TRI-HP PROJECT | Trigeneration systems based on heat pumps with natural refrigerants and multiple renewable sources

Social issues of novel renewable energy heating/cooling systems

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CONTENTS

LIST OF ACRONYMS

ASHP	air source heat pump
DHW	domestic hot water
GSHP	ground source heat pump
H/C	heating and cooling system
HEMS	home energy management systems
HP	heat pump
HVAC	heating ventilation air conditioning
PV	photovoltaics
RE	renewable energy
ST	solar thermal

Executive summary

This Deliverable 2.1 presents the results of Task 2.1 “Social issues enabling acceptance” and Task 2.2 "Safety, regulatory and market barriers" of the TRI-HP project, which aims to develop systems based on electrically driven natural refrigerant heat pumps coupled with PV to provide heating, cooling and electricity to multi-family buildings with an on-site renewable share of 80% reducing the installation cost by 10–15%. The objective of working package 2 (WP 2) is to understand potential social impacts of TRI-HP systems and improve the stakeholders’ acceptance towards these systems. Particular emphasis is given to market acceptance in order to understand potential barriers and hindrances for the adoption of TRI-HP by market participants. Furthermore, the institutional settings of Renewable energies (RE) by key stakeholders (socio-political acceptance) and the views of local stakeholders and residents (community acceptance) are considered.

Based on a literature review focusing on empirical social science studies on the acceptance and adoption of innovative renewable heating and cooling systems (RE H/C), key social and contextual factors are identified in this report that could promote or impede further developing and upscaling of TRI-HP systems. Empirical surveys show a general agreement on RE in Europe from which TRI-HP can take advantage. RE H/C and electricity systems are well accepted. However, this ‘acceptance in principle’ does not necessarily lead to an active adoption of TRI-HP systems. For example, despite the generally high level of social acceptance and widespread awareness of REs in Europe, public comprehension of RE H/C technologies is still low. Furthermore, specific local context conditions, such as the structure of the buildings stock, the tradition of housing tenure as well as national and local governance may provide additional barriers that need to be considered carefully.

In order to determine these factors more accurately, the perception and social acceptance of individual RE H/C technologies and components, i.e. heat pump (HP), solar thermal (ST), photovoltaics (PV), use of natural refrigerants and smart control are analysed and discussed. The findings show that economic and non-economic factors, like socio-cultural issues, local contexts and user practices play an important role for the acceptance of RE H/C systems and must be seriously taken into account for TRI-HP systems. The compilation of empirical examples suggests that the respective individual technologies that are part of the TRI-HP systems have their own issues and that these issues can vary from stakeholder to stakeholder.

Main barriers for TRI-HP to overcome are a lack of awareness towards HPs in many European countries, high installation costs, in particular in existing buildings, long payback periods, the structure of the building stock and legal restrictions due to the conservation of historical buildings and building ensembles which can restrict the use of PV and ST. Other barriers are different decision-making processes in condominiums and a high complexity of hybrid systems, while many users are reluctant to adapt heating habits to a new technology.

A switch towards RE H/C systems can be supported by non-monetary benefits of HPs, such as thermal comfort, safety etc., but needs also supportive political and market framework conditions (e.g. the availability of reliable funding and financial services). On a personal level, environmental concerns of potential adopters are conductive factors that support the adoption of RE H/C.

Thermal storage is an essential feature of TRI-HP systems. Studies on battery storage suggest that flexibility and enhanced self-supply are appealing to homeowners and could support the adoption of TRI-HP. However, additional costs for storage could also increase upfront costs and boost existing barriers against the use of ST and PV. Furthermore, householders’ capacity for load shifting is limited by the inertia of routinized practices of energy use. These restrictions have to be taken into account when assessing the overall performance of TRI-HP systems.

The acceptance of natural refrigerants, such as CO_2 and propane, is mainly depending on a safe and reliable installation and operation of TRI-HP systems. Main barriers TRI-HP needs to address are safety hazards and capacity building and education of installers, maintenance technicians and consumers etc. A detailed analysis of regulatory barriers is presented in chapter 4. Insights from social studies of science and technology underline the need to include professionals as important stakeholders from the beginning. TRI-HP should not only focus on investors and planners as decision-makers, but should also take 'middle actors' such as HVAC consultants, technicians, operators and intermediary actors (energy agencies etc.) into account.

A gender analysis shows that RE H/C systems are not 'gender-neutral' and gender has an influence on the perception, adoption and use of RE H/C systems. Gender aspects are highly relevant for the TRI-HP project and should be considered in order to enhance the acceptance of RE H/C technologies. A higher environmental concern of women has been identified as an important factor that supports energy transitions and can promote the acceptance of RE, both in personal and professional contexts. Women tend to have a higher carbon print at home since they are still the primary home carer. However, women are still underrepresented in the energy sector and H/C areas. H/C technologies intersect with gendered practices in private households. However, up to now the empirical thermal comfort model that is based on a metabolic rate of an average man, is failing to match the needs of women. Respecting these links can help to question implicit assumptions in technology development in order to get a more realistic picture of the users' needs. In particular, the different biophysical requirements of women and men related to the experience of thermal comfort have to be taken into account. The specific needs of women to control H/C of indoor environments provide another issue that should be considered when designing the user-system interface.

The reviews on standards, regulations and on market barriers points to further issues that are to be respected. Important topics are maximum refrigerant charges, requirements for components as a function of design pressure, temperature limitations with hydrocarbons, construction requirements, testing, etc. Furthermore, energy efficiency and labelling requirements are discussed. Particular emphasis is given to hydrocarbons and CO_2 as working fluids in TRI-HP HPs. Market barriers for propane HPs emerge from safety concerns regarding the high flammability of propane, additional manufacturing costs due to the characteristics of propane and lack of knowledge and training needed for developers, installers and maintainers and limitations on refrigerant charge. Main market barriers for CO_2 HPs are costs, which are linked to the low critical temperature and a lack of training and knowledge about CO_2 vapour compression systems.

1. INTRODUCTION

The overall aim of the TRI-HP project is the development of a tri-generation system providing heating, cooling and electricity. These are based on electrically driven natural refrigerant heat pumps coupled with multiple renewable energy sources and storages to provide heat, cooling and electricity for multi-family apartment buildings. The objective of WP 2 is to understand potential social impacts of TRI-HP systems and improve the stakeholders' acceptance towards these systems. This includes in particular:

- the analysis and identification of the interests and needs of end-users and installers, i.e. fitter, plumber, craftsmen etc., regarding TRI-HP systems in different countries
- exploring market, safety and regulatory barriers
- understanding and determining other key stakeholders' acceptance of TRI-HP systems

In WP 2 the consideration of social acceptance focuses on market participants in order to understand their potential barriers and hindrances towards the adoption of the solutions proposed. Three groups of market participants will be considered who have an immediate influence on the decision-making process, installation and maintenance:

- end-users (i.e. investors / building owners who make investment decisions for a building)
- installers and other decision makers for the installation of energy systems (e.g. planners, architects, engineers)
- building/facility managers who are in charge of the operation of the systems

Residents (owners/tenants) are another relevant group to be considered, but they have only indirect influence on investment decisions for energy supply in apartment buildings.

Deliverable 2.1 presents the results of Task 2.1. Based on a literature review focusing on the social acceptance of innovative (RE H/C), key social and contextual factors are identified that could promote or impede further developing and upscaling of TRI-HP systems. Hybrid systems, like TRI-HP, use many components which are already established in the market, i.e. HPs, ST, PV, etc. Therefore, the analysis of the perception, valuation and use of these RE technologies for H/C and electricity generation by different groups of stakeholders can draw on empirical insights and case studies on existing H/C in order to identify relevant topics. These topics will be explored further and elaborated in greater detail in the Tasks 2.3 and 2.4 using qualitative interviews and stakeholder workshops. Gender aspects may have an important impact on the acceptance of RE H/C systems. Therefore, a gender analysis is included in the overall work of WP 2.1. The results are presented in section 3.5.

The report is structured as follows: first, a short presentation of the social science perspective on REs and H/C is given. Among other things, the concept of social acceptance is explained in more detail here. Subsequently, an evaluation of the researched empirical case studies is carried out regarding the individual technical components of the TRI-HP system, but also with regard to potentially relevant stakeholders, gender aspects and more. Finally, an overview of market, regulatory and safety issues as well as a summary of main barriers is given.

In addition to Task 2.1, focusing mainly on non-economic drivers and barriers of RE H/C systems, Task 2.2 investigates legal and economic barriers related to the development of TRI-HP systems. In order to give a more comprehensive view, a short summary of the main results of this task is included in this report in section 4.

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Methodology

The in-depth literature research was mainly conducted through Google Scholar, Web-of-science, the European Commission database and bibliographies of researched literature. The time scale covers mainly the last 10 years, with some exceptions made for important and highly quoted „classics“. About two thirds of the sources researched are peer-reviewed journal articles, 20 % are project reports or deliverables and the rest are monographs.

The methodological approach was as follows: First, the following and related keywords were searched for:

- renewable energy
- combined heat and power
- heating/cooling systems (HVAC, refrigeration)
- micro-generation
- solar power (photovoltaics and solar thermal)
- (domestic) heat pumps
- ground source (geothermal) and air source heat pumps
- storages (thermal, energy, ice)
- natural refrigerants
- smart homes, smart control etc.

Technologies such as wind power or biomass which are not relevant for TRI-HP systems were explicitly excluded from the search. Second, the results have been combined with other search terms covering the social dimension, such as social acceptance, perception, social issues, (social) barriers and hindrances etc. A third delimitation concerned the geographical setting. As Spain, Germany, Switzerland and Norway are target countries of the TRI-HP project, they have also been used as key terms. Some studies from other countries were also taken into account, e.g. if they were neighbouring countries or if the results were to be used for the purpose of this paper regardless of the context. In a second step, those sources were selected for in-depth analysis whose title and abstract suggested that they might be of interest for WP 2, or if they were frequently quoted.

2. Social science perspective on renewable heating/cooling systems

2.1. Social acceptance

Researching social acceptance in the fields of energy and innovative socio-technical systems means to take ‘non-technical factors’ very serious. These include economic as well as non-economic and behavioural factors, e.g. in relation to decision-making and the resulting consequences of actions by relevant stakeholders in supporting or rejecting transformation processes. Today, social acceptance is a major concern in energy policy and technology marketing. Nevertheless, more issues need to be considered than technology design or pricing mechanisms.

