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Diffusion barriers and strategies for heat pump systems with integrated storage and photovoltaic in Austrian 1-2 family dwellings: an explorative investigation for the IEA HPT Annex 55/ECES annex 34

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Abstract

The Austrian building sector accounts for 16 percent of national CO_2 emissions. This makes it a key sector to decarbonize if long-term environmental targets are to be met. Relevant measures focus on the thermal-refurbishment of existing buildings and the phaseout of fossil-based technologies. The task specified by the Austrian government, involves replacing 600.000 oil heaters currently in use against renewable alternatives by 2035. This is the point of departure of this study. We investigate key barriers and solutions for the switch from fossil-based systems to c*omfort & climate boxes* (CCBs) in the Austrian 1-2 family housing segment. CCBs are integrated systems encompassing a heat pump, storage and integrated control. The study applies a two-step approach: First, 11 problem-centered stakeholder interviews are conducted and evaluated using quantitative content analysis. Next, a stakeholder survey is conducted to assess the subjective relevance of barriers identified in the interviews. Results yield 45 barriers clustered into 6 categories. We identify discrepancies in the relevance-perceptions between stakeholder groups, especially between researchers and key market actors. We advise realigning research agendas along market actors' perceptions, as these actors possess closeup insights about the market environment for CCBs.

Keywords: Heat pumps; innovation system; integrated storage; market barriers

1. Introduction

In line with the long-term goals of the European Parliament and Council, Austria has pledged to reach carbon-neutrality by 2050. These goals are to be met in part by national "effort-sharing": measures targeted at by increasing energy efficiency, the share of renewables in sectors not included in the European Emissions Trading Scheme (ETS). In 2017, the building sector accounted for over 16 % of total Austrian CO_2 emissions (excluding ETS sectors). Nearly a third of total energy consumption is used for space-heating, of which 17.6 % is provided using oil-based heaters and 28.2 % using natural gas [1]. Alternatives to these systems exist and are diffusing into the market at an accelerating pace, stimulated by falling technology prices and technical improvements, stronger environmental awareness and conducive policy shifts.

While the efficiency of heat pumps, thermal and electoral storage devices and solar PV systems is constantly improving, integrated systems that combine all or several of these individual technologies, are less common in Austria. Their integration, however, could valuably contribute to sectoral decarbonization. Integrated systems consisting of heat pumps and storage are an important technological option to accelerate the use of renewable energy for heating and cooling, in many countries worldwide. By combining heat pumps and storage, several issues may be tackled, such as: balancing and controlling electricity grid loads; capturing a larg(er) share of renewable (local/regional) input (i.e. solar thermal, solar PV); optimizing economics, CO_2-emissions, fuel use throughout time; providing optimal security of supply to buildings.

Commercial development of this type of solution is progressing very slowly in most countries, even in those who have relatively mature heat pump market. Therefore, the combined Annex HPT Annex 55/ECES Annex 34 (international collaboration project) was initiated in 2019 as a collaboration between two TCPs (Technology Collaboration Programmes) by IEA and the Mission Innovation initiative. This annex will aim at accelerating market diffusion of combined heat pump / storage packages including integrated control, a so called "Comfort and Climate Box", or "CCB". The work within the Annex is focused on systems that will be close to commercial realization, have a high quality and be adopted to their local market.

Aligned with the Annex goal, the aim of this study is to identify the factors hindering the diffusion of CCBs into the Austrian 1-2 family housing segment and to derive solutions for overcoming them. Findings may provide useful insights for industry strategy as well as targeted policy making on both a national and international level that could accelerate CCB diffusion.

The rest of this paper is structured as follows. Section 2 presents the technical CCB definition used. Section 3 introduces the conceptual framework used, as well as the key actors of the CCB system. Next, Section 4 explains the methodological design of the study. Section 5 presents research findings. Following a brief discussion in Section 6, we finish with conclusive remarks in Section 7.

2. CCB Definition

Contrary to the broader definition of CCBs used in the international IEA HPT Annex 55/ECES Annex 34 project, the data collection process of the present study mandates a more precise definition, as presented in Fig. 1.

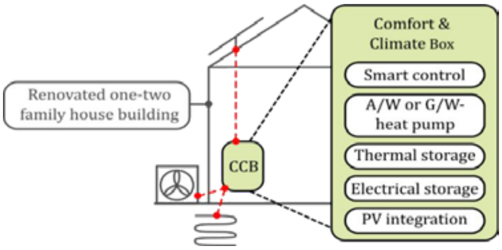

Fig. 1 Definition of the CCB for the present study

While heat pumps with integrated thermal storage are well-established in the Austrian market, their smart integration with PV systems and electrical storage is rather unknown. Ground- and air-source heat pumps with up to 10 kW heating power report rising yearly installation figures in Austria of +14.5% and +11.6 %, respectively [2]. Therefore, both systems are of great interest for this study. In line with the international annex definition, electrical and thermal storage as well as smart controls are included. Additionally, we include a PV system, as the increased installation of PV is a crucial measure specified by the Austrian government to reach climate goals [2]. Moreover, the combined use of PV and heat-pumps is associated with a higher proportion of own-consumption and lower electricity bills.

