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Drivers and Barriers in the Adoption of Green Heating and Cooling Technologies: Policy and Market Implications for Europe

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Abstract: Space heating and cooling (H&C) constitute nearly half of Europe's total energy consumption, yet only 23% of this demand is fulfilled by renewable sources. Green H&C technologies, characterized by both renewable energy usage and energy efficiency, remain underutilized despite their significant environmental and economic advantages. This study aims to identify the socio-economic barriers and drivers influencing the adoption of green H&C technologies across Europe. Employing a comprehensive analysis of policy, technological, and market dynamics, this study indicates how a synergy of policy frameworks and market forces can enhance the diffusion of these sustainable technologies. The results showed that key barriers, including dependence on fossil fuels, electricity supply challenges, lack of professional know-how, inertia, and concerns over noise and supply security, can be substantially mitigated through strategic policymaking and technological advancements. Moreover, policy measures, subsidies, incentives, R&D activities, and regulatory frameworks can effectively reduce uncertainties and enhance the competitiveness of green H&C systems compared to conventional methods.

Keywords: green heating and cooling technologies; decarbonization; socio-economic barriers and drivers; renewable energy

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1. Introduction

Space heating and cooling (H&C) currently account for nearly half of Europe's total energy consumption across the residential, service, and industrial sectors [1]. However, only 23% of this demand is currently met by renewable sources [2].

In this study, we classify green heating and cooling (H&C) technologies as renewable and energy-efficient. Notably, the term "green H&C technologies" encompasses energy-efficient systems that are capable of heating and cooling buildings while maintaining a low environmental impact: examples of these technologies include heat pumps and solar thermal systems. Although policies encourage the adoption of these green technologies due to their environmental and economic benefits, they remain underutilized in many regions of Europe [3]. This underutilization prompts an exploration of the primary barriers to the wider adoption of green H&C technologies and the main drivers that can facilitate broader implementation. Understanding how these drivers can help overcome existing barriers is crucial. However, the literature lacks comprehensive analyses of the socio-economic challenges influencing the adoption of green H&C technologies across various European regions. This study aims to explore these topics, providing insights into the barriers and drivers that shape the adoption of green H&C technologies and informing strategies to accelerate their diffusion.

1.1. Local Challenges and Opportunities in Adopting Green Heating and Cooling Technologies in Europe

The adoption of green H&C technologies in Europe is critical for reducing greenhouse gas (GHG) emissions and achieving ambitious climate goals. Current research presents a complex picture, examining both the opportunities and challenges associated with these technologies. In this study, the H&C sector of 11 European Union (EU) member states (MSs—Austria, Cyprus, Denmark, Estonia, France, Germany, Italy, Poland, Romania, Spain, and Sweden) was analyzed: the 11 MSs were selected to represent diverse geographical areas: for the purposes of this research, southern Europe includes Cyprus, Spain, and Italy; eastern Europe comprises Estonia, Poland, and Romania; western Europe includes France; central Europe encompasses Germany and Austria; and northern Europe consists of Sweden and Denmark. This distribution allowed for robust data collection on technologies, considering the different energy requirements across various climate zones. The selected EU11 MSs account for over 75% of Europe's total population, which, according to Fleiter et al. [4], are the most energy-intensive within the EU27+UK aggregate. This selection aimed to enhance data scouting for technology based on temperature-driven energy needs, focusing on the most energy-consuming regions in the EU27+UK. Furthermore, the focus on these 11 MSs is aligned with the tender criteria that underpinned the research presented in this paper.

The environmental impacts of adopting different technologies across the analyzed European countries reveal that prioritizing renewable energy systems significantly reduces emissions. However, their effectiveness varies across regions based on the energy source, with fossil-fuel-dominated countries like Poland and Cyprus showing higher emissions even with electricity-powered systems. This emphasizes the need for more comprehensive decarbonization policies [5]. Aquifer thermal energy storage (ATES) has emerged as a promising solution for efficient H&C. Despite technical and organizational barriers, several pilot projects across Europe have demonstrated how ATES can be combined with other technologies like solar power to boost adoption and reduce barriers [6]. Further research highlights the significant potential for ATES to transform energy markets through integration with smart grids and soil remediation, fostering a viable transition to sustainable heating [7]. Technological innovation in the EU generally aids green growth by promoting renewable energy use and improved climate-friendly practices, despite persistent challenges around transport and production emissions [8]. However, systemic barriers, including financial constraints, resistance to change, and knowledge gaps, continue to hinder the broader adoption of green building technologies [9]. Economic concerns are paramount, with cost barriers significantly impacting adoption rates for nearly zero-energy buildings and other sustainable technologies [10]. Green roofs and adaptive thermal comfort strategies offer additional pathways for improving building energy efficiency. However, their regional suitability and adoption are heavily influenced by climate and government incentives [11]. Moreover, energy poverty remains a significant yet often overlooked challenge, particularly in regions susceptible to extreme H&C deficiencies [12]. As seen from this review, despite the adoption of green H&C technologies being essential for Europe's climate targets, today the sector faces barriers ranging from regional disparities and financial limitations to knowledge gaps and legislative issues.

1.2. Aim of This Study

This study aims to investigate the factors that facilitate and hinder the adoption of green H&C technologies, providing a comprehensive analysis of how policy, technological advancements, and market forces can work synergistically to expedite the sector's transition toward sustainability. The scope is to point out the drivers and barriers impacting the adoption of these technologies, focusing on their policy implications and the dynamics of the market. This analysis aims to assist institutional stakeholders, including policymakers, legislators, regulators, and administrative agencies, in addressing these issues and developing strategies to accelerate the adoption of green H&C technologies in Europe. The insights provided are also valuable to other market participants operating in the H&C sector.

2. Materials and Methods

A quantitative methodology utilizing a strengths, weaknesses, opportunities, and threats (SWOT) analysis was implemented. This methodology, widely adopted for assessing the performance of both individual enterprises and markets, as noted by Nadine [13], provides valuable insights into various factors influencing the adoption of green H&C technologies. It helps clarify potential barriers (weaknesses and threats) and drivers (strengths and opportunities) affecting the diffusion of these renewable and energy-efficient technologies. The objective is to concentrate on specific barriers, raising awareness among stakeholders so that these issues can be addressed to facilitate the widespread adoption of green H&C technologies. Drivers should be reinforced and harnessed, while barriers need to be minimized, as suggested by Pezzutto et al. [14]. The analysis enables an understanding of how drivers can help overcome barriers and clarifies the interconnected factors influencing the adoption of green H&C technologies. This understanding serves as the foundation for more comprehensive policy recommendations. By leveraging the synergies between barriers and drivers, significant progress can be made in tackling low-carbon energy challenges, as emphasized by Singh et al. [15].