The use of the term ‘social acceptance’ in research literature is inconsistent, with various interpretations and approaches associated with it. While the meaning of the concept ‘social’ can range from a general ‘public’ to specific groups of stakeholders, the term ‘**acceptance’ is used for attitudes and behaviour varying between passive consent and more active participation**. Thus, a distinction can be drawn between **‘acceptance in**

principle', which is more interested in general evaluations and attitudes of people, and 'acceptance in actual adoption and use', which looks more closely into actions, decisions, use, and behaviour.

> *"[A]cceptance in principle does not necessarily mean that stakeholders are willing to, capable of, or prone to investing in or using a particular solution. The level of public acceptance in terms of actual adoption depends on the social conditions and/or investment behaviour conditions of the decision makers, such as the building owner." (Jung et al. 2016: 815)*

The term 'social acceptance' is also frequently used synonymously with the term 'public acceptance', e.g. of REs (cf. Heiskanen et al. 2014; Wolsink 2018). The latter, however, refers to society as a whole ('the public'), without distinguishing between different groups and stakeholders, each with different and often conflicting interests and motives for action. In the field of (social) energy research and with special reference to the TRI-HP project, relevant stakeholders include not only energy consumers, producers and suppliers but also homeowners, engineers, architects, building professionals, manufacturers, craftsmen and further actors with specific needs, requirements, expectations, etc. In short, all actors involved in the process of installing TRI-HP technology in apartment buildings (see chapter 3.4).

For example, as representative surveys such as the *Eurobarometer* show, in all European countries REs are accepted in principle, i.e. with a high degree of approval. At the same time, however, and especially in the case of large infrastructure projects, such as constructions of wind turbines, this general acceptance can also go hand in hand with local resistance at a community level – a phenomenon that has been described as 'social gap' (Fast 2013). **Researching social acceptance of innovative technology systems, therefore, not only needs to consider the plurality and heterogeneity of stakeholders but also the specific technology at stake and the different meanings of RE technologies that can coexist within the same society, local community and even individuals** (Batel and Devine-Wright 2014).

So, the crucial question is the following: *Who* accepts *what*? Who is the subject and what is the object of acceptance? As the research literature suggests, **the degree of acceptance strongly depends on the specific technology, the stakeholders involved and the broader context in which this acceptance process is embedded**. It plays a major role, for example, whether the social acceptance of plans to construct a wind power plant in rural areas are examined or whether research is done on individual investment decisions for a hybrid micro-generation system that is intended for domestic use. In the latter case, much more 'active' acceptance by the individual is required in terms of the willingness to invest in and adopt these technologies, meaning that a technology must be accepted by homeowners within their household instead of just being tolerated outside of it. 'Passive' acceptance therefore requires less involvement, i.e. no actual adoption. Similarly, non-acceptance cannot be equated with active resistance, e.g. against a wind power plant. Much more social science research is needed to understand how such micro-generation systems are integrated into domestic routines (Watson 2004; Sauter and Watson 2007; Wüstenhagen et al. 2007; Wunderlich 2012; Stadelmann-Steffen et al. 2018).

With regard to the different types of acceptance, the much-cited distinction made by Wüstenhagen et al. (2007) between the three dimensions of social acceptance – socio-political, community and market acceptance – has proved particularly helpful (Wüstenhagen et al. 2007). This distinction will also be applied for the analysis of the acceptance of TRI-HP. As Schumacher et al. (2019) put it:

> *"Social-political acceptance deals with the acceptance of institutional settings of REs by key stakeholders as well as the acceptance of REs by the larger public; community acceptance refers to*

specific RE plants and the reactions of the local stakeholders which are directly affected, such as residents and local authorities. Market acceptance refers to the diffusion of RE technologies within the market and the extent to which its participants, such as consumers and companies, accept them" (Schumacher et al. 2019: 316).

In a systematic review of the literature about the social acceptance of RE from the last 25 years, Fast (2013) has found that the number of studies has steadily risen since 2005, especially in the field of socio-political and community acceptance. Macro-generation technologies such as large wind power or biomass plants and associated community resistance were most frequently investigated, especially in the UK and Germany with regard to the so-called NIMBY effect.[1] On the other hand, micro-generation technologies for private use, generation processes such as geothermal energy and the role of stakeholders accounted for only a fraction of research literature to date (Fast 2013). The TRI-HP project is particularly concerned with micro-generation, e.g. in apartment buildings, and with stakeholder processes beyond a supporter-protester distinction, e.g. by involving professional stakeholders. This means that a large part of the available literature was considered irrelevant and thus excluded for the purpose of this report. In particular, the numerous studies on community acceptance are negligible, as the focus here is not on collective siting decisions and questions of participation and legitimation, but on individual investment decisions.

2.2. THE IMPORTANCE OF LOCAL CONTEXTS AND SOCIAL PRACTICES

Technologies and their use do not exist in isolation. This must be taken into account when diffusing innovation. Brohmann and colleagues (2007) examined 25 case studies from several countries with regard to the framework conditions for a successful integration of new, renewable and energy efficient technologies. Their central finding is that, in addition to technology specific factors, the overall context is also of great importance (Brohmann et al. 2007). Khanam and Daim (2017) who investigated the market up-take of ASHPs using CO_2 as a refrigerant in the northwest of the USA come to the same conclusion. As they emphasise, it is not only the product properties that need to be taken into account in the technical development of a technology, such as energy and cost efficiency, robustness, safety, installation costs, etc. Rather, all measurable variables that can influence the desired functionality of the product are important when considering the overall context. For the technical and economic success of projects, it is therefore inevitable that further context conditions must also be taken into account. This specifically refers to the concrete geographical, socio-cultural, political, institutional, infrastructural, historical and economic context, which on the one hand can pose a problem for social acceptance, but on the other hand is also a source for new approaches and solutions (Devine-Wright 2005; Brohmann et al. 2007; Khanam and Daim 2017).

For example, support or resistance towards energy projects may have historical reasons, e.g. when they are founded in certain traditions of housing tenure and governance. Only 35 % of Swiss owners live in their own buildings, which is the case for more than twice that percentage in Norway and Spain. In Germany, approx. 35 % of the total building stock are owner-occupied single-family houses, 23 % are apartment buildings owned by landlords or housing cooperatives and a share of approx. 7 % falls on apartment buildings with owner

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[1] The acronym stands for "not in my backyard" and describes the observed phenomenon that the social acceptance of an object can decrease with increasing proximity to the subject of acceptance under certain conditions. However, the research results on this are not unambiguous. Cousse and Wüstenhagen (2019) come to the conclusion that familiarity with wind turbines in one's own environment can increase social acceptance of wind turbines.

associations. The picture is quite different in Spain, where 18 % are owner-occupied single-family houses, 33 % are owner-occupied apartment buildings and 27 % (about eight million residences) are secondary homes that are unused or partly empty throughout the year (Heiskanen et al. 2012). Since these country-specific differences also imply different decision-making structures in the housing sector, **it is apparent that country-specific solutions for the diffusion of energy efficient and RE H/C are of importance** (European Commission 2017c). Other differences can be identified in relation to socio-economic characteristics, energy sources used in buildings, RE growth rates, policies to promote renewable H/C, and public opinion and acceptance of energy renovations. Table 1 gives an overview and categorization of factors influencing the social acceptance and adoption of low energy buildings and RE H/C in the existing building stock in selected European countries, including Germany and Spain (Heiskanen et al. 2014).

General factors	
Initial cost, cost-effectiveness	Organizational barriers
Energy cost savings	Access to capital
Improved comfort	Availability of widely used and recommended solutions
Occasions for renovation	Availability of quality service
Context specific factors	**Technology specific factors**
Geography: climate, natural resources, industries Infrastructure: building stock, energy systems, compatibility of new solutions History and culture: Traditions of building governance, institutionalization of energy efficiency policy, good and bad experiences of solutions Policy: legislation & financial support, effectiveness of policy, political support (other than climate benefits) Markets and companies: availability and cost of solutions vs. cost of energy; established large companies offering solutions Expert and professional communities: level of integration and consensus Citizen and social movements: legitimacy and public support Media: public information and contoversies	Different decision criteria for early adopters of innovative technologies (environment, technology attraction) than for latercomers (more cost and convenience driven) Different financial valuation for technologies, with higher payback expectations for technologies perceived of as riskier Social and regional influence strong in growth phase: adoption by neighbours increases likelihood to adopt Particular concerns and constraints related to particular technologies (e.g. inconvenience, space requirements, perceived performance risks, permitting issues) Role of stakeholders e.g. installers for windows and HVAC, financial institutions for expensive solutions Importance of auxiliary services like finance and guarantees for mass market adoption

Table 1: Factors influencing the social acceptance of low energy buildings and RE H/C technologies (Heiskanen et al. 2014)

Furthermore, companies, expert and professional communities (e.g. universities), citizen and social movements and the media can play a decisive role in how innovative technologies are adopted within society. Especially in new heating systems different diffusion patterns could be observed, which cannot be explained by climatic conditions alone. Rather, historical and infrastructural factors are just as important as recommendations by friends, neighbours and local professionals. As some studies show, **the networks that have formed around a particular technology are pivotal for building trust, shaping attitudes and the local dissemination of knowledge** (Rogers 2003; Heiskanen et al. 2014). Network effects also include phenomena such as imitation or the development of local service markets. They can be as important as policies for driving, and adopting innovations. This emphasizes how important it is to involve stakeholders in project management at an early stage in order to positively influence social acceptance. It is not a guarantee that a given technology is adopted successfully, but it increases the chances considerably (Brohmann et al. 2007; Heiskanen et al. 2014).

Another reason why networks are important is that they play a crucial role in the emergence and maintenance of social practices and everyday routines. When we talk about integrating new technologies into certain contexts it is important to remember that they are not just individual objects. They also form part of material and social arrangements with complex path dependencies that influence people's behaviour. Changing this can be very difficult and time-consuming. This inertia has been perceived even in face of change being politically and socially recognised (Devine-Wright et al. 2017). As has often been observed, technical solutions are preferred to behavioural changes, which also means that they must fit existing behaviour. However, "new technologies cannot be merely 'dropped' into a new context without preparation or adaptation" (Brohmann et al. 2007: 10). They must therefore not only be discussed as context-free objects, but also as elements of decision-making (Wüstenhagen et al. 2007; Wolsink 2019). **Many everyday practices at home that consume energy, such as heating and cooling, cooking, doing one's laundry or having a wash etc., are interwoven with each other in fixed routines and habits that include practical understanding, know-how, rules, language and meaning.** In this way, they can counteract the appropriate use of new and efficient technologies (Stephenson et al. 2010; Strengers 2013; Reindl 2017). **Energy services provided to users should therefore always be examined from a perspective that includes practices of energy use in combination with everyday household routines** (Judson et al. 2015). In this context, 'comfort' means not only the sensory perception of a room temperature that is perceived as pleasant – and that the system should be capable of constantly providing. It should also mean the ability to maintain day-to-day practices and routine behaviour, e.g. doing laundry at preferred times. To what extent the rejection of a potential behavioural change is to be understood as a strong expression of autonomy, or merely as an inertia of existing energy cultures, remains an empirical question (Ambrosio-Albalá et al. 2019).