3. Technological innovation systems

The technological innovation system (TIS) provides a useful conceptual framework for our investigation of CCB diffusion in the Austrian 1-2 family housing segment. The central idea underlying TIS research is that technological innovation results from complex exchange of information and technologies between system actors [3]–[6]. Suurs et al. [3] describe a TIS in terms of its four principal components: its actors, institutions, technologies and their interrelations (networks). System *actors* include firms and non-firm organizations (such as interest groups, industry representatives, research organizations and authorities). *Institutions* refer to formal institutions (such as technical norms, laws and guidelines) as well as informal institutions (such as beliefs, habits and routines). Institutions play a pivotal part in the development of innovations, as they regulate actors' actions and the interactions between them, following Hekkert et al. [7]. The system *technology* refers to technical knowledge and skills, as well as technoeconomic factors such as costs and technical risks. Suurs et al. [3] stress that these technological factors are crucial for understanding feedback mechanisms between institutional and technological change.

The TIS framework focuses on a specific technology (or product) and is commonly applied to investigate what conditions foster or hinder the development of emergent technologies [7]. This makes the TIS framework ideal for the analysis of CCBs diffusion in the Austrian 1-2 family housing segment. Based on the expert knowledge about the research field within the research team – composed of applied researchers in the energy and buildings innovation nexus in Austria – a mapping of the system actors of the CCB TIS in Austria was conducted. The mapping is presented in Fig. *2* below. This mapping provided a useful basis for data collection and sampling decisions for the remainder of the research project.

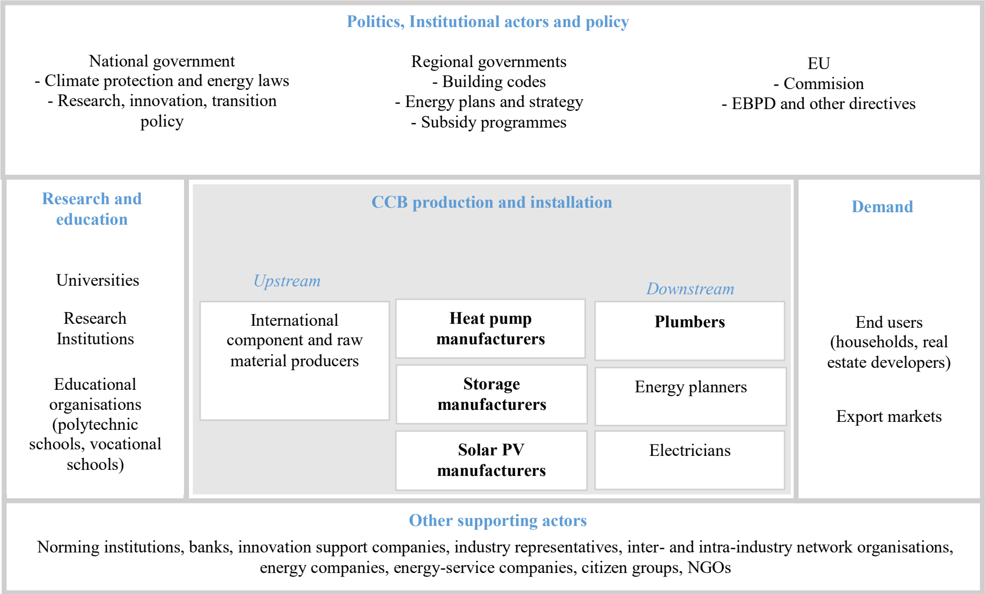

Fig. 2: Mapping of CCB innovation system actors - layout according to Hekkert et al. (2011) *[4]*. Key actors in bold.

A fruitful TIS does not develop overnight, but rather is formed with time during a complex build-up process [7]. A growing body of innovation system research has studied this buildup process by analyzing system functions (=key actions). This provided the starting point for the construction of our expert interview guidelines and provided support for our coding strategy in the data analysis section.

4. Methodology

This study adopts a mixed-method research (MMR) approach – an approach that combines at least one element of qualitative research with one element of quantitative research with the aim of increasing the depth of the investigation [8]. The benefits of mixed-methods research are increasingly recognized by the social science community, with authors such as Jungmann et al. (2015) [9] advocating for its wider application in multidisciplinary research domains such as that of innovation studies. The investigation is thus divided into two stages, as described in the following.

4.1. Expert interviews

In a first stage, 11 semi-structured expert interviews are conducted with key actors within the CCB TIS to identify potential barriers to CCB diffusion in Austrian 1-2 family housing segment. Expert interviews are an effective interviewing method commonly used in exploratory research to collect data about a specific field of interest. Following Meuser and Nagel (2004) [10], expert knowledge can be characterized as “specific knowledge in a particular field of action”. While there is much ongoing debate about what constitutes an “expert”, we adopt the broad definition of Bogner (2002) [11], where an expert is any actor who, due to his or her current and past professional experiences, is in possession of a (institutionalized) competence to provide information on a specific topic.