In this study, market data pertaining to strengths, weaknesses, opportunities, and threats were organized into a SWOT matrix (Figure 1). The data populating this matrix were obtained through interviews with experts in the H&C sector. A total of 20 experts, including researchers, policy specialists, and industry representatives in H&C, were consulted via questionnaires and direct interviews. It was assumed that these experts could represent the perspectives of both private end-users and consumers. The questionnaires, designed to be open-ended to allow experts to include additional factors and assessments, are provided in Appendix A. However, the list of interviewees is not included to maintain their privacy. In the SWOT analysis, the various characteristics of the studied H&C technologies were categorized according to their influence on the adoption of green, renewable, and energy-efficient H&C technologies.

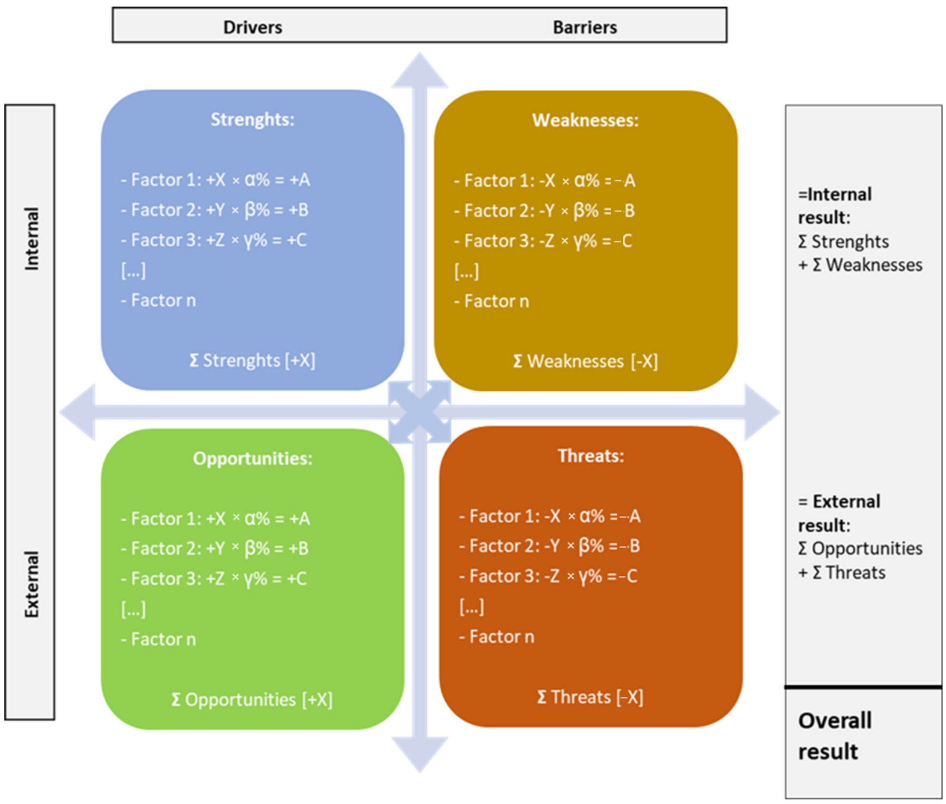

Figure 1. The approach utilized in the strengths, weaknesses, opportunities, and threats matrix.

In Figure 1, the effects of various drivers and barriers on the adoption of green H&C technologies are quantified. Each factor contributes to the overall outcome. The quantified weaknesses are aggregated and then subtracted from the sum of strengths, while the total threats are deducted from the sum of opportunities. The cumulative result demonstrates the extent to which opportunities and strengths driving the diffusion of green H&C technologies outweigh the weaknesses and threats. The comprehensive framework provided by the SWOT analysis enables institutional stakeholders to critically assess how different aspects of H&C technologies influence the adoption of green H&C systems.

Finally, the following Table 1 reports the technologies considered in this study.

Table 1. The list of technologies in the scope of the analysis. Please note that CHP stands for combined heat and power plants.

End-Use Heating Technologies	District Heating Technologies	Cooling Technologies
Liquid fuel boilers	Coal-fired district heating plant (non-CHP)	Space cooling systems (air-conditioning)
Coal-fired boilers	Gas-fired district heating plant (non-CHP)	District cooling
Gas-fired boilers	Biomass-fired district heating plant (non-CHP)	Thermally driven heat pumps
Biomass boilers	Efficient district heating plant (Geothermal)	
Combined solid fuel boilers (biomass-based material, such as wood or pellet)	Efficient district heating plant (Solar)	
Solar thermal	Efficient district heating plant (using heat pump)	
Solar PV-driven heat pumps	Efficient district heating plant (using CHP)	
Geothermal installations	Efficient DH (using waste heat)	
Heat pumps (HPs)	DHP utilizing thermal storage	
Electric heating	Low-temperature district heating network (DHN)	
Hydrogen boilers	High-temperature district heating network (DHN)	
Micro-CHP (natural gas)	District heating plant (DHP) utilizing solid waste	

The subsequent sections provide a detailed explanation of the SWOT methodology and the classification of various characteristics of H&C technologies as strengths, weaknesses, opportunities, or threats. The characteristics are further categorized as either internal or external to the technology (Section 2.1) and as barriers to or drivers of the diffusion of green H&C technologies (Section 2.2). The features are then evaluated according to their direction of influence, intensity, and relative importance (Section 2.3). Lastly, the relationships and interactions among these features are analyzed (Section 2.4).

2.1. Internal and External Factors

Within the framework of the SWOT analysis, "internal factors" referred specifically to those elements directly associated with H&C technologies. During the analysis, strengths and weaknesses were considered as internal factors. In contrast, "external factors" pertained to the external environment surrounding these technologies. External factors included characteristics of the external environment, such as regulatory policies, and the broader impact that these technologies have on their surroundings, including the implications for stakeholders and potential adoption. Opportunities and threats were classified as external factors, as noted by source [13]. The identification of both internal and external factors was achieved through brainstorming sessions and the incorporation of open-ended questions in surveys.

2.2. Drivers and Barriers

The factors influencing the diffusion of H&C technologies were classified not only as internal or external but also as drivers or barriers. Drivers exert a positive influence on the adoption of these technologies, while barriers have a negative effect, as described in [13]. Specifically, strengths and opportunities are considered drivers, while weaknesses and threats are regarded as barriers. Strengths and weaknesses are intrinsic to the technologies themselves, whereas opportunities and threats pertain to external environmental factors.

