten Ergebnisse und Empfehlungen, die aus dem DECARB-Forschungsprojekt hervorgehen, in Form von drei Memoranden zur Verfügung.

Résumé

L'objectif du projet de recherche DECARB est d'étudier les combinaisons d'instruments politiques qui permettraient à la Suisse de respecter ses engagements climatiques et d'atteindre l'objectif d'émissions nettes nulles d'ici 2050. Dans ce contexte, nous nous concentrons sur les émissions liées à l'énergie qui proviennent de quatre secteurs, à savoir : la production d'électricité, les transports, les bâtiments et l'industrie. Nous évaluons diverses mesures politiques, ainsi que leurs combinaisons, en fonction de plusieurs dimensions pertinentes pour les décideurs politiques, notamment l'effectivité environnementale, l'efficacité économique et la faisabilité politique. Nous adoptons des méthodes complémentaires pour effectuer nos analyses à cet égard. Tout d'abord, nous tirons des leçons de la littérature scientifique existante sur l'élaboration de politiques climatiques. Deuxièmement, nous utilisons un modèle de simulation numérique augmenté pour quantifier les effets économiques des trajectoires de décarbonation pour la Suisse. Troisièmement, nous étudions le soutien public à diverses mesures politiques grâce à une enquête auprès de résidents suisses.

Nos analyses révèlent que des arguments solides peuvent être avancés en faveur d'une combinaison d'instruments politiques si la Suisse veut atteindre la neutralité climatique d'ici 2050. En effet, une fois que les complexités du monde réel sont prises en compte, la supériorité accordée autrefois à la tarification du carbone en tant que mesure incitative unique est compromise. En effet, une combinaison judicieuse d'instruments politiques est susceptible d'engendrer des synergies positives substantielles à plusieurs égards, offrant ainsi la possibilité d'optimiser la politique climatique. Il est important de noter que les combinaisons souhaitables d'instruments politiques diffèrent d'un secteur à l'autre, compte tenu des technologies et des agents ciblés. Les résultats correspondants ont été présentés lors de conférences internationales et ont donné lieu à quatre articles scientifiques, qui seront soumis et à terme publiés dans des revues évaluées par des pairs. Les principales conclusions et recommandations politiques issues du projet de recherche DECARB sont présentées sous la forme de trois mémorandums.

Main findings («Take-Home Messages»)

- Resorting to combinations of policy instruments to abate energy-related emissions offers the potential to make ambitious climate policy both more efficient and more socially acceptable. Indeed, there is strong evidence that mixes of policy measures can alleviate key shortcomings of single policy instruments, be they e.g. (carbon) taxes, subsidies, or bans.
- Mixes of policy instruments should be differentiated across the power, transport, buildings and industry sectors – and if possible sub-sectors – given the distinct targeted technologies and agents. Some level of carbon pricing should be an integral part of policy packages in all these sectors, although the necessary price signal diminishes significantly in the presence of complementary measures, compared to the case where it is implemented alone.
- Abating energy-related emissions to a level compatible with Switzerland's overall climate neutrality target will not necessarily come at the expense of economic objectives. By spurring investment into additional renewable energy capacity and low-carbon technologies while decreasing the country's reliance on fossil fuel imports, the energy transition may induce gains.
- Since trade-offs between various policy objectives cannot be fully avoided even with carefully-designed mixes (e.g. GDP can be boosted with subsidies, but they require income tax increases), policymakers will have to prioritise certain objectives over others. One immutable feature across all policy packages is the need for immediate action if the decarbonisation process is to be smooth and successful.

Contents

List of abbreviations

CCS	Carbon capture and storage
CGE	Computable general equilibrium
CH-ETS	Swiss emissions trading scheme
CHF	Swiss franc
CO_2	Carbon dioxide
EII	Energy-intensive industry
ETS	Emissions trading scheme
EU	European Union
EU-ETS	European Union emissions trading scheme
FSO	Federal Statistical Office
GHG	Greenhouse gas
GDP	Gross domestic product
Mt	Megaton
NET	Negative emissions technology
OECD	Organisation for Economic Co-operation and Development
UK	United Kingdom
WP	Work package

1 Introduction

1.1 Context and motivation

Consistently with the latest scientific evidence, policymakers across the world face the urgent task of engaging economies in decarbonisation pathways. Containing global warming and limiting the risks of extreme adverse consequences thereof (IPCC, 2021) justifies this course of action. Switzerland has fomally committed to halve its emissions by 2030 relative to 1990 (UNFCC, 2022) and, as one of 96 countries (ECIU, 2024), including the European Union [EU] Member States (UN, 2021), attain net zero greenhouse gas [GHG] emissions by 2050 (FF, 2022). The question of how to achieve the latter objective, i.e. through the implementation of which policy instruments, serves as motivation of the DECARB project.

Given the mixing properties of carbon dioxide [CO_2], the idea of introducing a uniform carbon price across sectors – and if possible, countries – greatly appealed to economists because of its theoretical properties, namely achieving an efficient allocation of resources across markets. However, a lack of sufficiently high carbon prices and an incomplete emissions coverage has been observed so far. Although the planned emissions trading scheme [ETS] at the EU level for buildings, transport and small industry (i.e. EU-ETS2), suggests there is room for progress, the current context also calls for considering alternative measures to drive change at the speed and to the degree required. The main challenge with implementing ambitious carbon pricing concerns political feasibility: additional costs are incurred by polluting industries, while the public perceives the instrument as highly inequitable and detrimental (Klenert et al., 2018; Carattini et al., 2018). Furthermore, national climate policy landscapes, including that of Switzerland, reveal a variety of coexisting sectoral measures that aim to curb CO_2 emissions, pointing towards a gap between the dominant economic viewpoint and real-world policy implementation. Concurrently, an alternative strand of literature departed from the recommendation of a single uniform carbon tax, or an all-encompassing ETS to address the environmental issue at hand. Indeed, multiple studies have shown evidence that a suite of complementary instruments may be warranted for a plurality of reasons, ranging from information problems to institutional constraints and technology spillovers.