Interviewees were selected using a theoretical sampling strategy [12] and snowballing (interviewees suggest further interview candidates). The aim was to include key actors relevant for the production and market diffusion of CCBs in Austria. The researcher teams' experience-based knowledge on the development and diffusion of other energy-innovations in the Austrian building sector, aided them in identifying these actors. The interview-sample thus included: 3 energy and building innovation researchers, 4 heat pump and storage technology producers, 1 plumber, 1 regional official responsible for regional energy-planning and 2 real estate developers. Focus was placed on regional diversification and on professional experience within the 1-2 family housing segment. Insights from a brief review on energy-innovation and TIS research provided the basis for the construction of the interview guidelines. Each interview was started with a brief introduction into the research project and technical overview of CCBs by the interviewer. The recorded interviews were transcribed, and a qualitative content analysis is conducted. In line with Mayring (2012) [13] the transcribed interviews were (1) openly coded, then (2) axially coded and finally (3) selectively coded to generate categories of barriers. The interviews and coding were conducted in German, then translated into English by the research team.

4.2. Survey

The target population for the survey were key industry actors involved in the development and diffusion of CCBs in Austria. Survey participants were provided with a concrete definition of a CCB prior to the survey (see section 2), then asked to rate the barriers collected during the expert interviews with respect to their relevance for the diffusion of CCBs in Austrian 1-2 family houses. In line with general opinion research, as reviewed by Marsden and Wright (2010) [14], a five-point Likert scale from 1 (irrelevant for CCB diffusion) to 5 (completely relevant for CCB diffusion) was selected for the survey. A pre-testing of the survey was conducted to ensure the questions and rating schemes were comprehensible by the target survey-participants.

The survey was initially disseminated to the participants of a workshop during the e-nova conference in November 2020 (https://www.fh-burgenland.at/news-termine/veranstaltungen/e-nova-2020/). The conference brings together researchers and interested professionals from the energy, buildings and environment domain across Austria, thus providing for a very valuable and informed survey participant sample (n=30). The survey was then further disseminated across the networks of the research team's institutional networks, yielding a total sample size of n=58.

Due to the limited sample size, we decided to limit the analysis to a descriptive statistical analysis. Given a sufficiently large and representative sample, a multivariate analysis will be presented in a follow-up paper.

5. Results

5.1. Expert interview findings

The expert interviews lasted between 30 and 50 minutes and were conducted between August and October 2020. All interview recordings were transcribed and deleted upon transcription. The anonymity of the interviewees was consistently safeguarded. The qualitative analysis yielded 45 barriers, clustered into 6 categories: Financial barriers (F), information barriers (I), regulatory and policy barriers (R), barriers related to subsidies (S), technical barriers (T) and stakeholder-specific resistance (W). See Table 1 below. Note that the table also includes the survey rating results (column *"Score A(R/M/P)"*, which will be discussed in section 5.2.

Table 1 Experts Interview results and score of the survey (A)ggregated value and (R)esearcher-, (M)anufacturer- and (P)lumber-specific. The 10 highest rated barriers are indicated with a bold style score.

