Accelerating the diffusion of energy-efficient building technologies with policies – The case of Switzerland

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Abstract. The diffusion of energy-efficient building technologies is crucial for decarbonizing the building sector. However, many of these technologies diffuse slowly despite being economically superior compared to carbon-intensive alternatives. This study analyzes how combinations of different policies can effectively close this energy-efficiency gap. Applying an agent-based model that represents construction planning in Switzerland between 1995-2015, we ex-post evaluate the impact of four policies – financial incentives, mandatory building energy codes, voluntary energy labels, information campaigns – on the diffusion of three technologies – heat pumps, comfort ventilation, low-e glazing. Results indicate type and timing of policy combinations as key for successful technology diffusion.

1. Introduction

The energy sector offers a remarkable potential for the reduction of energy demand and carbon emissions. For example, energy demand from buildings and activities in buildings account for 31% of global final energy demand [1], of which three-quarters are for thermal purposes. This demand could be reduced by about 46% by 2050 compared to the 2005 levels by applying today’s best practice energy-efficient building technologies (EEBTs) – technologies that either use renewables as an energy source or are more efficient than standard solutions [2].

However, many of these EEBTs still do not, or only slowly diffuse despite being economically superior compared to their carbon-intensive alternatives [3]. As a consequence, many countries introduced policies to support the uptake of EEBTs. Policies that have proven to be effective to achieve this goal are financial incentives, mandatory building energy codes, voluntary energy labels, and information campaigns [4]. Although the general approach of supporting diffusion of EEBTs with policies is well understood, we require a better understanding of how policies are successfully tailored to the specific characteristics of different EEBTs [5], introduced over time in a larger policy mix [6], and can target actors’ decision-making during construction planning. However, most studies that evaluate the impact of policies on the diffusion of EEBTs consider construction planning as a black box rather than the complex multi-stakeholder process it is.

To fill this gap, in this study, we open the black box of actor’s decision-making in construction planning and quantify how policies can effectively target involved stakeholders and, in turn, accelerate the diffusion of EEBTs. To do so, we develop an agent-based model that represents construction planning in Switzerland, and ex-ante simulate the diffusion of three successful EEBTs in Switzerland, namely heat pumps, comfort ventilation, and low-e glazing, from 1995 to 2015. Agent-based modelling
is particularly well suited to do so, as it allows to analyze both the local interaction of stakeholders in different construction projects and how individual policies influence these stakeholders.

2. The case of energy-efficient building technologies in Switzerland

In Switzerland, energy demand from buildings is even higher than the global average, reaching a share of 44% of final energy demand, and an equally important share of CO₂ emissions in 2016 [7]. The Swiss building stock is dominated by residential buildings, which were built before 1980 and use 80% of their energy demand for space heating and domestic hot water. Solutions to reduce this energy demand thus focus mainly on building systems that address the energy use for heating, in particular, the building’s envelope, heat distribution, and heat generation.

For each of these building systems, we select one energy-efficient building technology based on the following selection criteria: (i) a market share higher than 30% in Switzerland – successfully diffused technologies allows us to identify the mechanism between policy interventions and diffusion; (ii) significant support by policies – the analysis of policies is the main focus of this study; (iii) Switzerland is considered to be the lead market – we thus assume that technology diffusion has not been affected by the presence of foreign policies or global technological development. Applying these criteria, we selected the following three technologies:

Heat pumps are devices that use electricity to transfer heat from a low-temperature source to a high-temperature source based on thermodynamic principles. Heat pumps began to diffuse in the 1970s with an increasing number of companies entering this promising market. However, many firms started using low-cost components and undersized designs which caused malfunctioning of the heat pumps, resulting in a distrust towards the technology and, ultimately, in a market collapse at the end of the 80s in Switzerland. Later, due to increased performance and standardisation of the components, the market share for heat pumps stabilised again, peaking already in 2008.

Comfort ventilation represents a ventilation system used in residential buildings. It supplies fresh air, removes exhaust air, and supports heat recovery. The demand for comfort ventilation increased with stricter requirements for insulation and airtightness of the building envelope as owners of energy-efficient buildings experienced problems of bad air quality and mildew. The installation of comfort ventilation addresses both problems while keeping energy use low by bringing fresh air into the apartment and simultaneously using the old air for heat exchange. Comfort ventilation started to diffuse in 1995. Initially installed in larger buildings only, in 2000, the sales also increased for single-family buildings.