Nevertheless, several research gaps become apparent in the existing scientific literature, which the DECARB project seeks to address. First, knowledge on mixes of policy instruments tends to be highly dispersed, suggesting a need for integration to allow for a clear understanding of synergies and trade-offs between measures across all sectors of the economy. Second, economy-wide quantitative assessments of net-zero scenarios relying on alternative policy measures appear to be lacking, thus pointing towards an interest in performing relevant simulation exercises. Third, while increasingly recognised as the main barrier to ambitious climate policy, citizen support remains understudied, especially with respect to sectoral differences and combinations of measures, calling for novel appraisals taking these dimensions into consideration.

Using previous research as a stepping stone, the DECARB project thus seeks to advance the state of knowledge with respect to instrument mixes along several dimensions relevant to policymakers, with a special focus on the case of Switzerland.

1.2 Project objectives

We interpret the target of net-zero GHG emissions by 2050 as implying virtually zero CO_2 emissions from energy. Throughout, we hence focus on energy-related emissions only, which stem from the power, transport, buildings and industry sectors. The technical feasibility of decarbonising the Swiss energy system has been demonstrated by Prognos et al. (2021), and a first economic assessment of reaching net-zero, based on stylised policy packages, has been performed by Ecoplan (2022). Nevertheless, the question of how to steer the behaviour of all economic agents toward that end remains debated.

The intention of the DECARB project is to propose a set of (simultaneously) effective, efficient, acceptable and – more generally – feasible mixes of policy instruments that would allow Switzerland to respect

its climate commitments and reach the net-zero emissions target by 2050. Four interrelated research questions arise from this overarching objective, namely:

- What are the theoretical and practical underpinnings for resorting to mixes of policy instruments?
- What are the advantages and shortcomings of individual policy instruments, including carbon pricing, and how might they be affected when measures are combined?
- Are there rationales for implementing distinct mixes of instruments across different sectors of the economy?
- What are the inevitable trade-offs between competing instrument mixes, as well as stand-alone carbon pricing, when expanding the set of evaluation criteria beyond efficiency?

To answer these multifaceted questions, we resort to diverse methods, each of which offers insights of its own, to derive balanced policy recommendations. To begin with, we conduct a literature review to identify complementarities and trade-offs between a wide range of policy measures in different sectors. Then, we perform simulations of instrument mixes that would lead Switzerland to climate neutrality in 2050, and evaluate economic effects quantitatively, based on an augmented numerical model of the Swiss economy in its international context. It should be noted that a significant activity under this grant consisted in enhancing the modelling framework, which we describe in detail in the relevant scientific papers rather than herein. Finally, we elicit the public acceptability of instrument mixes leading to climate neutrality among Swiss residents via a stated-preference survey conducted in the early months of 2024.

1.3 Structure

Given the diversity of methods employed in the DECARB project, we summarise the key findings of our research by virtue of three thematic policy briefs. Each of them is backed by at least one academic research paper, written during the course of the funded venture and available online.

The first policy brief (based on our first work package [WP1]) derives strategic lessons regarding mixes of policy instruments across four sectors – namely power, transport, buildings and industry – from a review of the international scientific literature.

Employing a quantitative model to analyse economic effects, the second policy brief (based on WP2, WP3, WP4) provides recommendations hinging on simulations of net-zero scenarios induced by mixes of policy instruments in Switzerland.

The third policy brief (based on WP3, WP4) informs on how mixes of policy instruments leading to full decarbonisation perform in terms of public acceptability among Swiss residents.

Finally, the common conclusion integrates and synthesises the insights from the individual policy briefs to draw key recommendations based on a plurality of factors.

2 Policy brief – Lessons on combining policy instruments from the international literature

Author: Fleance Cocker (EPFL)

Overview

Carbon pricing was long considered the ultimate tool to mitigate climate change. However, the timid enforcement of emissions taxes and emissions trading schemes [ETS] around the world is testimony to the issue of political feasibility surrounding the measure. At the same time, various strands of literature have suggested theoretical as well as practical reasons to depart from a single uniform carbon price and instead opt for mixes of policy instruments to decarbonise energy systems. Nevertheless, drawing policy lessons remains challenging given the large diversity of contexts and methodologies employed, thus resulting in fragmented appraisals. We contribute to the literature by integrating and harmonising previously produced knowledge along a number of dimensions, to paint a more complete and nuanced picture of climate policy efficacy.

Reviewing the literature

The focus of the study is on decarbonising four sectors that release energy-related emissions – i.e. power, transport, buildings and industry – while evaluating climate policy design according to four widely-adopted criteria – i.e. environmental effectiveness, economic efficiency, social equity, political feasibility. Note that ancillary costs and benefits of decarbonisation itself (e.g. health benefits, energy security, etc.) that occur regardless of design, were not considered in the current paper despite their expected large effect on political feasibility. Given the wide scope of potential studies to be considered, we performed a literature review of the narrative type. Papers included in the review were found thanks to searching appropriate keywords in Elsevier's database Scopus. In order to maximise the level of relevance for the Swiss context, we retained both theoretical, as well as empirical studies focusing on western Europe, the United States of America, and Canada. The approach resulted in incorporating close to 350 high-quality references offering a diverse range of findings in our review.

To structure the gathered insights, we adopted a four-step procedure to derive rationales for resorting to mixes of policy instruments on a sectoral basis. First, decarbonisation levers are presented. Second, the main barriers to emissions abatement are extracted. Third, instruments that enable the said levers with proven effectiveness are elicited and their ability to concurrently address the identified barriers is investigated. Fourth, interactions between instruments are analysed and promising combinations thereof deduced depending on the prioritisation of policymakers' objectives.

Main results

- There exist multiple barriers, all different in nature, which impede environmentally effective, economically efficient, socially equitable and politically feasible abatement efforts. Importantly, while common themes emerge (e.g. social acceptability), hurdles are contingent on the characteristics of both decarbonisation technologies and targeted agents, rendering them highly sector-specific, and in many cases, even subsector-specific. For instance, tenants might oppose refurbishments due to comfort considerations, while landlords are more concerned about the long payback periods of such investments.
- Policy instruments advanced by the existing literature differ significantly across sectors. The specific design characteristics of these measures are of paramount importance with regard to their performance along the stated evaluation criteria. Yet, specifying desirable design characteristics often constitutes a set of complex choices. Even with a state-of-the-art design, no individual instrument is found to be superior according to all criteria, nor is any single measure able

to address all barriers. It follows that trade-offs are inevitable. For instance, ensuring that future key decarbonisation technologies will be available at a low cost typically implies “picking winners” today by supporting some of them to the detriment of others.