Summing up, TRI-HP will put a strong focus on market acceptance, but will also consider institutional settings of RE by key stakeholders (socio-political acceptance) and the views of local stakeholders and residents (community acceptance). Furthermore, specific local context conditions, such as the structure of the buildings stock, the tradition of housing tenure and local governance in Germany, Norway, Switzerland and Spain are important factors that need to be taken into account. Another topic that needs to be reflected is how TRI-HP intersects with established practices and routines of energy use in households.

3. SOCIAL ACCEPTANCE OF RENEWABLE HEATING AND COOLING TECHNOLOGIES

3.1. GENERAL ATTITUDES AND (PUBLIC) ACCEPTANCE OF RENEWABLE ENERGIES IN THE EU

The *Eurobarometer* surveys regularly record public opinion on specific topics in the EU member and candidate countries. For this study the following *Eurobarometer* surveys have been reviewed and relevant results summarised: "Special Eurobarometer 468: Attitudes of European citizens towards the environment" (European Commission 2017a), "Special Eurobarometer 459: Climate Change" (European Commission 2017b), and "Standard Eurobarometer 89: The views of Europeans on the European Union's priorities" (European Commission 2018). As Norway and Switzerland are not part of the EU, these countries are not covered by the *Eurobarometer*. For this reason, both the *European Social Survey* on "European Attitudes to Climate Change and Energy" (Poortinga et al. 2018) and the Swiss *Kundenbarometer* on "Renewable Energies" were also evaluated (Cousse and Wüstenhagen 2018, 2019).

For Europeans, climate change is one of the most important environmental issues and the third most serious global problem. Nine out of ten citizens consider it to be as a serious problem. In this respect, a growing consensus can be observed in the last years that can also be found in Switzerland. The concern about climate change is higher in Spain and Germany than in Switzerland and Norway (European Commission 2017a, 2017b; Cousse and Wüstenhagen 2018).

For EU citizens, investment in research and development of improved technological solutions is seen as one of the most effective measures for tackling climate change. The most common answer in *Eurobarometer* to the question of what can be done about air pollution and high greenhouse gas emissions is stricter regulations for industry and energy producers. On a more individual level, reducing personal energy consumption and improving energy efficiency are among the most frequently mentioned climate change mitigation measures. One third of those surveyed said that they had recently upgraded an older appliance (e.g. boiler) and about one eighth said they had converted their heating system from a higher emission system, such as coal, oil or gas, to a lower one, such as gas, pellets and solar. A large majority of 79 % of EU citizens agree that climate protection can boost the economy and create jobs. Furthermore, they agree that promoting European know-how in RE technologies in non-European countries and reducing imports of fossil fuels from third countries can benefit the EU economically (European Commission 2017a, 2017b).

Almost three-quarters support a common energy policy among EU Member States, with Spain and Germany well above average. The priorities of such an European Energy Union are seen in the development of REs, environmental protection, keeping energy prices reasonable, combating climate change, and reducing energy consumption. **A clear majority agrees that import of fossil fuel and subsidies for them should be reduced, whereas public financial support for the transition to clean energies should be increased. Around 70 % of Europeans, including Norway and Switzerland, think that a large or very large amount of electricity should be generated from renewables** (European Commission 2017b; Poortinga et al. 2018; European Commission 2018; Cousse and Wüstenhagen 2018, 2019).

Perhaps the most striking data correlation is that those who see climate change as one of the biggest issues are more likely to agree that climate protection can boost the economy; that fossil energy reduction can improve energy security; that energy efficiency needs to be improved; that REs need to be financially promoted; and that national targets to increase the amount of REs are important. Therefore, concerns about climate change can serve as a strong indicator of the potential for transformation in the energy sector (European Commission 2017b).

The empirical surveys show a general agreement on RE in Europe from which TRI-HP can take advantage. The findings suggest that a RE H/C and electricity system will be well accepted. However, this ‘acceptance in principle’ does not necessarily lead to an active ‘acceptance in practice’. Between a positive attitude towards certain technological solutions and their voluntary adoption, there can be many hurdles. For example, despite the generally high level of social acceptance and widespread awareness of REs in Europe, public comprehension of these technologies is still low, especially of complex RE H/C (Heiskanen et al. 2014). In order to determine these barriers, it is necessary to take a closer look at the perception and social acceptance of individual components of TRI-HP.

3.2. Combined and individual components of TRI-HP systems

One of the points that make RE systems like the TRI-HP system special from the point of view of social sciences is that they require double acceptance for their market up-take: (passive) public acceptance in principle and (active) private willingness to adapt and invest. TRI-HP is a micro-generation system, i.e. a small-scale combined system of mainly renewable electricity provision and heat used by individual households, small industries, businesses, hotels, public bodies, social institutions or community buildings. Their end-users are therefore both energy producers and consumers. Unlike other user groups, these so called “prosumers” mix different consumer and producer logics and motives. They are actively involved in technology deployment and become their own energy suppliers:

> *“Although micro generation technologies are infrastructure technologies, their ‘construction’ or installation involves a considerably different view of acceptance and different societal groups as compared to ‘classical’ infrastructure technologies. In this case, new societal groups involved in the process of achieving acceptance are consumers or homeowners providing the site, investing and potentially changing their consumption.” (Sauter and Watson 2007: 2772)*

In most cases, prosumers own the system and ownership in general is likely to have a positive impact on market acceptance. On the other hand, having the technology installed in the home probably also means having to adapt behaviour in terms of electricity, heating or cooling consumption (Fischer 2006; Sauter and Watson 2007; Strengers 2013; Juntunen and Hyysalo 2015; Schumacher et al. 2019).

The combination of several RE technologies in one system increases the complexity of planning, installation, maintenance and necessary behavioural changes. Furthermore, decision criteria for or against each technology are manifold, especially when considered in the context of different countries. For example, what people in one country regard as ‘innovative’ may be conventional in another country. In this sense, HPs are not innovative in Sweden, but they still are in Germany. The opposite is probably true for solar power (Heiskanen et al. 2014). In addition, there are large country- and region-specific differences in quality and performance for some technologies, especially ASHPs, but also PV. When comparing between countries it is possible to find that very different problems are associated with each of these technologies. Some of them entail particular risks, concerns or constraints that may impede their adoption, e.g. integral changes to the property, which are associated with the installation of a GSHP. Reservations may also vary with climatic conditions. The example of Spain, which is explained in more detail below, shows that these differences may even occur within the same country.

However, there are studies that indicate that hybrid system solutions not only increase performance, stability, economic benefits, resolution of possible imbalances in system operation and environmental benefits (Karytsas et al. 2019) but also acceptance compared to a single renewable technology. For Finnish homeowners, for example, this is the combination of solar energy and GSHPs (Jung et al. 2016). **It is therefore possible that combined systems like TRI-HP can create synergies, which are able to compensate for certain (perceived) disadvantages of each single technology.** In this way, the efficiency loss of a ST system resulting from seasonal variation could be reduced by combining it with a HP and a thermal storage. **On the other hand, however, it may also be the case that a combination of technologies leads to an accumulation of caveats and barriers associated with the perception of the individual technologies.** The integrated use of ST and PV not only increases the roof space requirement but also aggravate seasonal dependence. And finally, an increased complexity of the system also requires a growing need for technological knowledge. Hybrid systems demand a comprehensive understanding of their function and operation, which may cause difficulties for lay people. Since lacking or erroneous knowledge has been found to be an important barrier to both social acceptance and efficient use of new technologies, a complex combination of them could likely increase this effect. For example, it could be shown that the efficient use and correct application of a HP system depends on how well the user understands it (Caird et al. 2012). Therefore, it is critical **that the complexity of the TRI-HP system does not reach the users and that a simple and reliable solution is provided to them.**

While the following subchapters provide empirical examples of the individual technologies relevant to TRI-HP in relation to the individual countries and their specific contexts, it is also important to consider and examine the challenges of installing an overall RE based system. Replacing a fossil heating system in an existing building by a HP, for example, requires an extensive refurbishment of the building when there is no low temperature heat distribution system. For this purpose, research literature in the field of energy renovating was also reviewed. It was found that comfort, timing, aesthetic factors, performance, investment costs, cost savings and branding are important factors for investments in the building sector, e.g. for H/C.

3.2.1. HEAT PUMPS

This chapter summarises findings on social issues about HPs and RE H/C, including ASHP, GSHP. Especially with regard to the countries relevant for TRI-HP, the available research literature is limited and rarely goes beyond performance and economic analyses. The vast majority of current social science research on the subject comes from Germany, Sweden and the UK and mainly involves single-family houses (Heiskanen et al. 2014). As field trials in Germany, Switzerland and the UK have shown, there is wide and not yet fully understood variation in efficiencies of the HP systems. However, user behaviour is assumed to be one of the main reasons, yet there is only little information on the experiences and practices of householders with HPs (Caird et al. 2012). With regard to the contextual conditions mentioned above, the following factors were identified that influence the adoption and thus market up-take of HPs: climate, government policy on energy and environmental issues, energy prices, availability of competing energy sources, electricity supply and generation characteristics, housing characteristics, history, geography and geology (Fawcett 2011; Judson et al. 2015). A cross-case finding is that in all studies in which user satisfaction was surveyed, **the use of HPs, especially in private households, was rated as very satisfactory by a large majority**.

Although the established HP market in the UK is very low[2], one of the first and most comprehensive long-term field studies on the use of both GSHPs and ASHPs by private homeowners was conducted there between 2008 and 2013. More than 80 households with ASHPs and GSHPs were selected in two phases in which both system performance and user satisfaction were assessed. What is remarkable about this study is that energy suppliers, manufacturers and installers with their practical knowledge were directly involved. The study concluded that HPs were accepted as a suitable alternative by most of the householders. **Users are satisfied**, in particular, **if high standards are applied**, if HPs are properly installed, and if there is a **functioning feedback between user and installer** (especially as regards efficient use). Finally, it was also found that broader system boundaries are recommended, as **user knowledge and behaviour was shown to have significant impact on HP performance**. As a consequence, user needs should be included in research and development, and an appropriate handover and **support from installers should be guaranteed** (Dunabin and Wickins 2012; Caird et al. 2012; Energy Saving Trust 2013).