Low-e glazing indicates a float glass which is coated with low-e, a thin layer of metal applied on top of the glass sheet. As a result of this treatment, the window shows a reduction in both emissivity and the heat transfer coefficient. It can consist of two or three layers, namely “double insulating glass” and “triple insulating glass”. In the following, we refer to the latter technology as low-e glazing.

Policies played an essential role for the diffusion of all three technologies. In 1986, the first national building energy code – while not being binding – was established, renewed in 1992, 2000, 2008, and 2014. Since the 2008 update, energy performance requirements mandate the installation of low-e glazing due to strict requirements for the building envelope and list heat pumps and comfort ventilation as a standard solution for compliance [8]. In 1994, the voluntary energy label named Minergie label was introduced and has been widely adopted since then. Between 2008 and 2014, the number of constructions according to Minergie increased from below 10% to almost 30%. Minergie requires the installation of low-e glazing and –although not explicitly mandating – promotes the installation of comfort ventilation. Nowadays, about 98% of Minergie buildings have installed comfort ventilation. Concerning information campaign, in the early 1990s, several Swiss municipalities initiated pilot projects of energy autarkic buildings with comfort ventilation. Additionally, in 2000, the Swiss Energy program launched the public leadership program “Energy2000”, aiming to support the diffusion of comfort ventilation. For heat pumps, in 1993, industry actors founded the Swiss heat pump promotion association, which coordinated information campaigns on education, training and networking activities.
Financial support for heat pumps was introduced in the 1990s while peaking in 1996 when adopters of heat pumps received a lump sum of CHF 3000; this amount was dropped to CHF 300 in 2007 and has remained at this level since then. Further, in 2006, the so-called ‘Gebäudeprogramm’ began to provide financial incentives for low-e glazing when retrofitting and constructing buildings.

3. An Agent-based model for construction planning in Switzerland

Our model aims to quantify the impact individual policies – while being part of larger policy mix – have on actors’ decision-making during construction planning and subsequently on the diffusion of three energy-efficient building technologies, namely heat pumps, comfort ventilation, and low-e glazing (c.f., Figure 1).

The scenario inputs to the model are four policies, namely (I) financial incentives, (II) building energy codes, (III) voluntary energy labels, and (IV) information campaigns. Our model represents the decision-making process for all new and retrofitted, residential and non-residential building construction projects in Switzerland. To do so, it depicts Switzerland’s awarding authorities (i.e., private, commercial and public) and construction organizations (i.e., general planner, general contractor, and singular contractor). We simulate the interaction between awarding authorities and construction organizations between 1995 and 2015, each year executing the three modules, namely ‘strategic planning’ (by awarding authorities), ‘design development’ (by construction organizations), and ‘project evaluation’ (by awarding authorities). The key outputs of our model are the diffusion of three energy efficient building technologies, namely (A) heat pumps, (B) comfort ventilation, and (C) low-e glazing. We calibrate the model based on historical deployment and policies. To derive the number of building construction projects, we develop a unique data set, which combines data on total annual investment in Switzerland, data on all Swiss buildings including location, type, and age (both received from the Swiss Federal Statistical Office), and the average construction project sizes from one representative region (received from the city of Zurich). In the following we describe Module 1 and 2 in more detail:

**Figure 1: Overview of ABM.**

**Module 1:** In the ‘strategic planning’, awarding authorities make the project specifications and select construction organizations. For the former, awarding authorities specify – besides the type and size of the building and budget limits – the target for buildings’ energy performance. While building energy codes define a minimum energy performance that the building has to comply with, awarding authorities can also opt for a stricter energy performance target to receive a voluntary energy label. The decision-making for the building’s energy performance target is affected by three decision criteria, namely the environmental awareness of the awarding authority (i.e., normalized distribution across the population), the experience of the awarding authority with voluntary energy labels (i.e., number of label projects done by awarding authority), and the general available information on voluntary energy labels (i.e., total number of label projects in Switzerland). If the weighted sum of the three normalized decision criteria