- No exception to the rule, we find evidence that although carbon pricing possesses undeniable advantages, it also suffers from drawbacks which vary across sectors, and which extend beyond the usual culprits of redistributive effects and limited political feasibility. For instance, it may accentuate the carbon lock-in when users of fossil-based technologies face financial constraints which prevent them from adopting low-carbon alternatives or fail to spur public investments into charging infrastructure for electric vehicles.
- Turning to combinations of instruments, we uncover signs that the potential for synergies is greater than previously thought, when considering a broader set of objectives beyond economic efficiency. However, even this dimension may be boosted once real-world aspects pertaining to e.g. political economy and further externalities are taken into account. For example, knowledge spillovers from technological innovation are likely to be an important consideration for the energy transition.
- As a corollary of the previous observations, desirable mixes of policy measures vary strongly across sectors. The fact that mixes should be differentiated is compatible with the introduction of carbon pricing – albeit not as a stand-alone measure – thereby allowing to reconcile two seemingly opposed strands of literature in the climate policy domain. Indeed, especially due to its ability to induce energy conservation and raise revenues, resorting to some level of carbon pricing appears to constitute a sound foundation of successful instrument mixes.
- Finally, we note that certain barriers to emissions abatement appear to be challenging to solve with the reviewed policy incentives. Nevertheless, as the sole decarbonisation lever to overcome many hurdles by nature, demand avoidance for the corresponding energy service seems to have been understudied in all sectors.

Policy recommendations

A case can be made for **combinations of policy instruments**, rather than stand-alone carbon pricing, even under the narrow criterion of economic efficiency. Indeed, the superiority once granted to carbon taxes or ETS vanishes once the panoply of additional market failures, exogenous constraints and coexisting policy objectives present in the real world are considered.

Furthermore, we find evidence that desirable mixes of instruments should typically be **differentiated between sectors**, due to the distinct targeted technologies and agents, both of whom face different barriers to decarbonisation. **Implementing carbon pricing at least to some moderate extent in all sectors** – albeit not as a stand-alone instrument – has the potential for substantial positive synergies with many of the reviewed measures. If carefully assembled, packages of measures may benefit from further synergies between its elements, calling for the adage “the total may not be equal to the sum of its parts”, although the principle also applies to poorly designed mixes. A major finding from the literature is that an ETS (i.e. quantity-based instrument) — as opposed to a carbon tax (i.e. price-based instrument) — generally offers more limited potential for synergies with complementary measures. Indeed, given that the emissions cap determining abatement remains fixed in the former case, supplementary instruments cannot further reduce emissions, while typically compromising efficiency. However, from a broader perspective, additional measures may still prove useful if e.g. they allow to implement a more stringent cap ex ante or address additional barriers to decarbonisation.

Nevertheless, given that **trade-offs between various policy objectives remain unavoidable** even with well-designed mixes, the choice of the underlying policy instruments and their design characteristics should follow from a **clear prioritisation of objectives by policymakers**. For instance, improving public acceptability by enforcing subsidies might come at the cost of increased windfall gains, i.e. persons taking advantage of discounts although they would have purchased the new equipment anyway. Similarly, if the prime concern of policymakers is e.g. to avoid “picking winners” among potential

decarbonisation technologies, a market-driven mechanism would be more adapted, but this may compromise the development of currently expensive technologies that could be crucial in the more advanced stages of decarbonisation. When seeking to meet certain criteria – be it environmental effectiveness, economic efficiency, social equity or political feasibility – we offer a word of caution by underlining that **the devil is in the details** and that no general conclusion may be reached regarding aggregate classes of measures. For instance, both a carbon tax and a subsidy programme may be designed such as to have regressive or progressive redistributive effects. We further note that highly complex designs may result in unforeseen and convoluted interaction effects, while also increasing the administrative burden to oversee them. For instance, sophisticated auctioning mechanisms for supporting renewable energy deployment or refined vehicle emissions standards may be appealing on paper but could lead to e.g. unintended strategic behaviour by firms.

As a guiding principle, if a preponderant weight is to be given to environmental effectiveness, namely reaching climate neutrality by 2050, we recommend choosing **policy measures that jointly enable the full set of decarbonisation levers** at the sectoral level – including reducing demand for the energy service – while also addressing most of the corresponding barriers to decarbonisation. Indeed, by enacting a plurality of levers, the risk of a failed transition may be reduced. Employing the transport sector as an illustration, this would correspond to reducing the carbon content of fuels, improving the emissions efficiency of vehicles, switching to low-carbon modes of transport (e.g. public transportation, active mobility) and reducing travel demand. Finally, it cannot be stressed enough that **long-term policy transparency and certainty thanks to clear communication and strong commitments** are important, thereby allowing all economic agents to optimise their decisions and accelerate the transition.

Further information

The underlying scientific paper may be accessed at:

- https://go.epfl.ch/mixes-review

3 Policy brief – Economic effects of net-zero scenarios induced by mixes of policy instruments

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Overview

A growing strand of literature has advanced rationales for resorting to combinations of policy instruments rather than carbon pricing alone to promote greenhouse emissions mitigation. Quantifying the economic effects of such mixes prior to their implementation is however crucial to understanding which trade-offs are consequential and optimising climate policy design. In this regard, computable general equilibrium [CGE] models are a widely-employed class of tools for ex-ante policy assessments in the energy and climate domains, with the notable advantage of capturing economic interaction effects across sectors and countries. Nonetheless, modelling exercises performed so far appear to have missed two key aspects when simulating net-zero scenarios. First, very ambitious abatement targets have either implied extremely high carbon prices (several thousand Swiss francs [CHF] per ton of carbon dioxide [CO_2]), or large-scale use of carbon capture and storage [CCS] and negative emissions technologies [NETs] – even though their potentials for energy-related emissions are limited. Second, studies assessing rich packages of measures are rare and typically focus on a single sector, rather than the whole economy. We contribute to the literature by addressing both of these points in the context of Switzerland's 2050 net-zero target.