Financial barriers		Score A (R/M/P)
CF1	Installation costs are too high for households	2.7 (2.5/2.7/2.7)
CF2	System costs are too high for households	2.9 (2.5/3.1/2.9)
CF3	The efficient use of CCBs requires extensive refurbishment efforts by households	3.3 (3.5/3.4/3.3)
CF4	Planning bureaus lack the financial incentive to plan CCBs	3.2 (3.4/3.5/2.9)
CF5	Energy consultancy costs are too high for households	2.3 (2.0/3.2/2.1)
CF6	Older households prefer systems with low upfront costs over systems with low operating costs	3.1 (3.4/3.0/3.1)
CF7	If the existing system is functional, households lack the financial incentive to switch to CCBs	3.6 (4.6/3.4/3.4)
Information barriers		
CI1	Better information on flammable refrigerants is required	3.5 (3.9/3.7/3.3)
CI2	**The general shortage of skilled workers reduces product and service quality in the construction market**	**4.0 (4.1/4.1/3.8)**
CI3	CCBs are generally unknown by plumbers	3.4 (3.4/3.9/3.0)
CI4	The comparison of combined products, like CCBs, with individual products, like heat pumps, is difficult	3.1 (3.8/3.7/2.0)
CI5	System labeling could help but is rarely used in practice	3.7 (3.6/3.8/3.8)
CI6	Information shortages among older households reduces propensity to switch to CCBs	3.7 (3.9/4.1/3.4)
CI7	There is no central CCB contact for households.	3.5 (4.0/3.7/2.9)
CI8	**There are diverging opinions on the usefulness of CCBs in un-renovated buildings**	**3.8 (3.9/3.9/3.4)**
Regulatory barriers		
CR1	Relevant technical international and national norms are unharmonized	3.2 (3.3/3.6/3.3)
CR2	**The regulation on maximal sound-emissions is unharmonized**	**3.8 (3.7/4.1/3.7)**
CR3	**Requirements for thermal refurbishment and withdrawal from fossil fuels are not strict enough**	**4.0 (4.1/3.9/4.2)**
CR4	The directive on refrigerants is outdated	3.1 (2.5/3.5/3.1)
CR5	There is no universal coefficient-of-efficiency for energy systems that considers storage-management	3.6 (3.9/3.6/3.6)
CR6	**National property law requires unanimous consent among the ownership community**	**4.2 (4.2/4.3/4.4)**
CR7	Uncertainty about future feed-in-tariffs reduce the incentive to switch to PV-coupled systems	3.3 (3.3/3.6/3.3)
Subsidy-related barriers		
CS1	**Subsidy schemes are not harmonized between federal states**	**3.9 (3.9/4.3/3.9)**
CS2	Subsidies for air-based heat pumps are insufficient	3.2 (3.1/3.9/2.9)
CS3	**Subsidies for ventilation systems are insufficient**	**3.7 (3.9/4.1/3.7)**
CS4	Subsidies for other CCB components (storage technologies, PV, etc.) are insufficient	3.5 (3.7/3.8/3.5)
CS5	Federal subsidies prioritize biomass-based systems	3.4 (3.3/4.4/2.8)
CS6	Subsidies for energy consultancy and supply of public energy consultancy services are insufficient	2.9 (3.1/3.5/2.6)
CS7	**The application process for relevant subsidies is complicated and lengthy**	**3.8 (4.2/4.4/3.4)**
Technical barriers		
CT1	Sound emissions are too high	3.3 (3.4/3.2/3.3)
CT2	There is limited space for indoor components	3.2 (3.2/4.1/2.5)
CT3	Without thermal refurbishment, system efficiency is limited	3.5 (3.7/3.7/3.8)
CT4	**If flammable refrigerants are used, this can cause difficulties for indoor installation**	**3.8 (3.7/4.1/3.5)**
CT5	CCBs are not flexible enough for their use in renovation cases (e.g. combinable with existing components)	3.1 (3.0/3.5/3.4)
CT6	If a ventilation system is included in the CCB, this can complicate the installation process	3.6 (3.6/4.4/3.3)
CT7	There is no universal communication protocol for energy systems	3.7 (3.8/4.3/3.2)
CT8	A CCB must be able to withstand power outages for extended time periods	2.3 (2.1/2.3/2.6)
Stakeholder-specific resistance		
CW1	The efficient use of CCBs requires behavioral adaptations by households	2.9 (2.6/3.6/2.8)
CW2	**Households prefer simple systems that require minimal adjustments to the building structure**	**4.0 (4.5/4.2/3.4)**
CW3	There is resistance against combined products by producers who do not produce these	3.2 (3.7/3.4/3.1)
CW4	There is resistance against combined products by plumbers, as the low required installation effort reduces their fees	2.7 (3.7/2.6/2.3)
CW5	There is resistance against combined products by housing companies, as they expect additional maintenance costs	3.1 (3.5/3.2/2.9)
CW6	Consultants and planers disregard CCBs, as they focus on systems that are eligible for subsidies	3.4 (3.2/3.7/3.5)
CW7	CCBs are only useful in passive-houses	1.9 (1.9/2.0/2.3)
CW8	Households that install complex energy systems tend to be demanding and require a lot of support	2.3 (2.1/2.9/2.4)

5.2. Survey findings

The close-ended survey was conducted using the online tool *Mentimeter* (https://www.mentimeter.com/) and was filled out by 58 individuals. The participants derived from different occupational groups from within the CCB TIS (as detailed in Section 3). Figure 1 shows the share of participants per occupational group. We find that 48 participants (83 %) were manufacturers (16 participants, 27 %), researchers (14 participants 24 %) or plumbers (18 participants, 31 %). We focus our analysis on the aggregate survey results and on occupational-group specific results of the aforementioned three groups only. The ten barriers with the highest mean rating across all occupational groups are indicated in bold in Table 1 above.

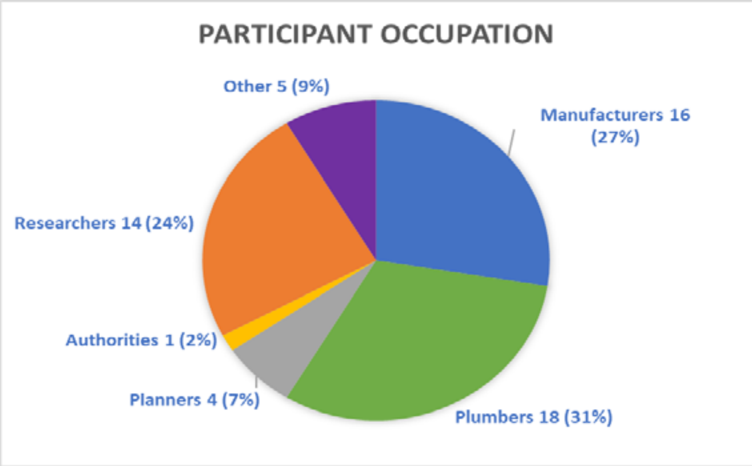

Fig. 3 Survey participants by occupational group

Notably, no financial barriers rank among the top 10 highest-rated barriers across occupational groups. In fact, the highest financial barrier (CF7) ranks 15th of 45. The top 10 highest-rated barriers are dominated by regulatory/policy-based barriers (CR6, CR3, CR2) and subsidy-based barriers (CS1, CS7, CS3).