Strengths represent features inherent in the technologies that facilitate the adoption of green (renewable and energy-efficient) H&C technologies over conventional alternatives. Opportunities, on the other hand, are external elements or environmental impacts that support the diffusion of green H&C technologies. Conversely, weaknesses are intrinsic features of the technologies that hinder the uptake of green (renewable and energy-efficient) H&C solutions. Threats are external factors, including environmental impacts, that impede the dissemination of green H&C technologies. Understanding this classification is crucial for identifying and addressing the drivers that promote adoption and the barriers that need mitigation to accelerate the transition toward sustainable H&C technology solutions.

2.3. Quantifying Barriers, Drivers, and Relative Importance

The SWOT analysis not only classifies factors into strengths, opportunities, weaknesses, and threats but also quantifies barriers and drivers in terms of their intensity and relative importance concerning the adoption of green H&C technologies. The influence, intensity, and relative importance of these various factors were quantitatively evaluated in collaboration with experts specializing in H&C. Ten experts, including three researchers, three policy specialists, and four industry representatives, assessed the intensity of these factors. In addition, a separate group of ten experts—three researchers, four policy specialists, and three industry representatives—evaluated the relative importance of these factors. Their insights were gathered through questionnaires and direct phone interviews, where they were asked to evaluate the various barriers and drivers affecting the adoption of green H&C technologies. While the questionnaires can be found in Appendix A, the names of the interviewees have not been disclosed to protect their privacy. As depicted in Figure 1, the weighted values reflect the impacts of various advantages and disadvantages on the adoption of green H&C technologies. These values were calculated based on the intensity or strength of each factor, the direction of its influence (as indicated in Questionnaire A), and its relative importance to the adoption of green H&C technologies (as captured in Questionnaire B). This dual-questionnaire approach enables a comprehensive evaluation that not only quantifies individual features but also allows for comparison between them. In the first questionnaire, experts assessed the direction of each factor's influence (whether a barrier or a driver) on the adoption of green H&C technologies, as well as the intensity of each feature (see Questionnaire A in Appendix A). This involved providing two types of information: (a) indicating whether a feature is generally considered a barrier or a driver for green H&C adoption using a minus (−) sign for barriers and a plus (+) sign for drivers; and (b) assigning a score to the intensity or strength of each factor on a scale ranging from 0 (neutral) to 10 (very strong). Barriers were rated from −10 (very strong) to 0 (neutral), while drivers were rated from +10 (very strong) to 0 (neutral). For instance, operational stability, the reliability of green H&C technologies, was consistently rated as a driver (+) with a relatively high score of 7.12—please see Section 3. A key aspect of the SWOT analysis methodology is the comparative evaluation of each factor's influence on green H&C technology adoption. While operational stability may strongly and positively influence adoption, it needs to be compared against other considerations, such as monetary factors. To facilitate this comparison, a second questionnaire was distributed among a separate group of experts to evaluate the relative importance of each factor. In this second questionnaire, experts were asked to assign percentage weights to the relative importance of each factor for the adoption of green H&C technologies (see Questionnaire B in Appendix A). Ten experts rated each factor's importance on a scale from 0% (not important) to 100% (essential). For instance, operational stability and monetary considerations were assigned significant weight due to their crucial impact on green H&C adoption. The results of these ratings were averaged across the expert group.

This comprehensive SWOT analysis methodology covered the direction of a factor's impact, its intensity or strength, and its importance compared to other relevant features. The two separate questionnaires and expert interviews provided a detailed quantitative assessment, offering a nuanced understanding of the key factors affecting the adoption of green H&C technologies.

2.4. Matchmaking

In the realm of strategic planning, matchmaking plays a pivotal role in enhancing SWOT analysis by identifying interconnections. Also referred to as "matchmaking", this concept involves linking weaknesses and threats with corresponding strengths and opportunities, particularly in the context of green H&C technologies. By doing so, this approach generates more refined strategies that not only pinpoint the underlying mechanisms driving the diffusion of green H&C technologies but also provide valuable insights for strategic planning. Rather than offering prescriptive solutions focused exclusively on mitigating weaknesses and avoiding threats, the approach emphasizes a comprehensive examination of the SWOT matrix. This analysis involves setting the four domains of strengths, weaknesses, opportunities, and threats against each other, with particular attention to how strengths and opportunities can be leveraged to counteract weaknesses and threats. Such a methodology reveals the intricate relationships and connections among these factors, providing the foundation for developing strategies based on the mechanisms underlying these connections. This nuanced exploration aids in crafting robust strategic plans for the effective promotion and implementation of green H&C technologies [13].

3. Results

Table 2 presents the findings derived from the questionnaires, detailing the direction of influence, intensity, and relative importance of various features associated with H&C technologies. Furthermore, the table provides a comprehensive explanation of each feature examined, elucidating their relationship with H&C technologies. The data offer valuable insights into the distinctive attributes of these features and their interconnectedness, contributing to a deeper understanding of their roles within the broader context of H&C technology development.

Table 2. Results of Questionnaires A and B (sorted in alphabetical order of feature).

Features of H&C Technologies	Explanation of Features	Direction of Influence (+ or −) and Intensity (0 to 10)	Relative Importance (in %)
Awareness	Influence and Intensity: What is the level of awareness about the advantages and disadvantages of green H&C technologies among end-users? Relative Importance: Compared to other features, how important is awareness among end-users about the advantages and disadvantages of green H&C technologies for their diffusion?	+5.44	4.86
Building professional know-how	Influence and Intensity: To what degree is it necessary to expand existing know-how among professionals (e.g., engineers, installers, energy managers) to ensure a successful installation of green H&C technologies? Relative Importance: Compared to other features, how important is the expansion of existing know-how among professionals (e.g., engineers, installers, energy managers) for the diffusion of green H&C technologies?	−6.30	55.45
Complexity in maintenance	Influence and Intensity: How complex and frequent is the maintenance of green H&C technologies compared to conventional ones? Relative Importance: Compared to other features, how important are complexity and frequency in the maintenance of green H&C technologies for their diffusion?	+3.22	45.74