Simulating the Swiss energy transition

In order to simulate scenarios compatible with Switzerland's net-zero target, we employed an international recursive-dynamic hybrid CGE model, which is comparable to other CGE frameworks built by reputable modelling teams and institutions across the world and includes bottom-up features. Details of the model are given in Box 1. The Swiss decarbonisation scenarios focus on individual and mixes of policy instruments, as described in Box 2. The considered measures – whether alone or in combination – consisted of:

- carbon pricing (i.e., the Swiss emissions trading scheme [CH-ETS] for the concerned sectors and a uniform carbon tax for the remaining sectors),
- bans on the purchase of high-carbon equipment (i.e., equipment that uses fossil energy for its operation, as opposed to low-carbon, which does not),
- subsidies for the purchase of low-carbon equipment,
- taxes on the purchases of high-carbon equipment.

High-carbon equipment includes combustion engine vehicles and gas or oil boilers, while low-carbon equipment includes battery-electric vehicles and fuel-cell electric trucks, and heating systems fuelled by non-fossil energy carriers. It also includes energy-efficient building envelopes. In the industry sectors, we differentiate between machines and plants running on fossil and non-fossil energy.
The revenues from carbon pricing are redistributed as transfers to households to ensure progressivity (e.g. Vöhringer et al., 2016; Imhof, 2012), whereas subsidy measures are financed via an increase in income taxes. In our model, the recycling of tax revenues and the financing of subsidy expenses translate into household income tax adjustments. Various stringencies and time schedules for the measures are investigated. While mixes of instruments all achieve a fixed target of 3.5 million tons of carbon

dioxide [$MtCO_2$] in 2050, equivalent to a 90% reduction compared to 2019, stand-alone measures are not necessarily as effective.[1]

We assume that the other countries also decarbonise their economies to large degrees. This applies as well to the reference scenario, i.e. the case where the whole world except Switzerland decarbonises.

Main results

- Standard CGE models represent smooth replacement of fossil by non-fossil energy, as the price of the former relative to the latter increases. This representation implies that an extremely high relative price of fossil energy is needed to drive it out of the market. It can be replaced by a more realistic (logistic) representation of technology adoption, which has the property that the "winning" technology diffuses faster in the extremes. As a result, the carbon price needed for deep decarbonisation is significantly smaller, as are the costs in terms of gross domestic product [GDP] and household consumption.
- Under standalone carbon pricing, decarbonising the Swiss economy to a great extent in a context of global deep decarbonisation, would cost in the order of 0.2% of real GDP per annum on average (non-discounted) over the 2025-2050 period. From a dynamic perspective, carbon pricing progressively reduces GDP up to 2050 (-0.4%), when the carbon tax is highest, both adversely affecting consumption and terms of trade.
- When the sole instrument leading to deep decarbonisation is carbon pricing (tax and ETS), this generates enough revenue to allow for significant income tax reductions: 3.8 billion CHF_{2022} per year on average over the 2025-2050 period, with a peak of 6.4 billion CHF_{2022} in 2044.
- Bans on the purchase of new high-carbon equipment are highly effective as a standalone measure conditional upon timely implementation. For the residential sector, this implies enforcing a ban at latest by 2030. For the transport sector, waiting a few more years would be sufficient, given the shorter lifetime of vehicles. In energy-intensive industries, with the very long lifetimes of their machinery, an immediate ban is needed, but very few clean alternatives are currently available.
- Conversely, our results indicate that subsidies on the purchase of low-carbon equipment constitute the least effective measure when implemented as a standalone, because a great deal of its effect is lost when beneficiaries spend the extra income or take advantage of the reduced prices of goods manufactured in Switzerland (rebound effect). Subsidies alone do not allow to reach the 3.5 $MtCO_2$ target in 2050, even when assuming an immediate implementation in all sectors and maximal subsidy rates. Indeed, standalone purchase subsidies attain a mere 6.7 $MtCO_2$ by 2050, thus seriously compromising the objective of climate neutrality for Switzerland once non-energy emissions are taken into account.
- Turning to instrument mixes, the necessary carbon price to steer the Swiss economy towards climate neutrality is significantly reduced when concurrent policy measures are implemented. It can be divided by two to three throughout the simulation horizon, compared to the case of standalone carbon pricing, still reaching a level of 585 to 875 CHF_{2022}/tCO_2 by the year 2045 depending on the instrument mix. The price signal required to abate the final emissions tends to rise sharply in the two years preceding 2050. Yet, 90% of the emissions abated are not subject to carbon taxes above 1,000 CHF_{2022}/tCO_2.
- The lower carbon price combined with other instruments lowers public revenues, and thus the possible income tax reductions, particularly if the supporting instruments are subsidies rather than bans.

[1] For the same emissions scope, Prognos et al. (2021) obtain a lower value of 1.0 $MtCO_2$ stemming entirely from industry; indeed, full decarbonisation of given sectors remains challenging with CGE models.