The highest ranked barrier (CR6, score: 4.2) refers to the Austrian property laws (*Wohnungseigentumsgesetz* WEG2002). The law requires that any "unusual" changes to the building be unanimously agreed upon by the owner community. One abstention can block intentions to replace energy systems. This barrier is not relevant in a single-family house but becomes an issue in two- or multifamily houses. The second highest regulatory barrier for CCBs is CR3 (insufficiently strict requirements for thermal refurbishment and withdrawal from fossil fuels) with a score of 4.0. Without adequate regulatory pressure to reduce energy demand and emissions from buildings, demand growth for emerging renewable energy technologies like CCBs will be sluggish. The third regulatory barrier (CR2, score: 3.8) among the top 10 barriers, refers to unharmonized sound emission regulations across federal states in Austria. This requires and manufacturers to learn and monitor changes to different regulations when developing and installing CCBs all over Austria

Similarly, a lack of harmonization across subsidy-schemes between federal states (CS1, score 3.9) is rated a highly relevant barrier for CCB diffusion. Participants generally agree that complicated subsidy application processes and extensive waiting periods for subsidy-approval can hinder CCB diffusion (CS7, score 3.8). CS3 with a score of 3.7, refers to insufficient subsidies for ventilation systems. While not essential according to this study's CCB definition, several CCB currently on the market also include ventilation (see for example PKOM-4 from *Pichler Luft*). In several federal states, ventilation systems are not subsidized directly, but indirectly by means of subsidies for thermal refurbishments.

The fact that households prefer simple systems that require only minimal adjustments to the building structure (CW2, score 4.0) is rated as second highest overall CCB diffusion barrier. The installation of CCBs can in fact involve extensive adjustments to the building structure – far more than just the replacement of one heating system for another. Therefore, solutions that can use as much as possible of the existing system should have advantages over others.

Two information/knowledge barriers are listed among the top 10 most relevant barriers: CI2 with a score of 4.0 addresses the general shortage of skilled workers in the CCB market. The need to plan and coordinate multiple CCB components require high-skilled work force. However, arguably many installation aspects could be simplified or standardized by manufacturers prior to installation. Diverging opinions on the usefulness of CCBs in unrenovated buildings (CI8, score 3.8) was also rated highly relevant.

Uncertainty among experts / consultants contribute to financial and technical uncertainty among decision-makers, thus reducing end-users' (household) willingness to invest and, similarly, plumbers' willingness to install CCBs. Finally, one technical barrier scores among the top 10 barriers. It refers to the difficulty of indoor installation of CCBs when flammable refrigerants are used (CT4, score 3.8). This is an issue for every new installed heat pump with a low GWP refrigerant and a high flammability. Some manufacturers solve this issue by placing all components that contain refrigerants in the outdoor unit. Others install additional safety measures to comply with the local guidelines and laws, or even reduce the amount of refrigerant in the system to fall below the minimum quantity for ignition.

The survey results disaggregated by occupational group yield interesting insights. Fig. 4 shows the barriers with mean researcher ratings greater than or equal to 4 (i.e. barriers rated "very relevant"). Researchers stress the relevance of household motivation: as long as the existing system is functional, there is little financial incentive to switch to new systems (CF7). With new oil-boilers living up to 20 years, this could mean that owners of homes newly outfitted with boilers within recent years, will lack the financial incentive to switch to new systems before the end of the 2030s. Researchers also stress the relevance of household preference for simple (non-invasive) system changes CW2, national property law unanimity clauses (CR6), complex and lengthy subsidy processes (CS7), lacking strictness of refurbishment strategy and regulations (CR3) and the lack of required skilled workers (CI2). Moreover, they stress that households in the 1-2 family housing segment have no central contact person for CCBS. In the multi-family residential building sector, this is the planer. Planning bureaus do not tend to operate in this 1-2 family segment. The current contact person for heating issues in this segment is the plumber. Plumbers are conventionally not trained to be able to perform complex technology-field overarching planning and coordinating.

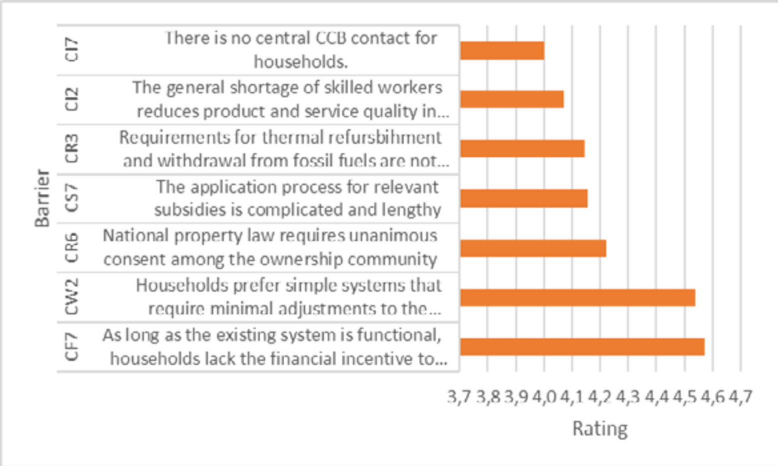

Fig. 4 Barriers rated 4 or higher by researchers

Thirteen barriers were rated greater than or equal to 4 in average by manufacturers, as seen in Fig. 5 We find a stronger perceived relevance of technical barriers and technology-oriented regulations among this occupational group. The surveyed manufacturers stress the relevance of CT6 (difficult retrofitting of CCBs with ventilation), CT7 (no standardized communication protocol), CT2 (limited space for indoor components)