| Scenario inputs | Agent-based model | Key outputs |
|-----------------|------------------|-------------|
| **Policy Instruments:** | **Module 1: Strategic Planning** | **Technology Diffusion:** |
| I. Financial Incentives | **Module 2: Design Development** | A. Heat Pump |
| II. Building Energy Codes | **Module 3: Project Evaluation** | B. Comfort Ventilation |
| III. Voluntary Energy Labels | | C. Low-e Glazing |
| IV. Information Campaigns | | |
exceeds the expected higher costs of building according to the energy label – which we measure as the ratio of the stringency levels of the energy label and the building energy code – then the awarding authority opt for the energy label. Further, awarding authorities choose the type of construction organization to work with. In our model, the selection of the construction organization is affected by four decision criteria, namely the risk aversion of the awarding authority (i.e., different types of construction organization take over parts of project risks), experience of the awarding authority with the individual construction organizations (i.e., number of projects done in collaboration), their spatial proximity, and the experience of the construction organization with the project specificities (i.e., if the awarding authority opts for the energy label, then number of label projects done by construction organization). Awarding authority chooses the construction organization with the highest weighted sum of the four normalized decision criteria.

Module 2: In the ‘design development’, selected construction organizations provide their project recommendation concerning technologies for the building’s envelope, heat distribution, and heat generation. For each of these three building system, they recommend the technology with the highest “utility”. Four decision criteria affect technologies’ utility in our model, namely the general information available on the technology (i.e., number of installations of technology plus information campaigns), the experience of the construction organization with the technology (i.e., number of installations of the technology done by the construction organization), the technology performance (i.e., relative performance compared to other technologies, for example, U-Values for building envelope technologies), and the technology cost (i.e., upfront investment cost minus financial incentives). The utility of each technology is then calculated as the weighted sum of the four normalized decision criteria.

Applying the model, we evaluate four distinct policies, namely building energy codes, voluntary energy labels, financial incentives, and information campaigns. Building energy codes define minimum requirements for technologies, building systems, and buildings’ energy performance. Aiming for a voluntary energy labels improves the energy performance of the building but typically comes with higher upfront investment cost compared to the building energy code. Financial incentives reduce investment costs of energy-efficient technologies. Information campaigns demonstrate how a certain technology improves a building’s energy performance and thus increase knowledge of this technology. While for each selected technology, a policy mix is affecting its diffusion, we aim to single out the impact of individual policies by switching off one policy at a time and evaluate the difference compared to the reference scenario. In addition, we evaluate how the focal technologies would diffuse without any policy support.

| Technologies   | All policies | No policies | Scenarios          | No code | No label | No financial | No info |
|----------------|--------------|-------------|--------------------|---------|----------|--------------|---------|
| Heat Pumps     | x            | x           | x                  | x       | x        | x            | x       |
| Comfort Ventilation | x          | x           | x                  | x       | x        | x            | x       |
| Low-e Glazing  | x            | x           | x                  | x       | x        | x            | x       |

4. Results and Discussion

Heat Pumps: Including all historical policies for heat pumps in the ‘all policies’ scenario, this reference scenario shows a similar diffusion pattern compared to the historical data (c.f., Figure 2). Shutting down all policies in the ‘no policies’ scenario, results in a deceleration of the diffusion of heat pumps, while still reaching a market share of around 50% in 2015. In the ‘no financial’ scenario, the diffusion of heat pumps remains stagnant until 2002 with an average adoption rate of 20%. However, between 2003 and 2006, the diffusion sky-rockets up to 68% market share, followed by a deceleration, resulting in a 75% market share in 2015. Removing building energy codes from the policy mix in the ‘no code’ scenario affects the diffusion only starting in 2006, resulting in a 15% lower market share. Without information campaigns in the ‘no information’ scenario, heat pumps diffuse similar to the scenario without any policy support.
Our results show that financial incentives are an essential driver of the diffusion of heat pumps in an early phase, stricter building energy codes become important in a later phase, while information campaigns are a crucial part of the policy mix during the entire diffusion period. In the early phase, financial incentives drive down annual total cost of heat pumps in the beginning of its uptake. Yet, two factors are responsible for the diminishing effect of financial incentives on the diffusion of heat pumps. First, starting in 2004, heat pumps were the lowest-cost technology available even in the absence of financial support. Second, since 1996, financial incentives have been gradually reduced over time. Building energy codes become important at a later stage of the heat pump diffusion by making its adoption almost mandatory for new buildings. However, our findings show that the primary policy driver of the heat pump diffusion are information campaigns. This finding is in line with prior research, which states that market strategies of heat pump producers was targeted at building cooperation with heating engineers, architects and planners [10].