- Certain combinations of instruments may avoid depressing GDP or even stimulate economic growth, although only slightly. Especially, subsidies on the purchase of low-carbon equipment in the residential sector, which combines heat-pumps with energy refurbishment, tend to have an expanding effect on GDP, given that energy refurbishment is carried out by the Swiss construction sector, without international spillovers.
- In all scenarios with a carbon price, it is made to rise over time until the mitigation target is met in 2050, whereas purchase subsidies, taxes, and bans are kept constant after implementation. This allows for interesting trade-offs across time for the levels of GDP, income taxes and household consumption. For instance, combining carbon pricing with a purchase ban may limit polluters' options for reducing their emissions compared to standalone carbon pricing, and thereby impose a penalty on GDP and household consumption when the regulatory measure is first introduced. However, the highly effective nature of the ban accelerates the adoption of low-carbon equipment, which mitigates the burden of the carbon price over time. As another example of interesting dynamics, mixes involving generous subsidies typically impose a high burden on taxpayers in the early years of their implementation – when a surge in financing needs arises and revenues from the carbon tax do not suffice to rebalance the public budget – but also in the later years of the simulation horizon – when revenues from the carbon tax decrease, this time due to reduced emissions, and large parts of the low-carbon equipment need to be renewed.
- Regarding the breakdown of non-abated emissions in 2050, all considered decarbonisation scenarios indicate that the residential sector continues to generate significant emissions (1.0-1.3 $MtCO_2$), unlike household private transport which is largely decarbonised.
- Sectors participating in the Swiss emissions trading system are found to rely extensively on purchases of emissions permits, from the EU-ETS market, to comply with their abatement target. Indeed, net purchases of allowances represent in the order of 2.8-3.1 $MtCO_2$ by 2050 given the relatively low cost at which they are available to Swiss firms, thanks to European negative emissions technologies. Within our modelling framework, a significant fraction of these unabated emissions stems from the power sector, which is assumed to rely on natural gas for grid balancing. Nonetheless, studies focusing specifically on electricity markets typically demonstrate that with the right capacity and infrastructure investments, the Swiss power sector may be entirely decarbonised.
- Under climate-neutral scenarios, energy consumption in 2050 is lower by 19% to 27% compared to the case where Switzerland does not decarbonise. The greatest reduction is achieved with standalone carbon pricing, as the measure also induces energy conservation in addition to incentivising the switch from fossil to non-fossil energy carriers. Mixes involving generous subsidies reduce energy consumption the least, given their encouraging effect on consumption of clean energy equipment. All decarbonisation scenarios feature a high share of electricity (approx. 55%) in the Swiss energy mix.

Policy recommendations

Our simulations of scenarios compatible with Switzerland's 2050 climate neutrality objective indicate that **mixes of policy instruments allow to significantly reduce the carbon price** required to reach given abatement targets. High carbon prices are seen as a major barrier to the enactment of ambitious climate policy, even when revenues collected from the measure are redistributed to households in a progressive way. Therefore, incorporating additional instruments into the landscape represents an opportunity.

In a context of global deep decarbonization, **reducing Swiss energy-related emissions to levels close to the net-zero target may have limited effects on Swiss gross domestic product [GDP]**. Compared to the case where Switzerland does not decarbonise, we find a maximum GDP loss of 0.2% per year on average (non-discounted) over the 2025-2050 period. It could even be turned into a GDP gain if subsidies on the purchase of low-carbon equipment (including building refurbishment) boosts sectors less exposed to international competition, such as construction. Nevertheless, household

consumption cumulated over the whole simulation horizon remains adversely affected regardless of the instrument mix. Although not the focus of our research, a sudden hike in investment demand across all sectors could result in potential bottlenecks, such as labour and materials shortages for refurbishing buildings, hence pointing towards the need to set up e.g. (re-)training programmes. Crucially, such **subsidies should not be implemented on their own given their limited climate effectiveness, in particular for non-transport energy use by firms**, due to significant rebound effects. Indeed, by lowering production costs, subsidies boost firms' outputs, thereby increasing their use of fossil energy carriers and counterbalancing the initial effect of switching toward non-fossil energy carriers.

Furthermore, our modelling exercise highlights the **importance of considering (sub-) sectoral lifetimes of energy-related equipment when designing packages of policy tools and setting the stringencies as well as the implementation schedule thereof**. Indeed, for a sector to reach zero energy-related emissions by 2050, it is necessary that the last investment into high-carbon equipment is made at latest in the year equal to 2050 minus the lifetime of the equipment, so that the vintage is replaced at latest in 2050. In this regard, **bans on the purchase of high-carbon equipment are a very effective way, if they are implemented in a timely manner – much more than taxes and subsidies**. The latter are found to provide insufficient incentives to reach zero emissions from energy **in key sectors, especially buildings but also transport**, despite the existence of readily-available low-carbon equipment.

Regarding implementation schedules, a progressive phase-in of subsidies – whereby the bulk of low-carbon equipment with longer lifetimes (e.g., heating systems, machines in energy-intensive industries) is targeted first, while the bulk of low-carbon equipment with shorter lifetimes (e.g., trucks) is targeted later on – could prove more feasible in terms of public financing needs. In addition, aiming for a smooth but steady energy transition could avoid bottlenecks related to updates in the power supply infrastructure required for an electricity-dominated economy, although this constitutes a consideration beyond the scope of our study. We further advocate a **prudent approach in setting timelines of all instruments**, in that fixed average sectoral equipment lifetimes fail to take into account both the diversity of lifetimes in a given sector and various sources of uncertainty (e.g., agents potentially extending the lifetime of high-carbon equipment to take advantage of higher subsidies in the future), both of which may reduce the effectiveness of decarbonisation measures.

Box 1: the GEMINI-E3 model

In addition to Switzerland, four international regions were represented based on countries' economic fundamentals and climate policy ambitions, namely: the European Union [EU] together with the United Kingdom [UK], the remaining members of the Organisation for Economic Co-operation and Development [OECD], China, and the rest of the world. The Swiss economy was structured according to a classification of 21 production sectors, including energy-transforming sectors (e.g. refining, power, district heating), energy-intensive industries (e.g. cement, pharmaceutical and chemical products) and various transport sectors (e.g. road, rail), as displayed in Table 1. Regarding energy carriers, the model includes coal, crude oil, natural gas, refined oil, electricity, district heating, biofuels, biogas, wood, waste, as well as green hydrogen. Furthermore, a total of 13 power plant technologies are accounted for in the electricity generation sectors.

Carbon capture and storage [CCS] for Swiss industry plants was not modelled, given the ability of concerned firms to offset emissions via allowance purchases in the Swiss emissions trading scheme [CH-ETS]. The scope of emissions taken into account consists of Swiss territorial CO_2 emissions from energy, excluding emissions from international aviation and from waste, after deduction of net purchases of EU-ETS allowances. The model has an annual time resolution and extends to the year 2050. Its business-as-usual scenario is in line with the *Weiter-wie-Bisher* scenario of the Energy Perspectives 2050+ (Prognos et al., 2021) for Switzerland, and authoritative international sources for the other regions.