Table 2. *Cont.*

Features of H&C Technologies	Explanation of Features	Direction of Influence (+ or −) and Intensity (0 to 10)	Relative Importance (in %)
Dependency on electricity supply	Influence and Intensity: In how far do green H&C technologies depend on access to electricity supply? Relative Importance: Compared to other features, how important is the dependency on electricity supply for the diffusion of green H&C technologies?	−8.51	11.89
Energy sources dependency	Influence and Intensity: To what extent do H&C technologies depend on fossil fuels? Relative Importance: Compared to other features, how important is the dependency on fossil fuels (as an energy carrier) among H&C technologies for the diffusion of green H&C technologies?	−8.25	45.21
Fuel storage needed	Influence and Intensity: How frequent is the requirement of installing fuel storage to make use of green H&C technologies? Relative Importance: Compared to other features, how important is the potential necessity to install fuel storage for the diffusion of green H&C technologies?	+8.13	24.69
Health	Influence and Intensity: Compared to conventional H&C technologies are green H&C technologies related to more health risks (e.g., legionella)? And to what extent? Relative Importance: Compared to other features, how important are potential health risks for the diffusion of green H&C technologies?	+1.58	38.92
Inertia	Influence and Intensity: Are end-users resistant to the adoption of green H&C technologies due to habits or required behavioral changes, despite the benefits? And to what extent? Relative Importance: Compared to other features, how important is the end-user's potential resistance to the adoption of green H&C technologies (e.g., due to habits or required behavioral changes) for the diffusion of green H&C technologies?	−5.40	5.58
Legislation and regulation	Influence and Intensity: To what degree does the legislative and regulative environment (other than subsidies and incentives) in the European Union facilitate the diffusion of green H&C technologies? Relative Importance: Compared to other features, how important is the legislative and regulative environment (other than subsidies and incentives) in the European Union for the diffusion of green H&C technologies?	+8.45	98.48
Monetary	Influence and Intensity: In how far do benefits related to an investment in green H&C technologies outweigh the costs? Relative Importance: Compared to other features, how important is the cost–benefit ratio of green H&C technologies for their diffusion?	+2.56	96.12
Need for refurbishment to make use of green technologies	Influence and Intensity: To what extent is it necessary to refurbish facilities/apartments/buildings to make use of green H&C technologies? Relative Importance: Compared to other features, how important is the necessity to refurbish facilities/apartments/buildings to make use of green H&C technologies for their diffusion?	+8.78	81.57
Noise	Influence and Intensity: To what degree are green H&C technologies noisy, in so far as this noise is experienced by end-users or neighbors? Relative Importance: Compared to other features, how important is noise related to green H&C technologies in general for their diffusion?	−2.14	54.23

Table 2. *Cont.*

Features of H&C Technologies	Explanation of Features	Direction of Influence (+ or −) and Intensity (0 to 10)	Relative Importance (in %)
Operation stability	Influence and Intensity: To what extent are green H&C technologies reliable and to what degree is their provision of energy stable? Relative Importance: Compared to other features, how important is operational stability and the stable provision of energy through green H&C technologies in general for their diffusion?	+7.12	85.23
Research and development (R&D)	Influence and Intensity: What is the extent of research and development activities for green H&C technologies compared to R&D on conventional H&C technologies? Relative Importance: Compared to other features, how important are research and development activities related to green H&C technologies in general for their diffusion?	+3.10	70.21
Risk and uncertainty	Influence and Intensity: To what extent do end-users or other stakeholders (e.g., public officials) perceive the in-vestment in and usage of green H&C technologies as risky or uncertain, for example, due to poor performance in the past that causes a lack of trust in the technology? Relative Importance: Compared to other features, how important is the perception of investments in green H&C technologies as risky or uncertain for their diffusion? (perceived risk may be caused, for example, by poor performance in the past that leads to a lack of trust in the technology)	−2.50	36.73
Security	Influence and Intensity: Compared to conventional H&C technologies, to what degree are green H&C technologies related to security risks other than health risks (for example, the risk of fire)? Relative Importance: Compared to other features, how important are potential security risks other than health risks (for example, the risk of fire) that may be related to green H&C technologies for their diffusion?	+2.31	32.35
Spatial constraints	Influence and Intensity: To what degree are green H&C technologies related to space constraints? Relative Importance: Compared to other features, how important are space constraints that are related to green H&C technologies for their diffusion?	+1.24	61.46
Subsidies and incentives	Influence and Intensity: To what degree do subsidies and incentives in the European Union favor or disfavor green H&C technologies? Relative Importance: Compared to other features, how important could subsidies and incentives in the Euro-pean Union be for the diffusion of green H&C technologies?	+8.12	97.32
Supply security	Influence and Intensity: To what degree are H&C technologies in general related to risks that stem from insecure energy supply (e.g., due to imports of fossil fuels)? Relative Importance: Compared to other features, how important are risks that stem from insecure energy supply (e.g., due to imports of fossil fuels)?	−7.88	90.74
Training	Influence and Intensity: To what extent does training of professionals (e.g., engineers, installers, managers) accelerate or impede the diffusion of green H&C technologies? Relative Importance: Compared to other features, how important is the training of professionals (e.g., engineers, installers, energy managers) for the diffusion of green H&C technologies?	+4.40	65.36

The data collected from Questionnaires A and B underpin the SWOT analysis, illustrated in Figure 2. As previously described, each factor's influence and intensity are evaluated in relation to the feature's relative importance. For instance, the operational stability factor scores +7.12 for influence and intensity, which is then multiplied by a weight of 0.8523 (85.23%), representing its significance compared to other features. Within each category, the aggregated factor-specific results contribute to the internal and external outcomes. Based on the results of the calculation, which are explicated in Figure 2, the SWOT analysis demonstrates that green H&C technologies exhibit notable strengths and opportunities that surpass the existing barriers. This dynamic ultimately results in a positive internal assessment, as the advantages of green H&C technologies clearly outweigh their weaknesses. Furthermore, the external assessment aligns with the internal analysis, revealing that opportunities outbalance threats. Various contextual factors, including economic and political influences as well as the environmental impacts of green H&C technologies, actively promote the adoption of these renewable and energy-efficient systems. Thus, the external findings reinforce the conclusion that green H&C technologies are poised for wider diffusion.