As a technology that could replace fossil heating systems in residential buildings, Fawcett (2011) sees HPs as presenting a dilemma. Although they are technically reliable and theoretically well suited for the mass market, “they can also be described as expensive, disruptive in existing homes, only relevant to a minority of householders” (Fawcett 2011: 1555–1556). She further notes that the European market for residential HPs varies considerably from country to country and a transition towards HPs in the mainstream is strongly

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2 HPs represent 1% of the heating systems in the UK and ASHPs are considerably more common than GSHP https://www.greenmatch.co.uk/blog/2016/03/the-future-of-heat-pumps-in-the-uk [2019-09-20]

depending on national regulations and political conditions, e.g. funding schemes for RE. **In 2011, a significant market had been established only in Sweden, Switzerland and parts of Austria, whereas in the remaining countries market share was too small and HPs are not the first choice when it comes to renewing old heating and hot water appliances**. Compared to most alternatives, both ASHPs and GSHPs have higher capital costs and in some cases also running costs, which is a reason why they are sold as environmentally beneficial rather than cost-effective (Fawcett 2011). In recent years, this situation has changed as the market share of HPs has increased in Sweden, Norway, Finland, Austria and France.[3] This is reflected in a representative study with Swiss homeowners who were asked what investments they would make if the money were available. The survey showed that a HP is a more likely option than, for example, renovating the kitchen or bathroom (Cousse and Wüstenhagen 2018).

In terms of energy efficiency, GSHPs have proven to be better than ASHPs. The former, however, have much higher installation and capital costs and require the necessary geological conditions and access to land. ASHPs are therefore more flexibly applicable but their operating costs are also higher. The best performance is achieved when HPs are used in buildings with low temperature distribution system. This is a notable handicap for a broad market up-take in existing buildings, if existing high temperature heat distribution system cannot be easily adapted towards lower temperatures, making installation more expensive and disruptive. In these cases, the technical effort and the social and economic barriers associated with the installation and use of HPs in existing buildings are higher and more complex than in new buildings. Fawcett concludes that HPs are not the technology that will introduce a low carbon future in the existing building stock, but rather a follow-on technology that will spread if the necessary political and economic foundations are laid (Fawcett 2011).

Spain

Another reason for the low market share of GSHPs is the **lack of awareness** that people have of this technology, especially that it can also be used for cooling (Karytsas and Theodoropoulou 2014). Particularly in Spain, this has been identified as one of the main reasons why no market has yet developed. While around 20’000 GSHP units were sold in Germany in 2017, only 95 were sold in Spain, with only 1’400 already in operation. A different picture emerges for the ASHPs: 71’000 units were sold in Germany in 2017 compared to 910’000 in Spain (EurObser'ER 2018). At the same time, however, it is also important to point out that one should not naively assume that the provision of more technical information alone could remedy the situation, as this would ignore the specific context conditions, everyday routines, etc. Raising awareness of heat pumps requires a package of measures adapted to the situation (Judson et al. 2015).

In general, reluctance to adopt RE systems is prevalent in Spain. H/C and DHW use in the Spanish residential sector is still dominated by fossil fuels and electricity and **people are generally satisfied with their solutions**. Only 10 % of Spanish dwellings are equipped with heat pumps (Ortega-Izquierdo et al. 2019). Consequently, the market is still immature and experience of designers, installers, etc. is limited. Ortega-Izquierdo et al. (2019) conducted a survey on factors influencing Spanish consumers to choose a renewable H/C. In addition to the different climatic zones, the authors found that knowledge of the technologies and the willingness to pay for

[3] In 2017, the market share of HPs in newly built single family houses was above 90 % in Norway, Sweden and Finland and around 35 % in Austria and France. In the renovation market, the share of HPs was only around 10 % in Germany, Austria and France (EurObser'ER 2018).

them are of great importance. **More than half of the respondents would pay up to 5 % to 10 % more for a renewable H/C. However, many people in Spain are not familiar with that technology.**

Most existing cooling systems in Spain are located in the Mediterranean region, the greater part of them being ASHPs. The reasons for this are found not only in the different needs but also in a lack of awareness and knowledge of GSHP, in particular. While ST is known to 60 % of Spanish respondents as RE and can be considered to be the preferred solution in the field of heating, geothermal energy is hardly known or supported. Furthermore, 70 % were not able to name a renewable cooling technology. Empirical evidence of this could also be found in other countries (Karytsas and Theodoropoulou 2014).

The main reasons against adopting renewable H/C brought forward in Spain are approval by neighbours[4] (42 %), initial investment (31 %) and structural changes to the dwelling (20 %). Since knowledge is a crucial factor in deciding whether to adopt or reject H/C in Spain, the authors also asked for sources of consultation and found **that relatives and friends are the second most important group after professionals** (architects, installers, etc.). This shows the **strong involvement of personal channels in the formation and modification of attitudes towards technologies** (Ortega-Izquierdo et al. 2019).

GERMANY

The importance of personal motivations and attitudes towards RE technologies is also supported by other authors. Michelsen and Madlener (2016) made a statistical analysis of survey data on German owners of single and apartment buildings who have replaced their old fossil heating systems with newer systems such as HPs. Their results show that **sociodemographic characteristics have much less influence on whether a renewable system is chosen than personal motivations, perceptions and preferences**. The survey respondents expressed great doubts and uncertainties about the retrofit regarding comfort, convenience and integration into everyday life. **A psychological barrier was also identified for HPs, namely the perceived difficulties of getting used to the system and understanding its basic function. The data suggests that HPs are often confused with electric heaters and therefore associated with increased running costs for electricity**. In addition, it was found that the high purchase price represents a statistically significant barrier. Provided that these barriers are addressed appropriately, however, the authors see an opportunity to spread renewable heating systems for residential buildings on a large scale in the coming years, since today's residential heating systems in Germany (e.g. boilers) are between 15 and 20 years old and have thus reached their theoretical lifespan (Michelsen and Madlener 2016).

NORWAY

A completely different picture emerges for Norway. The most important heat source in Norway is electricity, as the country has a large hydro power capacity. This is especially true for the residential sector. Attempts to establish a market for HPs (ASHPs) through subsidies were only partially successful. Around 25 % of Norwegian families own a HP today (Winther and Wilhite 2015). Most of them were adopted in western Norway,

[4] A lack of approval by neighbours turns out to be an important barrier for the acceptance of RE H/C. However, no further information is given to what concerns (e.g. aesthetics, noise, protection of historical heritage, difficult decision-making in multi apartment buildings etc.) these objections refer.

partly due to a milder climate. Sopha et al. (2010) investigated by means of a questionnaire, which factors influence the potential choice of a future heating system based on Norwegian households' perception.[5] Their results show that **those who already heat with electricity would clearly prefer to switch to HPs**. However, factors were also identified that would make switching more difficult. Firstly, it is unlikely that a change is considered if there is a high level of satisfaction with the existing system. Finally, **age also plays a role, as older respondents find it more difficult to adapt their usual heating behaviour to a new technology (Sopha et al. 2010)**.

A different approach was taken by Winther and Wilhite (2015), who used qualitative interviews and participant observation for data collection in Norwegian homes. They found **several reasons why people bought and installed HPs**. In addition to the **energy and cost savings**, the removal of the old heating system was due to **non-monetary benefits**, such as higher **thermal comfort, a better comfort (e.g. no more desire to chop wood), greater safety (e.g. if previously heating with oil) and the desire to heat more environmentally friendly**. Finally, HPs were considered to be the best option when carrying out already planned refurbishment work. The **main sources of information from which knowledge about HPs is obtained are the extended family network, friends, neighbours, colleagues and craftsmen, as well as the installers who also maintain the device** (Winther and Wilhite 2015).

The review of studies on ASHP and GSHP shows that main barriers for TRI-HP to overcome are: high upfront costs, in particular in existing building, lack of awareness, different decision-making in condominiums, complexity, in particular of hybrid systems and reluctance to adapt heating habits to a new technology, in particular among older people. A switch towards HP can be supported by non-monetary benefits, such as thermal comfort, comfort, safety and environmental concerns. The most important networks to support this technology after experts are family and friends.

3.2.2. Solar energy: ST and PV

Compared to HPs as a renewable technology for space heating, the social acceptance of ST is hardly ever controversially discussed in the literature. This may be because ST appears to have more advantages than disadvantages and hardly any social barriers. It is considered to be safe, and easy to handle; and it can be combined with almost all heat support systems. In addition, ST does not affect the in-house air quality and has moderate acquisition costs, if ST is used for DHW only and is not integrated into the heating system. Dependence on roof orientation, weather and season is, on the other hand, very high. One of the problems associated with ST is its correct installation and the lack of trained engineers and plumbers. By its integration into hybrid systems such as TRI-HP, some of the disadvantages may be compensated, and synergy effects are likely to occur. However, meaningful and usable empirical results on the adoption of ST are not available.

Some authors suggest that contextual factors play an important role for the adoption of ST. According to Heiskanen and colleagues (2014), the **most promising building type identified for Germany for ST, as for GSHP and ASHP as well are single-family homes occupied by their owners. New buildings are more promising than existing buildings.** Although the majority of heating systems are based on gas and oil, Germany also accounts for slightly less than a third of the EU's ST market. Within the country, however, the

[5] As their focus was on wood pellet heating, the sample consisted of households already using that technology. Additionally, as a control group, they interviewed a smaller sample of randomly selected Norwegian households using mainly electric heating (Sopha et al. 2010).

different structure of the housing stock in rural and urban areas must also be taken into account, as well as differences between East and West Germany. Careful consideration of the different policies of the federal states has been recommended, too. Furthermore, due to difficult decision-making processes, the installation of ST on apartment buildings is considered to be problematic (Heiskanen et al. 2014).

Like ST, PV is an integral component of TRI-HP, which is externally attached to the building and therefore visible. Issues such as design or aesthetics may play a greater role here than with the less visible components. For example, the wrong colour can lead to rejection if it does not match the general appearance within the neighbourhood. In Spain, the approval by neighbours was shown to be very important when it comes to decision for or against renewable H/C (Ortega-Izquierdo et al. 2019).