Table 1: Sectoral classification in GEMINI-E3

Sector		Sector	
#	Name	#	Name
01	Coal	12	Construction
02	Crude oil	13	Other Industries
03	Natural gas (ETS)	14	Passenger rail & land transport
04	Refined oil (ETS)	15	Freight rail transport & Pipeline
05	Electricity (ETS)	16	Freight road transport
06	District heating (ETS)	17	Water transport
07	Agriculture & Fishing	18	Domestic air transport
08	Forestry	19	International air transport
09	Mineral (ETS)	20	Services
10	Pharma & chemical products (ETS)	21	Green hydrogen
11	Other EII (ETS)		

Notes: emissions trading scheme [ETS], energy-intensive industries [EII]. Source: own elaboration.

Compared to previous versions of the model, the framework was augmented in two major ways. First, we changed the dynamics which replace fossil by non-fossil energy carriers – and corresponding technologies – altering the function that governs that process such that the dynamics follow the empirically-observed S-shape. This alleviates the well-known issue of "sticky" substitution dynamics that has required previous CGE modelling studies to rely on questionable levels of CCS and negative emissions technologies [NETs], or very high carbon prices to reach deep decarbonisation targets. Since standard neoclassical assumptions regarding input substitution no longer hold in such a context, we refer to the model as "hybrid". Second, we explicitly represented the energy-specific capital (e.g. gas boilers, heat pumps, building envelopes, vehicles) transforming energy carriers (e.g. gas, electricity, diesel) into energy services (e.g. heating, transport), termed high- and low carbon equipment in this text. To maximise policy realism, our decarbonisation scenarios assumed subsidies and bans would be targeted at this equipment, rather than the energy carriers themselves. In the case of the residential sector and firms' non-transport energy use, explicit equipment vintages were also modelled to better take into account their turnover.

Box 2: the Swiss decarbonization scenarios

Below, we describe the Swiss decarbonisation scenarios in terms of rationale, instruments, stringencies and timing.

- Standalone carbon pricing
    - Rationale: policy measure to abate emissions regularly endorsed by many economists.
    - Instruments: increase of the uniform carbon tax over time in sectors which do not participate in the Swiss emissions trading system [CH-ETS]; proportional reduction of the CH-ETS cap with auctioning of the corresponding allowances.
    - Timing: as of 2025.
- Hard prescriptions (mix 1)
    - Rationale: preponderant use of prescriptive policy measures in environmental policies.
    - Instruments: bans on the purchase of high-carbon equipment, combined with more lenient carbon pricing.
    - Timing of purchase bans: as of 2035 in all sectors, except firm own transport (2045) and firm non-transport by energy-intensive industries (exonerated).
    - Timing of carbon pricing: as of 2025.

- Hard prescriptions (mix 2)
    - Rationale: preponderant use of prescriptive policy measures, with the addition of subsidies to improve acceptability.
    - Instruments: bans on the purchase of high-carbon equipment, combined with more lenient carbon pricing, as well as subsidies for the purchase of low-carbon equipment (60% for fuel-cell electric “hydrogen” trucks, 25% for all remaining technologies, based on price differentials between low- and high-carbon alternatives).
    - Timing of purchase bans: as in HP1.
    - Timing of carbon pricing: as of 2025.
    - Timing of purchase subsidies: 10 years prior to purchase bans.
- Rewards (mix 3)
    - Rationale: preponderant use of subsidies to reward climate-friendly behaviour.
    - Instruments: generous subsidies for the purchase of low-carbon equipment (80% for fuel-cell electric “hydrogen” trucks, 50% for all remaining technologies), combined with more lenient carbon pricing.
    - Timing of purchase subsidies: as of 2025.
    - Timing of carbon pricing: as of 2025.
- Rewards (mix 4)
    - Rationale: preponderant use of subsidies to reward climate-friendly behaviour, combined with purchase taxes on carbon-intensive technologies.
    - Instruments: generous subsidies for the purchase of low-carbon equipment (as in R1), combined with more lenient carbon pricing, as well as taxes on the purchase of high-carbon equipment (30% for all technologies, based on price differentials between low- and high-carbon alternatives).
    - Timing of purchase subsidies: as of 2025.
    - Timing of carbon pricing: as of 2025.
    - Timing of purchase taxes: as of 2025

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Further information

The two underlying scientific papers may be accessed at:

- https://go.epfl.ch/logistic-substitution
- https://go.epfl.ch/mixes-simulations

4 Policy brief – Public acceptability of instrument mixes in Switzerland

Authors: Fleance Cocker (EPFL), Philippe Thalmann (EPFL), Sylvain Weber (HES-SO)

Overview

Lack of social support has been identified as a major barrier to implementing ambitious climate policies. Opposition to carbon pricing has been particularly strong, due to the public's concerns about distributional effects and the perceived ineffectiveness of the measure – although various studies have shown that this fear is generally unwarranted (Vöhringer et al. 2016; Imhof, 2012). This had led scholars to investigate citizen support for alternative classes of instruments and deduce that subsidy programmes as well as command-and-control measures may typically enjoy higher levels of acceptability for various reasons. We contribute to this literature by considering two novel aspects that are expected to play a key role in preference structures. First, we explore combinations of instruments, rather than stand-alone measures only, thereby offering the possibility to alleviate shortcomings of individual policy tools. Second, we take into account an explicit sectoral nomenclature, in opposition to economy-wide measures, allowing for finer preferences elicitation, e.g. with respect to targeted agents (households vs. firms).

The survey

We conducted a stated-preference survey among Swiss residents on their favourite way to reach Switzerland's 2050 net-zero emissions target. Specifically, the sample on which we based our analyses consisted of 1,821 persons who were representative of Switzerland's overall population in terms of sex, age categories and language regions (German, French, Italian). The survey consisted of a series of tasks to be completed on an online interface designed in-house specifically for the purpose of the project.

In a first part, respondents were asked to design their preferred instrument mix in each of the transport, buildings and industry sectors. The five considered instrument classes, which could be implemented individually or in combination at the sectoral level, were as follows:

- a sectoral carbon tax,
- a tax on the purchase of new high-carbon technologies,
- a subsidy on the purchase of new low-carbon technologies, as well as for public transportation in the relevant sector,
- an efficiency standard on the purchase of new technologies,
- a ban on the purchase of new high-carbon technologies.