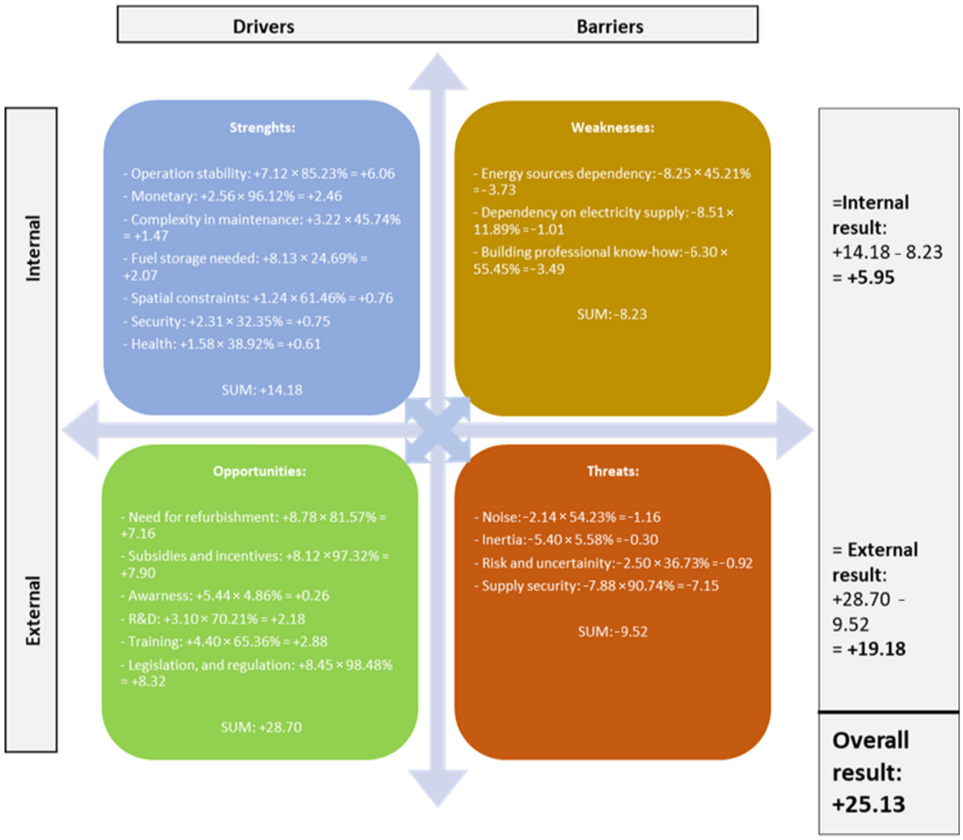

Figure 2. Results of the strengths, weaknesses, opportunities, and threats matrix.

As visible in Figure 2 above, for each of the two cases (internal and external), the drivers effectively overcome the barriers. This indicates that the analyzed market displays a positive development in both segments. Specifically, the drivers—factors that facilitate market growth—outweigh the barriers—factors that hinder growth—in both the internal and external contexts. The overall SWOT matrix, which assesses the strengths, weaknesses, opportunities, and threats of the market, yields a rather positive result of +25.13. This figure is a composite score reflecting the market's favorable conditions. Notably, the result for the external section of the SWOT analysis is +19.18, which is almost four times higher than the internal section's score of +5.95. This disparity highlights the significant impact of external factors on the market's positive trajectory. The strong positive characterization of the market is predominantly driven by external factors surrounding green heating and cooling (H&C) technologies. Key contributors to this positive environment include supportive laws and regulations, subsidies, and incentives. These elements create a favorable framework that encourages the adoption and development of green H&C technologies. For instance, legislation that mandates energy efficiency standards and regulations that incentivize the use of renewable energy sources play a critical role. Subsidies and financial incentives reduce the economic burden on consumers and businesses, making the transition to green technologies more attractive and feasible. These external drivers not only facilitate market growth but also ensure a sustainable and resilient development trajectory for green H&C technologies.

Afterwards, an expanded analysis of the SWOT analysis is reported for each point:

- Strengths: The impact analysis of both internal and external factors affecting the deployment of renewable and energy-efficient H&C technologies underscores several notable strengths. Chief among these is operational stability and favorable monetary benefits, particularly the cost–benefit ratio associated with sustainable H&C technologies. Additionally, low complexity in maintenance and the absence of the need for fuel storage enhance their appeal. Minimal spatial constraints, coupled with low health and security risks, further solidify the attractiveness of these systems. These characteristics collectively demonstrate a wide array of positive factors that drive the diffusion of green H&C technologies.
- Weaknesses: Despite the inherent advantages, several weaknesses limit the widespread adoption of green H&C technologies. A primary constraint is the persistent dependency on fossil fuels, as many existing and newly installed systems remain reliant on non-renewable energy sources, restricting the diffusion of renewable and energy-efficient technologies. Furthermore, a significant challenge lies in the necessity of fostering specialized professional expertise, particularly among installers, who hold substantial influence over consumer choices. Their advisory role to end-users significantly impacts market dynamics [16]. Additionally, the reliance on electricity supply and grid access compounds these weaknesses, particularly in areas where such infrastructure is limited.
- Opportunities: Beyond the technological features, several promising opportunities arise from the evolving political and economic landscape. Key drivers include government subsidies, incentives, and supportive legislation, all of which strongly promote the adoption of sustainable H&C systems. Their relatively low environmental impact, including reduced refurbishment needs, further enhances these opportunities. Moreover, investments in research and development (R&D), professional training for consultants, and public awareness initiatives significantly contribute to the growing adoption of green H&C technologies.
- Threats: Several critical threats persist that could impede the diffusion of green H&C technologies. Foremost among these is the lingering reliance on fossil fuels [17], making current systems vulnerable to supply disruptions. Conventional H&C systems also produce higher noise levels, exacerbating perceived risks and uncertainties regarding their functionality. Furthermore, end-user resistance, driven by inertia and skepticism toward the new technologies, remains a significant barrier. Together, these challenges hinder the broad adoption of sustainable H&C systems.

In summary, while both internal and external factors contribute to the positive market outlook, external factors—such as supportive legal frameworks and financial incentives—are particularly influential in driving the market's positive development. In fact, the higher score in the external section of the SWOT matrix underscores the importance of these factors in fostering a conducive environment for green H&C technologies. Ambitious policies and legislative developments, which establish clear and binding environmental targets, are poised to significantly enhance the dissemination of these technologies while providing substantial support for their implementation. For instance, the revised Renewable Energy Directive sets a target for 49% of energy consumption to come from renewable sources by 2030, along with a binding goal for an annual increase of 1.1 percentage points in the use of renewables for heating and cooling. It also includes an indicative target for an annual rise of 2.1 percentage points in renewable energy and waste heat and cold use in district heating and cooling networks [17]. Such measures will continue to accelerate the diffusion of green H&C technologies.

Matchmaking

The information output of a SWOT analysis can be used to generate improved strategies for specific H&C technologies, through the methodology described in Section 2.4; various drivers of green H&C technologies can overcome barriers. The following (not exhaustive) list sketches potential interconnections and sheds light on underlying mechanisms, which can form a basis for targeted policy formulation.