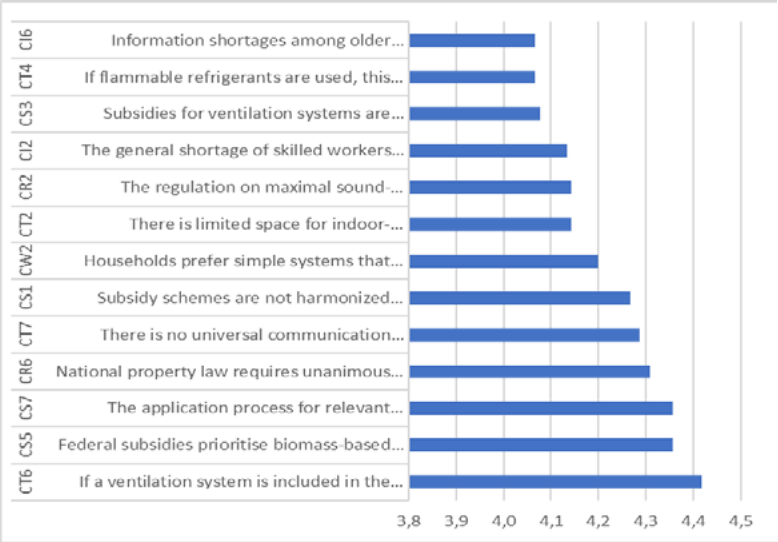

Fig. 5 Barriers rated 4 or higher by manufacturers

and CT4 (difficulty for indoor installation if flammable refrigerants are used). The focus on these technical/practical aspects by this group is unsurprising: They receive firsthand technical feedback from end-users and plumbers and can use this to improve product design, giving them a qualitative advantage over competitors.

Manufacturers consider the preferential treatment of biomass in federal subsidy schemes (CS5) a very relevant CCB barrier. Biomass is a strong competitor for heat pump-based systems in Austria, and very relevant for the 1-2 family house segment. Manufacturers also stress the generally complicated and lengthy subsidy application process (CS7) and their harmonization across federal states (CS1) that requires extensive bureaucratic efforts and reduces end-user incentives to apply for subsidies. They also stress the regulatory barriers CR6 (national property law, unanimity clause) and CR2 (unharmonized maximal sound emission regulation). Arguably, most of these regulatory and subsidy-based barriers refer to institutional phenomena that increase the *time* it takes to install CCBs. Thus, installation *speed* seems a crucial factor for CCB acceptance, according to manufacturers. Two information barriers are also rated highly: next to the issue of a general lack of skilled workers (CI2), manufacturers stress the limited access to relevant information among older generations. Of course, without awareness of innovative heating products and their benefits, households will not pursue them when engaging with their plumber.

Finally, two regulatory barriers were rated greater or equal to 4 by plumbers, as seen in Fig 6 below. CR6 (national property law unanimity clause) and CR3 (lacking strictness of refurbishment and withdrawal from fossil fuels). A closer look at the installers' survey results, yields a slightly larger variation in their rating behavior (standard deviation = 1.2 points), relative to researchers (= 1.12) and manufacturers (=1). This suggests a stronger heterogeneity of opinions among this occupational group and could explain its low count of highly relevant barriers. Exploring this further, however, exceeds the scope of this investigation.

Fig 6 Barriers rated 4 or higher by plumbers

There are significant differences between the barrier-relevance perceptions of individual occupational groups. This is illustrated in the following figures (Fig. 7, Fig 8, Fig 9). The figures display those barriers with differences in ratings greater than 1 between two occupational groups.

Figure 7 displays those barriers for which the difference between the manufacturer rating and the researcher rating is greater 1. While researchers consider CW4 (resistance against combined products by plumbers, due to low installation effort, thus reduced revenues) a rather relevant CCB barrier (score: 3.7) manufacturers find it less of an issue (score 2.6). In fact, plumbers (score:2.3, cf. Fig 9 오류! 참조 원본을 찾을 수 없습니다.) consider it even less relevant. To understand this discrepancy, it would be interesting to further explore the channels through which CCBs reach end-users, and whether the installation of CCBs in fact reduce plumbers' revenues, thus disincentivizing their uptake into plumbers' service-portfolios. The knowledge gap between the researchers and the other two survey groups is worth uncovering, to better steer product development in the future. Next, we see manufacturers rating CS5 (biomass is prioritized in subsidies) higher than researchers. As manufacturers are directly involved in the market for heating technologies, while researchers are not, this result seems less surprising: heat-pump producers for example, directly compete with biomass-based heating technologies. Plumbers on the other hand, consider this less of a relevant barrier (score: 2.8). This might be an expression of end-users' non-monetary preferences, for example a preference for technical simplicity, or reliability. This raises the question of substitutability between renewable energy systems. Arguably, someone with a strong preference for heat-pumps, will not consider biomass-heating a reasonable substitute. In this case, a biomass-subsidy may then only affect his or her decision to invest in heat pumps weakly.