High-carbon technologies referred to e.g. internal combustion engine vehicles, gas or oil boilers, as well as production equipment relying on fossil fuels. Low-carbon technologies referred to e.g. battery-electric vehicles and public transportation, heat pumps and energy-efficient building envelopes, as well as production equipment relying on non-fossil energy carriers or carbon capture and storage [CCS]. Every measure was described in terms of direct effect (incentive given towards decarbonisation), scope (users affected by the instrument), and indirect financial effect (revenue recycling, financing needs, or neutral). By setting instrument implementation levels on a five-point scale, ranging from 0 (the measure is not implemented at all) to 4 (the measure is very strongly implemented) and observing their effect on emissions abatement thanks to a dynamic chart, respondents could design a tailored instrument mix leading to zero emissions in 2050. The sectoral target could be met by setting a single measure to its maximum implementation level, implying that mixes were not required a priori.

Main results

- We find evidence of strong public support for ambitious climate policy, across all population strata, as measured by the acceptance rate of the submitted scenario in a hypothetical referendum. Indeed, depending on how we define persons who would vote against their own proposal, an approval rate between 76% and 85% is obtained. While encouraging, we argue that the result is likely due to facilitating factors that would not occur in a real-life vote. Nevertheless, we deduce that there is potential to leverage this favourable outcome with carefully designed policies.

- Many participants selected stringency levels for the policy instruments such that the sectoral zero-emission targets would be reached earlier than 2050, something they were made aware of through various prompts. This result can be interpreted as support for more ambitious targets, although it is not clear that such respondents were aware of the efforts this would require.

- Furthermore, our analyses indicate that, only a small minority of respondents rely on a single policy measure in any given sector to achieve the net-zero emissions target; indeed, the vast majority has an inclination towards implementing a combination of instruments, possibly to reduce the shortcomings of, and risks associated with, individual policy tools. Absent a contextual evolution and any further information that might affect the appraisal of measures by Swiss citizens, there is thus a strong case for resorting to instrument mixes if public acceptability is to be prioritised.

- In addition, we see that respondents tend to choose different measures in different sectors. Indeed, the purchase ban tends to be opposed in the transport sector, a result to be considered seriously given the recent EU regulation banning the sale of new petrol and diesel cars from 2035. A similar ban would not be easily transferrable to Switzerland, at least in the short run. Conversely, the purchase subsidy systematically comes out as the preferred tool in all sectors, in the sense that it tends to enjoy the highest implementation level, in line with the existing literature.

- In terms of language regions, we find that German-speaking participants are slightly less hostile towards the carbon tax and less in favour of subsidies than persons from Romandie or Ticino, a result that is robust across all three sectors. Finally, the industry sector displays the most balanced preferences between instruments in all three language regions, possibly pointing towards the fact that the consequences of decarbonising industry with a specific measure are less tangible for the lay person compared to transport or buildings.

- Sociodemographic characteristics tend to have little predictive power regarding the choice of instrument implementation levels, a finding consistent with the previous literature, which highlights the role of deeper beliefs and world views.

- An exception to the previous observation is the number of cars in the respondent's household which significantly affects instrument choice, even beyond the transport sector. While surprising at first sight, this result corroborates the well-established observation that self-interest motives and material factors are not the only determinants of people's attitudes with respect to climate policy, and that this variable may act as a proxy of deeper personal attitudes. Generally, the greater the number of cars, the higher the preferred level of the purchase subsidy, and the lower the favoured stringencies of the purchase ban and the carbon tax. The last effect dissipates in the industry sector, suggesting that the type of agent (household vs. firm) directly affected by the measure may play a role.

- In addition, the strongest predictor of instrument choice is the more subjective measure of perceived danger caused by climate change for the environment and people in Switzerland. Indeed, the optimal level of the purchase subsidy decreases in the severity of perceived danger, while that of the purchase ban increases. We hypothesize that persons who perceive global warming

as dangerous for Switzerland favour the more constraining ban because they may see it as a more effective tool to abate emissions than subsidies in the real world, despite being equally effective in our experiment.

- Lastly, we observe that a large variety of instrument mixes were chosen in every sector, indicating that meeting individual preferences would be – without surprise – impossible. However, thanks to clustering algorithms, stylised mixes which represent large groups of people with similar preferences were unravelled. Especially, we find that all sectors featured similar stylised mixes, namely: (i) a balanced mix with quite similar contributions by all instruments, which also happens to be the most popular, (ii) mixes showcasing a preeminent purchase subsidy and/or purchase standard, and (iii) a mix favouring the carbon tax and/or the purchase tax.

Policy recommendations

The data collected through our stated-preference survey suggest that **a majority of Swiss citizens were in favour of reaching zero emissions from energy by 2050** and that they have a **strong preference for combining various policy instruments** toward that end. Indeed, policy scenarios relying on a single instrument among the ones considered – namely a carbon tax, a tax on the purchase of new high-carbon technologies, a subsidy on the purchase of new low-carbon technologies (including public transportation in the relevant sector), an efficiency standard on new technologies, and a ban on the purchase of new high-carbon technologies – were only chosen in a minority of cases.

The **existence of distinct preferences across language regions and sectors calls for some level of differentiation** across these dimensions, which could be reflected in cantonal climate policy where possible. The French-speaking cantons and Ticino could be more generous with purchase subsidies for low-carbon solutions, while German-speaking cantons could favour measures that render carbon emissions more expensive. In terms of sectoral divergences, **support for the purchase ban is the least strong in the transport sector**, suggesting that any national policy seeking to anticipate the European Union regulation in that respect would be counterproductive at this stage. At the same time, **the purchase subsidy – including for public transportation in the relevant sector – should be given priority in the transport and buildings sectors more so than in the industry sector**. The last sector may rely on even contributions from all considered measures – at least from the perspective of public acceptability, which neglects industry interests.