1. Weakness: energy source dependency

Cause	Effect
Existing and newly installed H&C systems still mainly depend on fossil fuels [18].	This market saturation limits a broad diffusion of green H&C technologies. Opportunities that can overcome that weakness: subsidies and incentives, regulation and legislation, research and development (R&D).
Targeted policies (subsidies and incentives, regulation and legislation) support the diffusion of green H&C technologies. For example, tax exemptions or green certificates [19] and the reduction of fossil fuel subsidies, and the taxation of CO_2 emissions caused by conventional H&C systems increase the economic competitiveness of green H&C systems compared to fossil-fuel-fired ones in terms of costs [20]; research and development activities reduce the dependency on fossil fuels of H&C technologies.	The dependency of H&C technologies on fossil fuels is reduced, the competitive advantage of green H&C systems is increased, and the diffusion of green H&C technologies is facilitated.

2. Weakness: dependency on electricity supply

Cause	Effect
A number of conventional, as well as green H&C technologies, depend on electricity supply (grid access). For new market entrants, high connection charges for coupling an asset to the grid can be prohibitively costly if, for example, District Heating (DH) is price categorized on unequal comparable technologies [21]. This form of price discrimination can result in uncertainty regarding connection costs, which adds risks to the planning of green H&C systems such as Combined Heat and Power (CHP). Also, the grid can be a capacity constraint, as has been observed regarding renewable district energy [22].	This makes implementing green H&C technologies financially as well as practically less feasible. Opportunities that can overcome that weakness: R&D and legislation.
R&D activities can reduce dependency on electricity supply through accelerating innovation for example in standalone photovoltaic (PV) systems and battery storage [23]; regulation and legislation can effectively prohibit price discrimination (e.g., by avoiding that non-green electricity is sold as such); regulation based on a geographical mapping of grid capacities or the legislative introduction of a right to connect can address grid capacity constraints [20].	R&D reduces the dependency on electricity supply due to specific H&C technologies; regulation and legislation can effectively address price and capacity constraints caused by the requirement of grid access.

3. Weakness: building professional know-how

Cause	Effect
Suboptimal installation or inaccurate design cause malfunctioning H&C systems [24] and can be the result of a lack of professional know-how and a lack of experience [25]. The availability of professionals (e.g., engineers, installers, energy managers) who dispose of the required knowledge and qualifications is a necessary condition for the successful installation of green H&C systems.	A lack of professional know-how impedes the diffusion of green H&C technologies. Opportunities that can overcome that weakness: training.
Training equips professionals with the knowledge and skills that are required to install green H&C technologies.	An emphasis on the necessity to train professionals acknowledges the necessity to build professional know-how.

4. Threat: noise

Cause	Effect
While usually invisible to the passer-by, air source heat pumps can cause noticeable noise [25].	Higher noise levels may threaten the diffusion of heat pumps. Although diffusion may be desirable from an energy-saving and environmental point of view, noise concerns of e.g., neighbors may lead to a tipping point which take-up drops off [25].Opportunities that can overcome that threat: subsidies and incentives; R&D.
The operation of Thermally driven heat pumps (TDHPs) is relatively silent, due to the usage of a so-called 'thermal compressor' instead of a mechanical one [26]. Targeted subsidies and incentives can contribute to the diffusion of TDHPs, while R&D activities contribute to a general reduction of noise levels of air source heat pumps.	The level of noise produced by green H&C technologies can be reduced.

5. Threat: supply security

Cause	Effect
Energy supply security can pose a threat to existing and newly installed H&C systems that still often depend on fossil fuels [1]. In 2021, the EU imported more than 40% of its total gas consumption and 27% of its total oil consumption from Russia [27].	The market saturation and the high diffusion of H&C technologies that are dependent on fossil fuels and are susceptible to supply insecurity limits the broad diffusion of green H&C technologies, because the latter would need the old H&C technologies to be removed in order to be installed in their place. Opportunities that can overcome that threat: subsidies and incentives, regulation and legislation, and monetary considerations.
Policies (subsidies and incentives, regulation and legislation) can support the implementation of H&C technologies that do not depend on fossil fuels and are therefore less susceptible to insecure energy imports; monetary considerations affect the diffusion of green H&C technologies and the replacement of conventional ones [28]. And if less secure energy im-ports cause price increases for fossil fuels, green H&C technologies become relatively cheaper.	The diffusion of green H&C technologies is accelerated through comparative eco-nomic advantages and policies and mitigates risks related to energy security.

6. Threat: inertia

Cause	Effect
Inertia refers to resistance to adopting new technology, such as green H&C technologies. It accounts for aspects such as behavioral changes and the development of new habits. Inertia can occur in both individuals and organizations. For organizations, inertia may be critical if behavior takes significant time to change, regardless of benefits [29].	Inertia can lead to inefficient use of resources, such as a postponement of the instalment of green H&C technologies [30]. Opportunities that can overcome that threat: awareness, R&D, training, legislation and regulation, subsidies, and incentives.
Awareness campaigns can provide information on potential benefits and motivate tar-get groups to question their habits and induce behavioral changes [31,32]; R&D activities contribute to making green H&C technologies more user-friendly; Regulation and legislation can address inertia in organizations through introducing environmental and energy targets [33,34]; subsidies and incentives, such as tax incentives, make the diffusion of green H&C technologies economically more feasible.	These factors contribute to overcoming the threat that is posed by inertia and leads to effective behavioral changes among individuals and organizations.

7. Threat: risk and uncertainty

Cause	Effect
Perceived risks and uncertainty, e.g., concerning the functioning of H&C systems, impede their diffusion. For example, low credibility or poor past performance may lead to perceived risks and lack of trust for new and green H&C technologies [30,35].	If green H&C systems were conceived as unreliable or unstable, then this would threaten their diffusion. Strengths that can overcome this threat: health, security, operational stability, and complexity in maintenance.
Experts did not associate green H&C technologies with health or security risks or with issues related to operational stability or complex maintenance.	These strengths of green H&C technologies contribute to mitigating threats that would otherwise arise out of poor performance and perceived uncertainty.