In general, the PV market varies considerably among European countries, as does the installed capacity. Whereas Germany leads with more than 45 GW installed in 2018, the PV capacity in Spain had not reached 5 GW in the same year according to the “Photovoltaic Barometer” (EurObser'ER 2019). Less than 2 GW was Switzerland’s capacity in 2016, while the technology is virtually non-existent in Norway.[6] PV development in Europe is strongly linked to government subsidy programmes via favourable feed-in tariffs, incentive systems, and a sharp decline in production and installation costs. While there are relatively few barriers to the acceptance of solar energy in principle, various practical barriers can be identified in the countries – especially with regard to cost efficiency and highly variable installation costs (Heiskanen et al. 2014). Spain is a good example of why the seemingly ideal climatic conditions alone do not automatically lead to a successful diffusion of this technology. **The political framework conditions are just as important for this as, for instance, the public discourse.** Heras-Saizarbitoria et al. (2011) have investigated the predominately negative media coverage of PV in Spain between 2004-2010, suggesting that this has influenced public acceptance. Among the most frequent arguments against PV were that it is too expensive, that yield is limited, that it is not yet mature and that it makes electricity tariffs more expensive (Heras-Saizarbitoria et al. 2011). Currently, however, a PV boom is expected in Spain following the repeal of the sun tax in April 2019.

A combination with battery storage can have a positive effect on PV acceptance. In a representative study, the *Kundenbarometer*, Swiss homeowners were asked what investments they would make if enough money were available. The survey showed that a PV system with battery storage is a more likely option than a PV system without battery storage. This points to a high market potential for PV with storage systems. Of the homeowners who have already installed PV systems or planned to do so, about half are primarily motivated by environmental protection, while just over a third wants to reduce electricity costs. Only a fraction of them say they are motivated by subsidies. Among those who have not yet decided or say they **will not install solar modules**, the main reasons are a **long payback time and a lack of capital**. This suggests a potential for new financial services. Other reasons include possible problems related to the complexity of PV systems, and uncertainties about subsidies and cost developments. Regarding the demographic profile, it appears that young respondents would prefer to invest in PV to reduce their electricity costs, while older respondents tend to do so for environmental protection (Cousse and Wüstenhagen 2018, 2019).

A research project in the Swiss Alps investigated how residents of surrounding villages and tourists would accept PV modules attached to avalanche barriers. It showed that there were no strong reservations, as the view of the landscape was already affected by the barriers and the protective purpose of these was already accepted. It was found that PV modules on existing structures with a functional character are rated

[6] see https://www.volker-quaschning.de/datserv/pv-welt/index.php

significantly more positively than on historical buildings or in the 'open' landscape. As the authors conclude, the study is therefore a good example of how important it is to consider the local context and why the general attitude towards REs alone does not say much about whether a concrete project is accepted or rejected. In conclusion they stressed that there is still too little research on small-scale PV. Yet, this could be particularly important in tourist areas such as Switzerland, as the perception of 'natural' landscapes can have an influence on how certain changes in this landscape are accepted, e.g. by PV systems (Michel et al. 2015).

Finally, the diffusion of technology also has to do with certain user groups. In Germany, for example, it has been shown that an early adoption of ST is more likely to be found in rural areas among farmers and craftsmen, while PV is predominantly preferred by urban academics with high incomes and political interest, especially in energy issues (Fischer 2006). However, these may be different starting points in the sense of Rogers' 'early adopters' (Rogers 2003), and it does not mean that these technologies must remain limited to one group or another in the advanced process of market up-take.

The use of solar energy is widely accepted in the Europe. TRI-HP can build upon this general approval. However, TRI-HP should consider several factors that impede the adoption of PV and ST. Main barriers are high installation costs and long payback periods, structure of the building stock, legal restrictions due to the conservation of historical buildings and building ensembles and difficult decision-making in multi apartment houses. A switch towards ST and PV can be supported by monetary and non-monetary benefits, such as political framework (availability of reliable funding or financial services), enhancing self-supply (storage) and environmental concerns. As a hybrid system, TRI-HP can compensate some of the deficiencies of ST and PV by coupling the use of solar energy with energy storage and exploitation of different energy sources. TRI-HP should address the contexts of specific RE funding schemes in different European countries and link up with providers of innovative financial services.

3.2.3. Storage technology

The social acceptance of RE storages, be it electricity or thermal (sensible, latent), has so far been broadly neglected, especially by social scientists studying energy (cf. Devine-Wright et al. 2017). Hot water storage is included in (fossil) central heating systems and in ST use in the residential sector, but has hardly been evaluated as a separate technology to date . Consequently, there is a major need of research in this area, in particular in the area of thermal storage. Nevertheless, some studies were found and reviewed with respect to their usefulness for TRI-HP.

As already indicated above, hybrid system solutions with H/C and DHW can benefit from the best properties of the respective individual technology. Such systems can lead to higher performance, stability, economic benefits, resolution of possible imbalances in system operation and environmental benefits. If, in addition, a thermal storage is integrated, the system becomes even more efficient, stable, flexible, and a higher level of comfort is possible (Karytsas et al. 2019). The study by Battaglia et al. (2017) showed similar results, namely that a system of PV, HP, and thermal as well as electrical storage can lead to a higher PV self-consumption and to better grid stability. However, the authors also point out that any storage solution results in a loss of energy, which is why the efficient use of energy storage systems also depends on current electricity purchase and feed-in prices (Battaglia et al. 2017).

In a survey conducted in three European countries, including Spain, Karytsas and colleagues (2019) showed that 5 to 10 % of respondents are willing to pay and install a residential hybrid system combining GSHPs, ST panels and a thermal energy storage system. About 30 to 40 % would accept a payback period of 5 to 9 years. From this the authors concluded that **high investment costs are one of the main obstacles**, although respondents are generally in favour of this solution. Suggestions for how to overcome this barrier include cost reductions, financial incentive schemes and leasing schemes. Socio-demographic factors that were proven to have a positive influence on the willingness to pay are: Gender (men are willing to pay more and accept longer payback time), high level of education and scientific affinity, occupation, high **environmental awareness**, higher income, year of construction and size of the house, location (urban-rural, depending on the country) and whether innovations have already been carried out on the building (especially if ST is already available). **These results show the need for communication and dissemination activities that are necessary to ensure that such innovative systems are also adopted by people with lower levels of education and environmental awareness (Karytsas et al. 2019)**.

Ambrosio-Albalá and colleagues (2019) have conducted several focus group discussions in a study on the acceptance and adoption of battery storage at the household and community level in the UK. As their results show, the purchase of a household battery should be cost-effective and, ideally, subsidized for the respondents. Equally important was the fact that it should still be **possible to continue with the usual everyday routines,** e.g. doing laundry **independent of energy peak times. Changes in behaviour associated with the use of a battery were vehemently rejected**, especially when there were children in the household, as they were often cited as a prime obstacle to efficient energy use. What r**espondents expected from household energy storage devices was that they help them maintain their normal lifestyle**, i.e. their existing daily routines of energy consumption. Further demands made were on the design of the battery, which should be appealing. It should also be **possible to install it where it is not visible**. **The size of the battery was considered more important than possible health aspects**. All necessary information should be **easy to understand** and preferably provided by “independent” professionals or local decision-makers (Ambrosio-Albalá et al. 2019).

Until now, there is few research on the acceptance of thermal storage in H/C systems. Studies on battery storage suggest that flexibility and enhanced self-supply are appealing to homeowners and could support the adoption of TRI-HP. However, additional costs for storage could also increase upfront costs and boost existing barriers against the use of ST and PV. Furthermore, householders’ capacity for load shifting is limited by the logic of routinized practices of energy use. These restrictions have to be taken into account when assessing the overall performance of TRI-HP systems.

3.2.4. NATURAL REFRIGERANTS

HPs for water heating that use CO_2 as a refrigerant are being developed not yet for commercial use. The first HP was launched on the Japanese market in 2001. Challenges for the diffusion of this technology include better adaptation to local needs, targeted marketing, certification, financial incentives and compatibility with other technologies. Further technological challenges associated with the use of CO_2 as a refrigerant in HPs include the much higher lift or temperature difference required for efficient operation. In addition, the operating pressure is almost 40 bar in the evaporator and between 100 and 130 bar in the gas cooler, which requires particularly robust material (Khanam and Daim 2017).

The main objective of the EU-funded project "Next Generation of Heat Pumps Working with Natural Fluids (NxtHPG)" was to develop "several reliable, safe, high efficiency and high capacity heat pumps working with the two most promising natural refrigerants: Hydrocarbons and CO_2" (European Commission 2016). Although the project participants did not specifically address social issues, they also assessed possible non-technical barriers. In their final report they conclude that the project *"has proven that safe, reliable and cost effective heat pumps employing natural refrigerants are perfectly feasible, and will do its best in contributing to spreading the news of the advantages of a natural refrigerants technology. This will contribute to the general acceptance of the technology, overcoming psychological barriers for their penetration in the market." (European Commission 2016)*

The authors also point out that t**he use of natural refrigerants would require special training for installers and plumbers and new servicing and installing techniques, which could at the same time create new business opportunities and jobs** (European Commission 2016). This is also the view of the "Guide to Natural Refrigerants Training in Europe" which draws attention to the special duty of care of technicians and engineers involved in heating and cooling technology that uses refrigerants. "The health and safety duties require technicians to consider all risks, not only those for which regulations, codes of practice, and industry guides exist" (Skacanova 2017: 43). For example, CO_2 has an A1 safety classification which means that toxicity is low, and no flammability is given. However, CO_2 operates at a high pressure that has to be monitored constantly. For technicians it is therefore important to learn how to carefully charge CO_2 systems. Accordingly, this is the case with propane that is flammable and has an A3 safety classification (Skacanova 2017).

While special training on natural refrigerants is important, there are many reasons why it is not provided or taken up: lack of training facilities, materials and budget to cover the cost as well as the fact that mandatory certification requirements for natural refrigerant training is not compulsory at the EU level (Skacanova 2017).

Specialised training in relation to different systems working with different refrigerants but also questions of health risks, flammability and recycling are important aspects highlighted in the recent "Heat Pumps Barometer" by the EurObserv'ER project:

"the European heat pump industry is readying itself for a world where different refrigerants will be used. This will lead to further training for installers and maintenance technicians so that they can work on all appliances. Also, these gases must be recovered for recycling, regenerating or destruction when the appliances reach the end of their service lives. One HP can thus save on CO_2 emissions during its life compared to fossil fuel-based heating methods or direct use of electricity." (EurObser'ER 2018)

Finally, in the reviewed literature about HPs that use natural refrigerants it was concluded that **maintenance and servicing networks should be established and that installers, craftsmen but also consumers must be better educated to successfully disseminate this technology** (Khanam and Daim 2017).

The acceptance of natural refrigerants, such as CO_2 and propane, is mainly depending on a safe and reliable installation and operation of TRI-HP systems. Main barriers TRI-HP needs to address are safety hazards and capacity building and education of installers, maintenance technicians and consumers etc. A detailed analysis of regulatory barriers is presented in chapter 4.