Furthermore, since the number of cars in the household is a meaningful determinant of preferences, any effort made in successfully reducing the appeal of individual motorised transport prior to implementing price-based or regulatory instruments would help. Improving the service levels of public transportation or facilitating short-distance trips via careful urban planning may constitute potential solutions, although they were not investigated in our study.

Finally, **the most significant predictor both of support for ambitious climate and of instrument choice is the perceived danger of climate change** for the environment and people in Switzerland. Therefore, the importance of **educating the general public about anthropogenic global warming and reinforcing trust in scientists** cannot be stressed enough. Although four in five respondents already perceive the phenomenon to be dangerous, a share in line with data recently published by the Federal Statistical Office [FSO], increasing the awareness of the remaining persons may prove crucial in federal ballots where vote margins have sometimes been thin. In addition, people's instrument preferences may become more similar if their perception of climate change risks becomes more accurate. As a result, the odds of a favourable voting outcome would be increased when a common package of measures is proposed.

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Further information

The underlying scientific paper may be accessed at:

- https://go.epfl.ch/mixes-acceptability

5 Conclusions and outlook

The results of the DECARB research project clearly indicate that optimal climate policy relies on combinations of decarbonisation instruments. While no substitute to the main findings presented in the individual policy briefs, we herein discuss the inter-relationships between some key outcomes, given that common themes emerge from our three-pillar approach.

First, it is well established in the literature that carbon pricing as a stand-alone instrument suffers from a lack of public support, despite typically becoming more acceptable once its purpose and its functioning is properly explained to the public (e.g. Vöhringer et al. 2016). Indeed, voters tend to be highly concerned by the adverse redistributive effects of the measure – although this has been shown to be unwarranted in many cases – especially when the price signal is strong. This is confirmed by our survey on acceptability, where carbon taxes are rarely chosen as a single and highly stringent instrument to decarbonise the transport, buildings or industry sectors in Switzerland. At the same time, our quantitative assessment of scenarios compatible with climate neutrality confirms that mixes of policy instruments allow to significantly reduce the level of a carbon tax needed to meet abatement targets.

Second, the data from our stated-preference survey suggest that Swiss citizens have an inclination toward implementing subsidies on the purchase of low-carbon technologies – as well as for public transportation – in the transport and buildings sectors, more than in the industry sector. Concurrently, our numerical simulations indicate that purchase subsidies on carbon-free equipment are not effective in abating emissions in the industry sector due to significant rebound effects, but constitute effective decarbonisation measures in the transport and buildings sectors. Simultaneously, our review of the literature indicates that by targeting vulnerable households with subsidies rather than distributing them indiscriminately, one avoids that these subsidies trigger more energy consumption through rebound effects. This would be a second benefit of targeting subsidies, in addition to addressing equity concerns that may occur during the energy transition.

Third, our review of the literature highlights the need to prevent a “carbon lock-in”, i.e. conditions which delay the diffusion of carbon-free technologies and accentuate the dependence on fossil fuels, across all emitting sectors. Notably, carbon pricing is found to potentially induce this phenomenon by increasing financial barriers to the adoption of low-carbon equipment given the additional energy expenses. A complementary conclusion is reached with our numerical simulation framework. Indeed, when carbon prices are moderate and agents do not anticipate that they will be much higher in the (distant) future, the incentive to fully switch to low-carbon technologies is insufficient, highlighting the need for adequate policy design. Therefore, in our model, the adoption of long-lived fossil-based equipment that will still be in operation in 2050 continues, and the carbon price in the final years leading up to 2050 must drastically increases to make up for the lost ground. While not a weakness of carbon pricing per se, it highlights the need for strong commitments and clear communication (e.g. Bayer & Aklin, 2020). Simultaneously, according to our survey, ambitious climate policy is supported by a majority of persons in Switzerland, a large share of which even indicated that they would rather reach climate neutrality before mid-century – although they may have underestimated the required efforts to do so. Furthermore, our survey reveals that bans on the purchase on new carbon-intensive equipment in the buildings sector are not necessarily opposed by the Swiss population. Concurrently, the same instrument also happens to be particularly effective in decarbonising the buildings sector in our simulation framework, conditional upon early implementation. The literature we reviewed also suggests that bans are not necessarily as economically inefficient as traditionally advanced, due to the pervasive behavioural hurdles to decarbonisation in that specific sector which weaken the effect of incentive-based instruments.

Finally, despite not being the focus of the research project, all our analyses implicitly point toward the importance of information campaigns on the topic of climate change and the energy transition. As a complement, strong commitments toward climate targets would allow for a smooth energy transition.

In terms of future research, we identify two promising avenues, namely improving the current understanding of distributional consequences of various measures in Switzerland and investigating in more depth the optimal sequencing of policy instruments in a mix.

6 National and international cooperation

We collaborated with the market research company Intervista for the dissemination of the survey on stated preferences

7 Publications and other communications

As a result of the research project, four working papers were written, which are to be submitted and eventually published in peer-reviewed journals.

- Cocker, F. (2024). Mixes of policy instruments for the full decarbonisation of energy systems: a review. Available at: https://go.epfl.ch/mixes-review
- Cocker, F., Thalmann, P., & Vielle, M. (2024). Input factor substitution under climate-neutral pathways. Available at: https://go.epfl.ch/logistic-substitution
- Cocker, F., Thalmann, P., Vielle, M., & Vöhringer, F. (2024). Mixes of policy instruments towards climate neutrality in a computable general equilibrium framework. Available at: https://go.epfl.ch/mixes-simulations
- Cocker, F., Thalmann, P., & Weber, S. (2024). Reaching zero emissions with mixes of policy instruments: An assessment of public acceptability in Switzerland. Available at: https://go.epfl.ch/mixes-acceptability

In addition, some of the above studies were presented at national and international conferences:

- Fleance Cocker presented “Input factor substitution under climate-neutral pathways” at EAERE 2023 (27–30 June 2023).
- Fleance Cocker presented “Input factor substitution under climate-neutral pathways” at the SAEE Student Chapter Workshop (18 October 2023).
- Fleance Cocker presented “Mixes of policy instruments towards climate neutrality in a CGE framework” at EAERE 2024 (1-4 July 2024).

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9 Appendix

None.