4. Discussion

The results clearly suggest that policy measures targeting environmental goals, reducing uncertainty, and improving the relative competitiveness of green H&C technologies could mitigate most barriers hindering their adoption. Green H&C technologies are currently constrained by their dependence on fossil fuels, which dominates the existing and newly installed H&C systems. This market saturation limits their widespread diffusion. However, subsidies, incentives, regulations, and R&D activities could lessen this dependence, increasing their competitive advantage and facilitating adoption. Additionally, electricity supply dependency can impede the implementation of both conventional and green H&C systems, particularly due to the grid access charges and potential capacity constraints. Research into standalone photovoltaic (PV) systems and battery storage, alongside regulations prohibiting price discrimination and ensuring fair grid access, could reduce this dependency. A lack of professional expertise is another significant barrier. Malfunctioning H&C systems often arise from inaccurate designs due to insufficient professional know-how. Comprehensive training programs can address this gap, equipping professionals with the necessary knowledge and skills to ensure proper installation. Noise and supply security issues pose significant threats to green H&C diffusion. Air source heat pumps can generate noticeable noise, which may deter their adoption. Targeted R&D and the use of thermal compressors, coupled with subsidies, can reduce noise levels. Energy supply security, given the EU's reliance on imported fossil fuels, makes the switch to green H&C technologies imperative. Policies that reduce dependency on fossil fuels through incentives and regulation could expedite the adoption of these systems. Inertia, characterized by resistance to new technologies, can also impede adoption. Information campaigns, user-friendly designs through R&D, and strong environmental targets can motivate change. Additionally, the perception of risks and uncertainty about the functionality of green H&C systems threatens their uptake. However, the strengths of these systems, such as operational stability and ease of maintenance, counterbalance these fears. The quality of data regarding H&C systems varies significantly across the EU. While comprehensive data are available for central and northern Europe, information for southern and eastern member states is often incomplete and based on expert opinion. Therefore, research in these regions must be strengthen, focusing on mapping the technologies used, CO_2 intensity of electrical grids, and the efficiency of H&C systems.

The European cooling market, especially for services, remains underexplored. Research on cooling technologies should be expanded to cover the tertiary sector. An open repository compiling data and information could facilitate this research. Further studies should quantify energy consumption savings and GHG reductions achieved through natural cooling, passive cooling, and free cooling systems in various building sectors [36–38]. Nature-based solutions (NbSs) such as green roofs and urban areas also offer promising potential for reducing energy consumption in buildings. Behavioral changes could yield up to 50% energy savings [39]. The H&C sector must be closely studied to meet the EU's 2030 and 2050 goals. A life cycle assessment is crucial to capture the environmental impact of each technology throughout its lifecycle. Lastly, data collection should be comprehensive. Utilizing existing large databases alongside individual literature sources will provide a fuller picture. Accurate data on the age of existing H&C systems are particularly scarce. From a methodological perspective, addressing data gaps necessitates more than merely extrapolating and synthesizing information from comprehensive data tools, such as the EU Building Stock Observatory (2022) [40], In-vert/EE-Lab (2015) [41], and Tabula (2012) [42]. It is essential to delve into individual scientific literature sources, including journal articles, conference proceedings, books, and project deliverables. Such a meticulous approach enables the identification and resolution of data deficiencies, allowing researchers to establish robust and comprehensive evidence for their studies. The combination of broad data tools with detailed literature analysis ensures a thorough understanding of the research landscape. Expanding the analysis to include emerging technologies, such as photovoltaic thermal (PV/T) hybrid solar collectors and biomass-fired combined heat and power (CHP) plants, will offer better forecast scenarios for future technology trends.

5. Conclusions

This study has explored the drivers and the barriers that policy frameworks and market dynamics exert on influencing the adoption of green H&C technologies in Europe. In fact, despite their considerable environmental and economic benefits, these technologies remain underutilized, meeting only 23% of the region's H&C demand. Key barriers include the dependence on fossil fuels, the challenges of electricity supply, a lack of professional know-how, inertia, and concerns over noise and supply security. Nonetheless, this research shows that strategic policymaking, coupled with technological advancements, has the potential to substantially mitigate these barriers. Moreover, the results showed that policy measures, subsidies, incentives, R&D activities, and regulatory frameworks can effectively reduce uncertainties and amplify the competitiveness of green H&C systems over conventional methods. By establishing clear environmental targets, providing financial incentives, and enhancing training opportunities, policymakers can accelerate the diffusion of these sustainable technologies. Moreover, campaigns promoting awareness and innovative design solutions can help overcome resistance to adopting green H&C technologies among individuals and organizations. Stakeholders must prioritize comprehensive data collection and a life cycle assessment (LCA) approach to address the data gaps and fully evaluate the environmental impact of these technologies. Additionally, expanding research to cover emerging technologies and underexplored sectors, particularly in southern and eastern Europe, is critical for ensuring that renewable energy sources are integrated effectively across all sectors. Finally, the adoption of green H&C systems represents a pivotal step in reducing Europe's reliance on fossil fuels and achieving long-term sustainability goals. This study's analysis provides a roadmap for stakeholders to address socio-economic challenges and accelerate the shift towards sustainable, more efficient energy solutions across Europe.

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Appendix A

The following appendix includes Questionnaires A and B.

Questionnaire A

Please evaluate the intensity or strength (level) of each feature of H&C technologies by indicating a value ranging from −10 to +10 as follows:

- For factors, you consider barriers to the diffusion of green (renewable or energy-efficient) heating and cooling technologies: −10 (very strong) to −1 (less strong)
- 0 = neutral
- For factors, you consider drivers for the diffusion of green (renewable or energy-efficient) heating and cooling technologies: +10 (very strong) to +1 (less strong)

Whether a factor is considered a barrier or a driver (the direction of the influence) should be decided by answering the following questions:

Drivers: "What elements of H&C technologies facilitate the diffusion of green (renewable and energy-efficient) technologies instead of conventional ones?" Or "What features of the surrounding environment or impacts of H&C technologies on the environment facilitate the diffusion of green (renewable and energy-efficient) technologies instead of conventional ones?"

Barriers: "What elements of H&C technologies hinder the diffusion of green (renewable and energy-efficient) technologies instead of conventional ones?" or "What features of the surrounding environment or impacts of H&C technologies on the environment hinder the diffusion of green (renewable and energy-efficient) technologies instead of conventional ones?"

For example, if you think that end-users' awareness of the benefits of installing green H&C technologies affects their diffusion positively (and is, therefore, a driver), please choose a value be-tween +1 and +10 depending on the level of awareness among end-users you assume. If you assume that awareness affects the diffusion negatively, then please indicate a value between −1 and −10, again depending on the assumed level of awareness among end-users.

Table A1. Template structure utilized for data collection in Questionnaire A regarding the direction of influence and intensity of barriers and drivers of H&C technologies.