3.2.5. SMART CONTROL

Part of TRI-HP project is the development and testing of an advanced energy management system with embedded intelligence for self-diagnosis. This is to improve system efficiency and cost benefit and will enable TRI-HP technology's integration into smart houses and smart grids. In social science literature, the potential role of house owners as 'co-managers' of Home Energy Management Systems (HEMS) is broadly discussed.

However, user-oriented studies in actual smart environments are exceptions rather than the rule (Wilson et al. 2015; Smale et al. 2018). Variable energy tariffs and the possibility of programming and remotely controlling devices, house batteries and heat pumps pose new challenges to existing everyday practices related to home energy management. It has been shown in numerous studies on load shifting that flexibility of energy-consuming practices is limited (cf. Smale et al. 2018). Technology-oriented, automated solutions for HEMS can be interpreted by houseowners as a **loss of control over their own preferred energy management**. In this context, it was observed that t**rust and interest in smart grid projects can quickly be lost by homeowners**. In a smart grid pilot project in the Netherlands, for example, Smale and colleagues (2018) interviewed participants, focussing on monitoring technologies, smart heat pumps and home batteries. They found that **most households were satisfied in principle with their intelligent HP, but not with the algorithm that controlled the operation of the HP**. They criticized that it was too slow and unresponsive. In addition, **they lamented how in-home displays have replaced face-to-face communication**, e.g. with project representatives or professionals. Moreover, respondents were ambivalent about their household batteries. Although they appreciated the optimal use of their self-generated solar energy through automated charging and discharging, they also expressed strong **doubts as to actual performance and functionality of their batteries (Smale et al. 2018)**.

Using a combination of in-depth workshops, expert interviews and literature research, Balta-Ozkan and colleagues (2013) investigated social barriers to the introduction of smart homes in the UK. They found that experts on the one hand identified a **lack of fit to current and changing lifestyles, technological complexity, interoperability and standards, reliability, privacy and security as key barriers**. On the other hand, the loss **of control and apathy, reliability, privacy and security, trust, cost and the fact that smart home technology was seen as divisive, exclusive or irrelevant** could be identified as social barriers for laypeople. The authors point out, among other things, that the aspect of **trust should not be underestimated**. Consequently, companies should not only concentrate on promoting the advantages of smart technology but should also invest in trust-building measures with their customers. In addition to the concerns and obstacles to the adoption of smart houses, however, respondents were also **positive about the perceived benefits**. In addition to the expected **energy savings**, these included, for example, **an increase in safety and leisure** time and thus a better quality of life (Balta-Ozkan et al. 2013; Wilson et al. 2015).

Not a barrier but another **risk** that is associated with smart technologies is that they **can increase energy consumptio**n rather than decreasing it thus **sustain energy-intensive lifestyles**. In fact, whether and how HEMS can contribute to sustainable domestic lifestyles that are actively supported and implemented by households remains uncertain. In addition to the rebound effects described in the next chapter, social research on the consumer behaviour of HEMS products has also shown behavioural backslide effects. These are behavioural changes that can lead to considerable energy savings at the beginning of the use of a smart technology. However, these **savings could not be further maintained in the medium and long term** (Balta-Ozkan et al. 2013; Scheepens and Vogtländer 2018; Smale et al. 2018).

TRI-HP can build upon positive effects of HEMS, such as expected energy savings, increase in safety and leisure time that are perceived by users. However, TRI-HP will also have to address a lack of trust towards smart control systems which can be an important barrier for their adoption. TRI-HP should establish communication and dissemination activities also towards those groups of users who don't have technical skills or a high environmental awareness.

3.2.6. BUILDING RENOVATION

For owners of existing apartment buildings, installing a complex hybrid system like TRI-HP is a high investment that involves several risks and uncertainties. This considerably limits the target group to which the required capital is available. The most efficient performance of the TRI-HP system is to be expected in buildings in which a low temperature distribution system can be easily installed. If this is not given, increased renovation is required. Heiskanen et al. (2014) point out that energetic refurbishments are usually 'decisions with high participation'. However, laypeople do not always make their decisions according to the same criteria as energy experts. As a rule, they expect relatively short payback times. In addition, it has been observed that private house owners are more likely to engage in piecemeal and step-by-step renovations, rather than a single but extensive conversion. They usually prefer to save money for the next step instead of raising a large amount of external capital (Heiskanen et al. 2014). **For an integrated system like TRI-HP the barrier of high upfront costs can be reduced by step-by-step installation of the different components of the system.**

Another issue is that of very different objectives and expectations among the numerous stakeholders involved in building renovations. **The professional know-how is divided among several specialists and manufacturers and they have hardly any common and coordinated routines** (Heiskanen et al. 2014). D'Oca and colleagues (2018) have reviewed 31 EU projects dealing with 'deep renovations', including the installation of REs, heating, cooling, and smart systems, all of which make up TRI-HP systems. They were able to identify numerous major financial, technical and social barriers such as lack of standards, lack of skilled workers, high installation costs, lack of trust and disruption due to renovation work. In a guideline based on their findings, they argue for **a multi-solution approach of better political support, more targeted knowledge and awareness building, and a stronger focus on different stakeholder and user groups.** Among other things, they recommend taking greater account of non-technical costs in project planning, including the potential relocation of affected residents or training costs (D'Oca et al. 2018). Their detailed results are included in chapter 6.

> In existing buildings, the installation of HPs requires deeper renovations, if high temperature distribution system cannot be adapted to lower temperatures. Collaboration of building specialists and manufacturers can be improved by better political support, more targeted knowledge and awareness building, and a stronger focus on different stakeholder and user groups.

3.3. REBOUND EFFECTS

An obvious risk for a rebound effect lies in the HP's dual function of heating and cooling, which in one way or the other creates a potential to consume additional amounts of energy. HPs may therefore contribute to an increase in power consumption through higher cooling demands, especially with regard to an expected warmer future climate (Fawcett 2011; Judson et al. 2015). Lundgren-Kownacki et al. (2018) point out that more technical cooling can also lead to new dependencies and changed behaviour, as people get used to cooler temperatures both physiologically and mentally. For example, heat acclimatisation may be lost if a lot of time is spent in cooled environments. However, there is still need for further research in this area (cf. Lundgren-Kownacki et al. 2018).

Studies in Danish, Norwegian and UK households conclude that reductions in electricity consumption expected in theory are only partially achieved in real life practices (Gram-Hanssen 2010; Caird et al. 2012; Winther and Wilhite 2015). Not only design and installation of HPs affect energy efficiency but also their practical use (Judson et al. 2015). Winther and Wilhite (2015) conducted qualitative interviews and participant observations to investigate rebound effects of people's uses of HPs in Norwegian homes. They found that **two kinds of**

comfort rebound occur after people have installed HPs in their homes: a temporal and a spatial one. The temporal rebound refers to the behaviour to **expand the amount of time that the home is heated** (e.g. when leaving the house for a weekend), whereas the spatial rebound refers to the **effect of the physical expansion of the heated space**. To put it in other words, **with HPs people heat longer and more rooms.** As a result, new heating practices and thus changes in behaviour emerge. Heat could now be distributed evenly throughout the house, which increased freedom of movement, especially in winter. This was also positively emphasized with regard to caring for and supervising children, as doors could now be left open everywhere in the house, day and night. **In addition to economic reasons for purchasing and installing HPs, increased comfort was mentioned as an important factor for having the old heating system replaced**. Sometimes, however, the old system was retained. Those who had previously heated with a wood-burning stove continued to use it even after the HP had been installed, albeit less frequently. The reasons for this were additional warmth and comfort. The results of the study also underline the fact that the installation of HPs is often associated with larger renovations of the house, which entail an expansion of living space that obviously requires more heating and is a further cause for rebound (Winther and Wilhite 2015).

3.4. STAKEHOLDERS, MIDDLE ACTORS AND END-USERS

It has already been mentioned in previous remarks that the perspective of professional stakeholders needs to be taken into account. Which of them are to be considered in a social innovation process is a question that can only be answered on a project-by-project basis. However, there is agreement that it is important to consider them at an early stage. For example, **it is essential to check whether there is a functioning installer industry in the region (e.g. for HPs) where a certain technology is to be disseminated, i.e. whether the necessary local know-how is available**. If it is too small, too fragmented and if there is a deficit of skills, the best project design and the most efficient technology won't help (cf. Judson et al. 2015). In addition to the market conditions varying by regions, stakeholders have different backgrounds and interests (see for instance Berardi 2013); they can either actively influence or passively be affected by a particular project. They may or may not be members of the project coalition and involved in decision-making processes. They can also belong to different sectors. **Stakeholder mapping for a specific process**, i.e. identifying which stakeholders are ultimately relevant, therefore **is a complex task**. In the reviewed research literature, numerous stakeholders have been enumerated who can influence the adoption of innovative solutions for renewable technologies. It is therefore **recommended to consider the relevant stakeholders in the research and development process and thus to choose a polycentric approach that integrates the different types of knowledge of the respective stakeholders**. This addresses multiple societal groups which can be found at different levels and which work independently within the same energy system (Brohmann et al. 2007).

End-users that are decision makers in regard to TRI-HP solutions are building cooperatives and building owners, real estate companies, investors and residents. Further relevant stakeholders are installers, building professionals, engineers, HVAC designers, architects, HVAC and RES technology manufacturers, consultants, coating and coating applier industry, HP industry, refrigeration industry, policy makers, and standardisation bodies. Other potential stakeholders mentioned in the research literature may be engineers, house managers, planners, administration, technology suppliers, service providers, consultants, bankers, insurances, businesses, civil society and NGOs, media, and research institutes (Heiskanen et al. 2014; Devine-Wright et al. 2017; Reindl 2017; Chassein et al. 2017; Spiess et al. 2019). Concerning end-users, it should be emphasised that they are not only passive acceptors, but could actively shape energy conversion in their households. As Fischer (2006) notes, “users do not only accept or reject a new technology, but also *participate* in its development by giving feedback and interacting with producers” (Fischer 2006: 117, emphasis in original).

Some authors subdivide these different stakeholders into levels, such as national, regional and local; or macro, meso and micro. Governments, companies and consumers are then assigned to the appropriate levels (cf. Reddy 2013). Alternatively, a distinction is made between government and business on the one hand and the public and other interest groups on the other (Schumacher et al. 2019). What is often reflected in such distinctions is a 'top-down' or 'bottom-up' dichotomization that largely conceals the middle section and its autonomy. Middle actors cannot be easily classified into the category systems mentioned. It is therefore recommended to examine middle actors as a distinct category:

> *"Middle actors refer to those who work from the 'middle out' with the agency and capacity to influence transitions by making change upstream (to top actors), downstream (to bottom actors) and sideways (to other middle agents)." (Devine-Wright et al. 2017: 28)*

Middle professionals are often referred to as 'intermediaries or 'system builders' who have their own cultures of knowledge and practice. As experienced experts in a specific governance process who follow their own agenda with specific rules and regulations in their respective sector they **can have a significant impact on the diffusion of innovation and practices**. However, their role is often neglected, and more research is needed to understand how they facilitate or obstruct change processes (Devine-Wright et al. 2017). Who exactly belongs to the middle is unclear and still needs a finer delimitation. As Parag and Janda have pointed out, t**here is still no clear definition of who constitutes the middle, particularly in the context of energy systems** (Parag and Janda 2014; Janda et al. 2014; Reindl 2017).