Comfort Ventilation: The diffusion of comfort ventilation under the ‘all policies’ scenario follows historical diffusion patterns and reaches a 35% market share (c.f., Figure 2). Shutting down all policy support in the ‘no policies’ scenario prevents a diffusion. While switching off information campaigns in the ‘no information’ scenario only slightly decelerates the diffusion of comfort ventilation – resulting in a final market share of 28% – switching off labels in the ‘no label’ scenario prevents an uptake of comfort ventilation; by 2030, resulting in a market share lower than 5%.

Our results show that the uptake of the voluntary energy label is key to the diffusion of comfort ventilation. This finding is consistent with literature, which emphasizes Minergie (i.e., the voluntary energy label in Switzerland) as the main drivers for the diffusion of comfort ventilation. While Minergie did no mandate comfort ventilation it recommended its use. In turn, despite it is more expensive compared to alternatives for heat exchange such as radiators and floor heating, almost all Minergie buildings installed comfort ventilation. This was facilitated by a change of customer’s perception concerning comfort ventilation – Minergie shifted the perception from an energy saving device to a comfort enhancer.

Low-e glazing: The diffusion of low-e glazing under the ‘all policies’ scenario follows historical diffusion patterns and reaches a 72% market share (c.f., Figure 2); particularly striking is the drastic increase of the market share in 2016 by more than 20%. Without policy support, however, the ‘no policies’ scenario shows almost no diffusion of low-e glazing, resulting in a 10% market share in 2015.

Figure 2. Overview of results. Sources for historical data: heat pump [10]; comfort ventilation [11]; low-e glazing [12]; model results in ‘all policies’ scenario differ from historical data as a result of the calibration process.
While this highlights the importance of policy support for the successful diffusion of low-e glazing, switching off individual policies do not heavily change this result. Switching off financial incentives for low-e glazing in the ‘no financial’ scenario results in a 20% lower diffusion of low-e glazing, starting in 2006 – the year of the introduction of financial incentives for low-e glazing in Switzerland. In the reference scenario, the combination of this financial incentive and declining prices for low-E glazing due to technological learning led to a lower price of low-e glazing compared to its competitors. Removing building energy codes from the policy mix, the ‘no code’ scenario results in constantly lower diffusion level until 2015 but a particularly stagnant phase between 2008 and 2010. This is mainly because of the adoption of new building energy codes in 2008, which were only achievable by low-e glazing. The diffusion of low-e glazing in the ‘no label scenario’ begins to differ from the reference scenario in 2009. One of the reasons for this difference is the uptake of the voluntary energy label Minergie that pushed the installation of low-e glazing. Between 2008 and 2014, the number of constructions according to Minergie increased from below 10% to almost 30%.

Our results show that, until 2005, the primary driver of low-e glazing diffusion has been the strict requirements of the building energy codes. This is because financial incentives for low-e glazing are only available since 2006 and the share of Minergie buildings was rather small back then. After 2005, all policies affect the diffusion of low-e glazing. Switching off a single policy results in a decline of the diffusion, highlighting the importance of the policy mix. This is also confirmed by experts in this field. They note that, first, the lower price of low-e glazing was key for the diffusion of low-e glazing because the increasing glass quality and established functionality standards triggered adopters’ sensitivity towards prices. Second, they note that strict building energy codes and the launch of the energy label Minergie initiated the technology transition to low-e glazing.

5. Conclusion
In this study, we quantified the impact of individual policies – while being part of a larger policy mix – on actors’ decision-making in construction planning and, in turn, on the diffusion of three selected energy-efficient building technologies, namely heat pumps, comfort ventilation, and low-e glazing. To do so, we developed an agent-based model that represents Switzerland’s building sector, and ex-ante simulated the diffusion of the successful technologies from 1995 to 2015. Applying the model, we evaluated the importance for technology diffusion of four policies, namely financial incentives, mandatory building energy codes, voluntary energy labels, and information campaigns. Our results show that, policies affect different technologies to a different extent and are most effective when being harmonized and timed according to the stage of the technology’s diffusion.

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