More of a surprise is the difference in CF7 (households lack financial incentive to switch to new systems if the old one is still functional), which was rated significantly higher by the researchers (4.6) than by the manufacturers (3.4). Plumbers (3.4) rate this barrier similarly to the manufacturers. They seem to believe, that households are not uninclined to switch away from a functioning system. As manufacturers and plumbers have more regular interaction with households, this insight could be of value to researchers developing systems that can compete against functioning systems, not just new systems. Finally, CF5 (high energy consultancy costs)

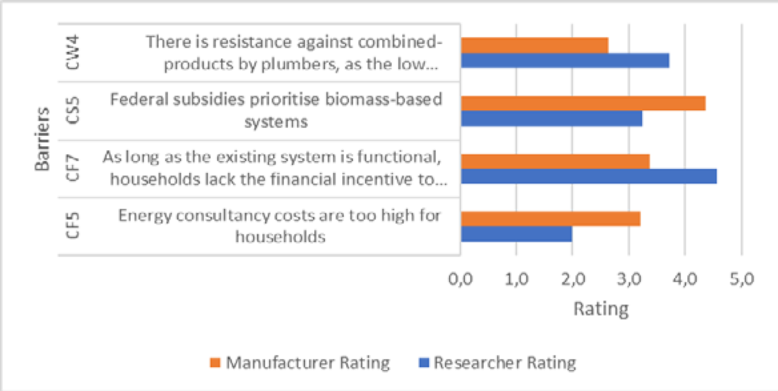

Fig. 7 Barriers with absolute difference in ratings greater than 1 – manufactures and researchers

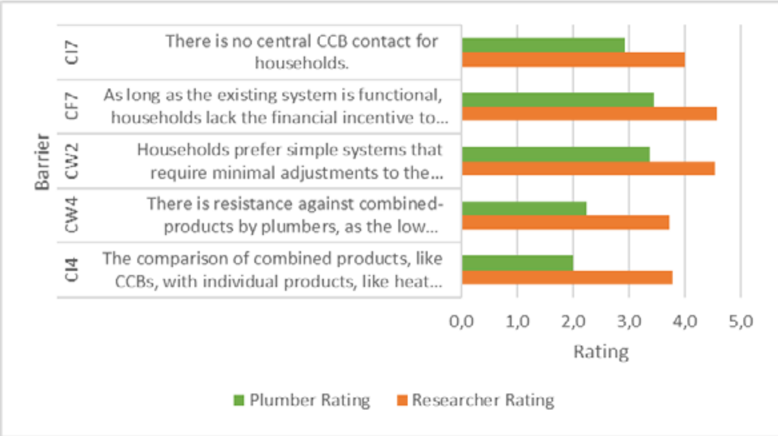

Fig 8 Barriers with absolute difference in ratings greater than 1 – plumbers and researchers

is rated rather irrelevant by researchers, while manufactures consider it relevant. Energy consultancy is a very heterogenous service and can range from a rudimentary consultancy provided (for free) by federal energy agents, to (costly) complex concept comparisons. These costs are often found lacking in technoeconomic studies of system alternatives.

Looking at Fig 8 we find that the largest rating differences between plumbers and researchers all refer to barriers perceived less relevant by plumbers. Like manufacturers, plumbers consider CW4 (plumber resistance against combined products) rather irrelevant for CCB diffusion, while researchers consider them very relevant. We also find that plumbers deem CI4 (difficulty of comparing combined systems) far less relevant than researchers (rating: 3.8) and manufacturers do (score 3.7., cf. Fig. 7 **오류! 참조 원본을 찾을 수 없습니다.**). One possible interpretation of this difference could be that the energy efficiency of the system is less important to plumbers than other points, such as reliability or simplicity of installation. Notably also, researchers seem to consider the fact that there is no central CCB contact for households (CI7) a more relevant barrier, while plumbers find it just relevant. Perhaps plumbers consider *themselves* the CCB contact for households. They may however be less informed about CCBs than researchers and might underestimate the extent to which CCB installation may differ from conventional heat pump installation processes.

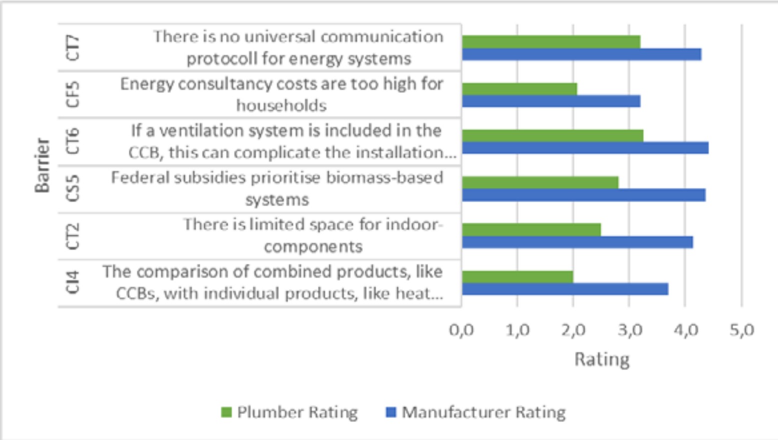

Fig 9 Barriers with absolute difference in ratings greater than 1 – plumbers and manufacturers