This means that the middle is more than a filler between top and bottom. It has its own characteristics, logic, capacities and agency. Middle actors make their own choices and they act and perform according to them. **Compared to the big actors at the top, e.g. energy utilities, middle professionals like installers, are more trusted among energy consumers at the bottom**. Trust depends on the perceived competence and intentions attributed to an actor, which is why NGOs are generally trusted more than industry (Wüstenhagen et al. 2007). This gives middle actors the legitimacy to shape social norms and actively promote the adoption of new technologies. In addition, they also possess the skills, knowledge and resources that the bottom lacks, "such as established procedures; information channels; the ability to coordinate activities, time, tools, expertise; and the ability to shape practices" (Reindl 2017: 36). For this reason, middle actors are important intermediaries between top and bottom, but their role is not limited to that. **They can be very powerful as they are able to exert their influence upstream, downstream and sideways**, meaning that they can manipulate the top, the bottom and other professionals in the middle in order to pursue their own interests (Reindl 2017).

Of course, this does not mean that middle actors are always aware of the importance of their role. In fact, landlords or installers often contribute to obstructing technological innovation through inactivity and inertia. A homeowner who has agency on the physical structure of the house, the choice of heating system used and whether or not insulation is installed may choose not to be innovative for various reasons. When it comes to explaining new and complex technologies, their application and maintenance, middle actors rarely make full use of existing capacities. For example, due to their position, **installers would be ideal for making energy transition as easy as possible for tenants**. They could best explain the technology to them and give them advice. **However, they are usually not trained well enough to do so** (Judson et al. 2015; Stephenson et al. 2015). Personal motivation may also play a role that should not be underestimated: Installers will most likely prefer to promote technologies if they provide high margins and are easy and safe to install.

Insights from social studies of science and technology point to the need to include professionals as important stakeholders from the beginning. TRI-HP should not only focus on investors and planners as decision-makers, but should also take middle actors such as HVAC consultants, technicians, operators and intermediary actors (energy agencies etc.) into account.

3.5. Gender analysis

In the past decades, gender aspects of energy policy and energy research gained increasing attention (European Commission 2001; Clancy et al. 2004; Anfinsen and Heidenreich 2017; Röhr et al. 2017). In an exhaustive literature review on gender, climate change and climate policy in the North, Röhr et al. (2017) present a considerable corpus of studies dealing with gender aspects in the field of energy policy and energy research. The importance of gender aspects in this field is also highlighted by the European Commission. Gender aspects refer to different fields of energy research. In particular, they

> *"…are to be found or can be assumed in access to energy technologies, perception of (risk) technologies, energy needs and use and in particular in the very small share of women in energy technology-related areas, resulting in an exclusion of their perspectives in research and development." (European Commission 2009: part 3.2.)*

As an integral part of Task 2.1, a gender dimension is included in the analysis of social acceptance. The aim was to identify critical gender aspects which might interfere with the social acceptance of novel renewable energy heating/cooling systems and which should be investigated more closely in the following tasks of WP 2. The gender analysis is based on an exploratory literature review. The review is structured according to gender issues which will be introduced below.

3.5.1. Sex/Gender

The term 'gender' refers to socially constructed norms, attitudes and behaviours, assigning specific social activities and roles, i.e. child care or reproductive household activities, to different social groups. Gender is distinct from 'sex' which refers to biological characteristics of sexually-reproducing organisms, generally female, male, and/or intersex. Gender can be regarded as an essential social structuring principle, positioning men and women in gender relations and associated hierarchies, i.e. questions of gender always concern, among other things, inequality and power relations (Verloo and Roggeband 1996). Gender and the individual gender identity are not seen as static entities. They are actively performed, produced and reproduced in everyday interaction by people themselves – this is also referred to as 'doing gender'. It is important to note that 'men' and 'women' cannot be regarded as homogenous groups. The social position of women differs, for example, according to educational status, income, caretaking duties and way of life.

3.5.2. Methodology

The gender analysis is structured according to an analysis tool which was developed in a recent research project to identify and analyse gender aspects of climate change and climate policy (Alber et al. 2018). The analysis tool encompasses multiple dimensions. These dimensions address those areas of life which, according to current research, are particularly marked by gender disparities. The main focus is put on inequalities and structural discriminations that frequently occur in these areas of life. The dimensions of analysis provide a search matrix which helps identify and analyse important gender aspects in the field of climate and climate change. In this study the analysis tool was adapted to identify gender aspects related to energy and energy technologies.

The dimension of the 'symbolic order' which describes being aligned with and upgrading typically masculine standards/life situations (so-called androcentrism) is effective as a cross-sectional dimension in all areas of life.

Dimension/area of life	*Leading question*
Symbolic order	Does the technology have any implicit orientation towards typically masculine or feminine stereotypes?
Care	Does the technology have an impact on the exercise of care work in private households?
Employment economy	Does the technology have an impact on vocational training, jobs or working conditions?
Public resources/infrastructures	Does the technology concern access to or use of public spaces or infrastructures?
Power to define and shape at actor level, e.g. in science, technology and politics	How are gender expertise and the perspectives of men, women and intersex (3rd gender) persons included in the preparation and implementation of the technology (including parity/gender balance)?
Body, health, safety	Does the technology have an impact on safety, physical, mental or reproductive health and sexuality?

Table 2: Dimensions of Gender Analysis (own compilation based on Alber et al. 2018)

3.5.3. Results

Attitudes towards the environment and renewable energy technologies

Gender has been found to be an important variable accounting for differences in environmental concern. **Women are found to show a higher concern for the environment than men** (Dietz et al. 2002). In a secondary analysis of a bi-annual representative survey on environmental awareness in Germany, gender was found to be the most important variable (Preisendörfer 1999). Differences in environmental awareness in Germany have been confirmed by the recent issue of the survey (BMU and UBA 2019).

Similar results can be found in other European countries. The special Eurobarometer survey on climate change (European Commission 2017b) shows a growing consensus in Europe that climate change poses an important threat to environment and society with only slight differences between socio-demographic groups. Nevertheless, w**omen are more likely to say that climate change is a very serious problem than men** (women 76 %, compared to men 72 %). **However, this concern with climate change does not imply a stronger commitment to a transition of the energy system**: Women rather tend to abate their carbon emissions by changing to less carbon intensive practices, e.g. buying locally produced and seasonal food. In contrast, **the item 'buying energy efficient appliances' is viewed almost equally by women and men**.

Women consider themselves less well informed about the advantages of a decarbonisation of the energy system. A majority of respondents in most Member States agree that reducing fossil fuel imports from outside the EU can benefit the EU economically. There are few significant differences between gender groups concerning this statement. The main difference is the share of 'don't know' answers (men 13 %, women 23 %). Women tend to be a bit more sceptical as men that reducing fossil fuels will increase energy security. In all Member States, a majority of respondents agree that more public financial support should be given to the transition to clean energies, even if it means subsidies to fossil fuels are reduced. Again women views on this statement tend to be less enthusiastic (total agree: women 76 %, men 81 %).

In their review on gender and alternative energy sources, Anfinsen and Heidenreich (2017) discuss the implications of a gendered environmental awareness for the evaluation of energy sources. A strong link between gender and attitudes towards nuclear power is confirmed by several studies, showing that nuclear energy was and is more appealing to men than to women. The authors conclude that women show a preference for energy sources with lesser environmental impact. However, the implications for the acceptance of RE sources are not so clear. **Some findings suggest that women show higher acceptance of – or less opposition to – RE technologies** (see e.g. Cousse and Wüstenhagen 2019). In contrast, a study on the environmental, social and economic impacts of RE sources in Finland comes to the conclusion that persons with higher income, male, younger and with pro-environmental attitudes showed higher preferences related to RE technologies (Kosenius and Ollikainen 2013).

Adoption of RE technologies

A recent study investigates the acceptance of consumers in Greece, Portugal and Spain in relation to a residential hybrid system that offers H/C and DHW (Karytsas et al. 2019). The authors investigate the adoption of residential H/C and DHW systems by analysing the self-reported intentions of consumers. The survey shows that RE adoption is significantly valued by consumers, but a majority of households the willingness to pay is not large enough to cover the higher capital costs for micro-generation energy technologies. Gender has been found to affect some issues. **Male respondents show a higher willingness to pay and accept a longer payback time for hybrid systems.** The level of education has also an important impact.

These findings point to the importance of socio-economic differences between women and men. A study has analysed the involvement of women and men in RE schemes operated by citizens' associations in Germany (Fraune 2015). Based on a comprehensive review of research on gender and energy, hypotheses about gender differences in the involvement in these schemes are derived and tested. The results show that **men have a higher average ownership rate of citizen participation schemes, invest more money in average and are overrepresented in decision-making bodies**. However, the author argues that these findings do not prove gender differences in individual preferences and investment attitudes. They rather point to the effects of structural socio-economic and political factors accounting for the unequal economic situation of women and men ('gender wealth gap'). Since different income situations also express power inequalities, it should therefore be taken into account that men have stronger decision-making power when it comes to whether and which H/C system is purchased. This bias is even more important as in many households energy technologies are associated with a male sphere of interest, possibly excluding women as agents of change (Strengers 2013).

CARE

Energy use in households has long been seen as an outcome of the household's income level. Recent studies show that **gender is also an important factor to explain the energy use in households** (Anfinsen and Heidenreich 2017; Röhr et al. 2017). Gendered aspects of household energy are mainly due to differing involvement in caring activities and an unequal distribution of household tasks between women and men. In many cases women are responsible for the provision of food, washing and cleaning and the health of the household's members. A study on energy use in Sweden, Norway, Germany and Greece shows that this unequal distribution of tasks leads to different patterns in energy use (Räty and Carlsson-Kanyama 2010). Based on a literature review on carbon emissions of households, Zhang et al. (2015) show that gender has a measureable influence on household energy consumption. **Women-headed households[7], for example, have a higher carbon footprint than man-headed households**. The authors argue that these differences result from an unequal distribution of labour, leading to different everyday practices of men and women. **Women spend more time at home – and therefor produce higher carbon emissions at home** – while men account for higher carbon emissions by travelling and leisure activities.