The Relative Importance of Features for the Diffusion of Green H&C Technologies		
Features of H&C Technologies Explanation of Feature Relative Importance in General (in %)	**Features of H&C Technologies Explanation of Feature Relative Importance in General (in %)**	**Features of H&C Technologies Explanation of Feature Relative Importance in General (in %)**
Awareness	What is the level of awareness about the advantages and disadvantages of green H&C technologies among end-users?	
Building professional know-how	To what degree is it necessary to expand existing know-how among professionals (e.g., engineers, installers, energy managers) to ensure a successful installation of green H&C technologies?	
Complexity in maintenance	How complex and frequent is the maintenance of green H&C technologies compared to conventional ones?	
Dependency on electricity supply	In how far do green H&C technologies depend on access to electricity supply?	
Energy sources dependency	To what extent do H&C technologies depend on fossil fuels?	
Fuel storage needed	How frequent is the requirement of installing fuel storage to make use of green H&C technologies?	

Table A1. *Cont.*

The Relative Importance of Features for the Diffusion of Green H&C Technologies		
Features of H&C Technologies Explanation of Feature Relative Importance in General (in %)	**Features of H&C Technologies Explanation of Feature Relative Importance in General (in %)**	**Features of H&C Technologies Explanation of Feature Relative Importance in General (in %)**
Health	Compared to conventional H&C technologies, are green H&C technologies related to more health risks (e.g., legionella)? And to what extent?	
Inertia	Are end-users resistant to the adoption of green H&C technologies due to habits or required behavioral changes, despite the benefits? And to what extent?	
Legislation and regulation	To what degree does the legislative and regulative environment (other than subsidies and incentives) in the European Union facilitate the diffusion of green H&C technologies?	
Monetary	How far do benefits related to an investment in green H&C technologies outweigh the costs?	
Need for refurbishment to make use of unconventional technologies	To what extent is it necessary to refurbish facilities/apartments/buildings to make use of green H&C technologies?	
Noise	To what degree are green H&C technologies noisy, in so far as this noise is experienced by end-users or neighbors?	
Operation stability	To what extent are green H&C technologies reliable and to what degree is their provision of energy stable?	
Research and development (R&D)	What is the extent of research and development activities for green H&C technologies compared to R&D on conventional H&C technologies?	
Risk and uncertainty	To what extent do end-users or other stakeholders (e.g., public officials) perceive the investment in and usage of green H&C technologies as risky or uncertain, for example, due to poor performance in the past that causes a lack of trust in the technology?	
Security	Compared to conventional H&C technologies, to what degree are green H&C technologies related to security risks other than health risks (for example, the risk of fire)?	
Spatial constraints	Spatial constraints	
To what degree are green H&C technologies related to space constraints?	To what degree are green H&C technologies related to space constraints?	
Subsidies and incentives	Subsidies and incentives	
To what degree do subsidies and incentives in the European Union favor or disfavor green H&C technologies?	To what degree do subsidies and incentives in the European Union favor or disfavor green H&C technologies?	

Questionnaire B

Please indicate the importance of each factor compared to other factors for the diffusion of green (renewable or energy-efficient) heating and cooling technologies by filling in a value ranging from 0% to 100% as follows:

- 0%: compared to other factors within the questionnaire, the factor is not important at all for the diffusion of green H&C technologies.
- 100%: compared to other factors within the questionnaire, the factor is essential for the diffusion of green H&C technologies.

For example, if you consider monetary considerations as important for the decision to implement green H&C technologies, choose a high percentage value. If you consider monetary considerations as less important for the decision to implement green H&C technologies, choose a low percentage value.

Table A2. Template structure utilized for data collection in Questionnaire B regarding the direction of influence and intensity of barriers and drivers of H&C technologies.

The Relative Importance of Features for the Diffusion of Green H&C Technologies		
Features of H&C Technologies Explanation of Feature Relative Importance in General (in %)	**Features of H&C Technologies Explanation of Feature Relative Importance in General (in %)**	**Features of H&C Technologies Explanation of Feature Relative Importance in General (in %)**
Awareness	Compared to other features, how important is awareness among end-users about the advantages and disadvantages of green H&C technologies for their diffusion?	
Building professional know-how	Compared to other features, how important is the expansion of existing know-how among professionals (e.g., engineers, installers, energy managers) for the diffusion of green H&C technologies?	
Complexity in maintenance	Compared to other features, how important are complexity and frequency in the maintenance of green H&C technologies for their diffusion?	
Dependency on electricity supply	Compared to other features, how important is the dependency on electricity supply for the diffusion of green H&C technologies?	
Energy sources de-pendency	Compared to other features, how important is the dependency on fossil fuels among H&C technologies for the diffusion of green H&C technologies?	
Fuel storage needed	Compared to other features, how important is the potential necessity to install fuel storage for the diffusion of green H&C technologies?	
Health	Compared to other features, how important are potential health risks for the diffusion of green H&C technologies?	
Inertia	Compared to other features, how important is end-users' potential resistance to the adoption of green H&C technologies (e.g., due to habits or required behavioral changes) for the diffusion of green H&C technologies?	
Legislation and regulation	Compared to other features, how important is the legislative and regulative environment (other than subsidies and incentives) in the European Union for the diffusion of green H&C technologies?	
Monetary	Compared to other features, how important is the cost–benefit ratio of green H&C technologies for their diffusion?	

Table A2. *Cont.*

The Relative Importance of Features for the Diffusion of Green H&C Technologies		
Features of H&C Technologies Explanation of Feature Relative Importance in General (in %)	**Features of H&C Technologies Explanation of Feature Relative Importance in General (in %)**	**Features of H&C Technologies Explanation of Feature Relative Importance in General (in %)**
Need for refurbishment to make use of unconventional technologies	Compared to other features, how important is the necessity to refurbish facilities/apartments/buildings to make use of green H&C technologies for their diffusion?	
Noise	Compared to other features, how important is noise related to green H&C technologies in general for their diffusion?	
Operation stability	Compared to other features, how important is operational stability and the stable provision of energy through green H&C technologies in general for their diffusion?	
Research and development (R&D)	Compared to other features, how important are research and development activities related to green H&C technologies in general for their diffusion?	
Risk and uncertainty	Compared to other features, how important is the perception of investments in green H&C technologies as risky or uncertain for their diffusion? (perceived risk may be caused, for example, by poor performance in the past that leads to a lack of trust in the technology)	
Security	Compared to other features, how important are potential security risks other than health risks (for example, the risk of fire) that may be related to green H&C technologies for their diffusion?	
Spatial constraints	Compared to other features, how important are space constraints that are related to green H&C technologies for their diffusion?	
Subsidies and incentives	Compared to other features, how important could subsidies and incentives in the European Union be for the diffusion of green H&C technologies?	
Supply security	Compared to other features, how important are risks that stem from insecure energy supply (e.g., due to imports of fossil fuels)?	
Training	Compared to other features, how important is the training of professionals (e.g., engineers, installers, and energy managers) for the diffusion of green H&C technologies?	

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