Similarly, as in Fig 8, we find that plumbers rate the relevance of six barriers lower than manufacturers. Differences largely concern technical barriers: CT7 (no universal communication protocol), CT6 (installation process if CCB it to contain a ventilation system) and CT2 (there is limited space for indoor components). Especially, the difference in CT2 ratings could be of great interest to manufacturers. Installers interact more closely with the end-users, so this insight could be used by manufacturers to reconsider their product development strategy. The difference in CT7 could be explained by the fact that manufacturers tend to be specialized on specific components (e.g. heat pumps, or thermal storage technologies), thus integrating their component into a comfort climate box using components of other specialized producers will prove difficult given unharmonized protocols. This is an issue that installers may not feel as strongly, as they can simply go to those producers who provide complete CCBS (i.e. produce all components with harmonized protocols). The differences for CI4 (difficulty in comparing CCBs with individual products like heat pumps) and CS5 (biomass is prioritized by subsidies) were already discussed previously. Furthermore, the difference in rating of CI4 and CS5 could also stem from competition issues experienced by producers and felt less strongly by installers.

6. Discussion and Limitations

The selected methodology succeeded in generating interesting first insights into the dynamics of emerging energy-system in the Austrian 1-2 family building sector. Most importantly, it produced an extensive list of barriers blocking the diffusion of CCBs. Notably, we uncovered several potential knowledge gaps between occupational groups. Researchers could use these results to redirect their research to address practical barriers experienced by manufacturers and plumbers. Similarly, manufacturers and plumbers, two key actors in CCB diffusion, can use these findings to better align or synthesize product and service development to better reach the market.

However, the findings from the descriptive statistical analysis are limited. They do not allow for a deeper investigation of the *reasons* for rating-differences between occupational groups. Follow-up research should be conducted to further investigate these differences. Moreover, increasing the survey sample size to a representative size would allow for a more thorough multivariate analysis that could be of value to industry and research. Also including socioeconomic, geographic and company characteristics would prove interesting to understand differences in barrier-ratings. We also acknowledge the need to include the end-users into follow-up research and data collection. It would be interesting to discover whether supply-side perceptions of end-user energy-system adoption preferences are in line with actual household preferences.

Within the HPT Annex 55/ECES Annex 35, drivers and barriers for market diffusion for CCBs in all participating countries, from Europe, Asia and America, are investigated. The results from Austria will be compared to results from other countries, in order to map which barriers and drivers that are general for many countries and which are unique for Austria. As a next step, recommendations to important stakeholders/targets groups on both international and national level, to overcome the most important barriers, will be outlined, based upon the findings withing the Annex work.

7. Conclusion

CCBs are a promising, ecological alternative to fossil-based energy systems in the 1-2 family housing segment. Driving its development is the observation that demand for renewable energy technologies is obstructed by numerous barriers related to financial, technical, information-based, regulatory, subsidy-based factors and stakeholder-specific preference. This study contributes to the identification of these barriers and provides insights into their relevance from 3 key occupational groups involved in the development, innovation and diffusion of CCBs.

We find strong differences in the relevance-perception of barriers between researchers and the two key market actors for CCBs – manufacturers and plumbers. By aligning technology research with market actors' barrier perceptions, research can generate more problem-oriented solutions, thereby contributing to the acceleration of CCB diffusion in Austria. Diverging relevance-perceptions between the two key market actors, clearly presents a need for stronger industrial alignment. Manufacturers could benefit from adapting their product development strategies to the information supplied by plumbers about end-user preferences and technology-selection behavior. Household preference for simple systems requiring minimal adjustments to the building structure, call for CCBs that are largely integrable into the existing building and energy system. Moreover, as plumbers are (currently) the intermediary between manufacturers and the end-user, manufacturers could be advised to consider plumber needs and abilities in their product-development and marketing strategies. The current shortage of skilled labor, as well as the cross-technological nature of CCBs, call for the development of easy-to-install or standardized CCBs. Furthermore, small specialized components manufacturers (e.g. heat pump manufacturers, solar PV manufacturers), without the inhouse expertise or means for producing all required components, could benefit from creating production consortia, to compete against large CCB producers.

As for policy and regulation, there is a unanimous call for the harmonization of building codes, subsidy schemes and norms. Moreover, calls for property law reforms and stricter obligations for thermal refurbishment are echoed by all surveyed system actors. Finally, policymakers are advised to focus on *actor-specific* barriers to develop truly effective measures.

Follow up research could yield more in-depth insights into CCB diffusion barriers as well as strategies for overcoming them, by extending the sample size and accounting for more system actors. Also, the inclusion of firm-level characteristics (e.g. firm size, segment-specific experience, networking behavior) could permit a more differentiated analysis of the results. We also advise to conduct a household-level investigation of heating-system preferences to augment this study's findings and generate fruitful insights for industry and research strategy.

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