These findings are confirmed by a detailed analysis of time use patterns of women and men (Torriti et al. 2015). Furthermore, the study also shows that temporal patterns of energy use are shaped by the gendered distribution of homework and caregiving activities: Women's activities are more fragmented throughout the day compared to than men's activities. **Households with children exhibit greater synchronisation and marginally less variation in their daily routines**.

The different roles and activities at home performed by men and women also affect the outcome of energy saving measures. Energy saving measures, e.g. using laundry dryers less frequently, intersect with everyday life practices. In many cases, these measures lead to an increasing burden on gendered homework activities. For example, **lower indoor temperature and fewer hot baths can have a greater impact on women than on men** (Carlsson-Kanyama and Lindén 2007). In a survey on flexible electricity pricing in Denmark, women and men stated different preferences regarding a temporal shift of energy consuming practices. An important reason for this are gender differences in household work task responsibility (Tjørring et al. 2018). The authors conclude that energy policies should consider potential gendered effects on households' activities.

Tjørring et al. (2018) and Sunikka-Blank et al. (2018) argue that **gender plays a central role in the negotiation of retrofitting**, both in the interaction between homeowners and energy advisors (who are typically male) and in the negotiation among homeowners (husbands and wives). The perception and evaluation of retrofit measures is shaped by the different everyday life practices of women and men. Furthermore, the findings suggest a cultural norm placing energy renovation rather in the sphere of interest of men which might reinforce a different engagement of men and women in renovation projects. Nevertheless, women play a strong role in the background and should be addressed appropriately. **The authors conclude that new strategies are needed to promote retrofits more effectively. These strategies should focus less on techno-economic aspects and pay more attention to the social dimension in order to engage women in households and harness their existing interest.**

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[7] Women-headed households are defined as households in which women have the control over the resources of the household. Women-headed households include single person households as well as households with several persons.

EMPLOYMENT

Moving from consumption to production, a strong imbalance between women and men exists in energy industry workforce and decision-making in the energy sector (Carlsson-Kanyama et al. 2010; Norman et al. 2015; Pearl-Martinez and Stephens 2017). In a survey on large energy companies in Germany, Spain and Sweden, Carlsson-Kanyama et al. (2010) found out that of the 464 companies investigated 64 % had no women at all in boards or management groups and only 5 % could be considered gender-equal by having 40 % or more women in such positions. **In 2019, the energy sector still remains one of the least gender diverse sectors in the economy, despite recent efforts to promote and encourage women's participation.** A recent overview of the Clean Energy, Education, and Empowerment (C3E) initiative on gender equality in the energy sector shows that women are underrepresented in energy related decision-making bodies both in the public sphere and in private companies (C3E and IEA 2019). The overview covers selected states, among them Canada, Sweden, Italy and Finland

This underrepresentation of women has also been stated for the RE sector. A review on existing academic and practitioner literature on women's employment in RE in industrialized nations, emerging economies and developing countries points to a severe underrepresentation of women. Moreover, available data from Canada, United States, Spain, Germany and Italy indicate that women being employed mostly in non-technical occupations in RE (sales, administrative positions) and only scarcely as engineers and technicians (Baruah 2017). A recent study on RE and gender shows, however, that the employment rate of women in the RE sector is increasing. In 2018, 32 % of RE jobs worldwide were held by women (IRENA 2019). The study points to that employment in the RE sector is more appealing to women than jobs in the global oil and gas industry, where women represent 22 % of the average workforce. But still, in the **women employment rate is much higher in administrative (42 %) than in technical jobs (28 %**).

POVERTY AND THE ACCESS TO ENERGY

According to Eurostat (2018), in 2016 118.0 million people or 23.5 % of the EU population were at risk of poverty or social exclusion. This means roughly one in four people in the EU suffered from monetary poverty, severe material deprivation, or are living in a household with very low work intensity. Women and young people are particularly vulnerable to poverty and social exclusion. Women had a higher rate of risk of poverty or social exclusion than men (the rate for women was 24.4 % compared with 22.5 % for men). Single-parent families, especially families headed by single mothers, are particular threatened by poverty or social exclusion.

Poverty and social exclusion have serious implication for the access to energy. According to Clancy et al. (2017), there are more than 54 million people in the EU-28, who have difficulty paying their energy bills or have limited access to high quality energy because of low incomes. Uninsulated homes, inefficient appliances (like for heating, cooking, hot water), and high energy prices are main reasons for energy poverty in the EU. Due to their lower average income, women are at a greater risk of energy poverty than men (Clancy et al. 2017). Energy poverty disproportionately affects single women and single-parent and female-headed households.

BODY, HEALTH – THERMAL COMFORT

The effects of gender on thermal comfort were analysed in a number of studies. In a path breaking study Karjalainen (2007) examined gender differences in thermal comfort and use of thermostats. A quantitative interview survey and controlled experiments were carried out in Finland and considered everyday thermal environments: homes, offices and a university. The results show significant gender differences in thermal comfort, temperature preference, and use of thermostats. **Women are less satisfied with room temperatures than men, prefer higher room temperatures than men, and feel both uncomfortably cold and uncomfortably hot more often than men**. The study also shows that women, although they are more critical of their thermal environments, use thermostats in households less often than men.

These empirical findings were confirmed by a broad literature review (Karjalainen 2012). The review shows that a growing number of studies have found significant differences in thermal comfort between the genders. A meta-analysis of these studies suggests that women are more likely than men to express thermal dissatisfaction. However, most studies found no significant difference in neutral temperatures between the genders. But women are more sensitive than men to a deviation from an optimal temperature and express more dissatisfaction, especially in cooler conditions. As a consequence, the author argues that **women have more rigorous requirements for indoor thermal environments** that should be respected. In particular, women have, on average, a greater need for individual temperature control and adaptive actions than men. The author concludes that **women should primarily be used as subjects** when examining indoor thermal comfort requirements. These findings are supported by a number of studies (e.g. Hashiguchi et al. 2010; Jin et al. 2017).

Kingma et al. (2015) point to the implications of these findings for the design and layout of mechanical ventilation and cooling systems. In a discussion of indoor climate standards in energy efficient buildings they argue that existing indoor climate regulations draw on an **empirical thermal comfort model that is based on a metabolic rate of an average male, failing to match the needs of females.** As a consequence, they argue that parameters for heating and ventilation should be based on biophysical models that account for the differing thermal demands of women and men in order to ensure that indoor climate standards respect the demands of all occupants.

In the past years, the gendered health effects of heat waves received increasing attention in health research and gender studies. As heat waves affect the indoor climate of residential buildings, these findings should also be considered in the context of H/C systems. The direct effects of heat waves on the health of the population show differences that are mainly, but not exclusively, due to biological sex. These include the effects of extreme heat on pregnancies and births (Kuehn and McCormick 2017) or the different morbidity and mortality rates of men and women during heat waves. An analysis of statistical data shows that the mortality rate of women during heat waves is considerably higher than that of men (cf. Nogueiro et al. 2005; Pirard et al. 2005; Filleul et al. 2011; Monteiro et al. 2013; Bogdanović et al. 2013). These differences are often attributed to demographic effects, e.g. a higher life expectancy of women. Recent studies question this assumption and highlight the importance of social factors: The higher mortality of women can also be an effect of the lack of care for single or widowed older women. The background here is the longer life expectancy of women, but also a lower commitment of men for caregiving activities (D'Ippoliti et al. 2010).

The exploratory review on gender and energy identified carious aspects which are highly relevant for the TRI-HP project. A gender perspective can give a broader and more comprehensive picture of the social implications of RE H/C technologies. It also provides a better understanding of the factors that influence the social acceptance of this technology. A higher environmental concern of women has been identified as an important factor that supports energy transitions and can promote the acceptance of RE, both in personal and professional contexts. Women tend to have a higher carbon print at home since they are still the primary home carer. However, women are still underrepresented in the energy sector and H/C areas. H/C technologies intersect with gendered practices in private households. But up to now the empirical thermal comfort model is based on a metabolic rate of an average male, failing to match the needs of females. Respecting these links can help to question implicit assumptions in technology development in order to get a more realistic picture of the users' needs. In particular, the different biophysical requirements of women and men related to the experience of thermal comfort have to be taken into account. The specific needs of women to control H/C of indoor environments provide another issue that should be considered when designing the user-system interface.

4. STANDARDS AND REGULATIONS

4.1. SAFETY

This chapter covers the safety standards, directives and regulations applicable to hydrocarbons and CO_2 as working fluids in TRI-HP HPs. It corresponds to the executive summary of the internal working paper of project partner NTNU about their 'Review of standards, directives and regulations applicable to TRI-HP heat pumps', covering standards (EN 378:2016, EN 14511:2018, ISO 817:2014, etc.), directives (EU 2009/125, 2010/30, 2014/68, etc.) and regulations (EU 842/2006, 517/2014, etc.) applicable to HPs in Europe. Among the topics discussed there are maximum refrigerant charges, requirements for components as a function of design pressure, temperature limitations with hydrocarbons, construction requirements, testing, etc. Furthermore, energy efficiency and labelling requirements and other topics relevant for heat pumps are discussed. Particular emphasis is given to hydrocarbons and CO_2 as working fluids in TRI-HP HPs.

The limitations in refrigerant charge per circuit are very strict for hydrocarbons, when compared to CO_2, due to their high flammability. The maximum refrigerant charge depends on different elements, such as location, type of occupancy, room volume, height at which the HP is placed, etc. In occupied spaces (households) the maximum refrigerant charge allowed could limit the capacity of HPs. Even if 1kg can fulfil the 10 kW heating capacity requirements in the TRI-HP project, it could be insufficient for a future, up-scaled system. An enclosure with suitable mechanical ventilation would suffice to increase the limit up to 5 kg and cover a higher capacity range. The ventilation system for enclosures and machine rooms must be mechanical, and with certain minimum requirements of air flows and reliability. Properly designed indirect systems could also lead to increasing the maximum allowed refrigerant charge. Different limitations apply to non-fixed systems. Relevant standards are EN 378:2016, ISO 5149:2014 and IEC 60335-2-40:2018.

In the case of CO_2 and maximum allowable refrigerant charge, the limitations are related to its toxicity at high concentration (the practical limit is 0.1 kg/m^3). Users could be affected in case the whole charge was released within a room of reduced volume and this must be avoided.

The relevant standards (EN 318-2:2016) and directives (PED Pressure Equipment Directive 2014/68/EU) categorize components (assemblies) depending on their maximum allowable pressure and their volume/pipe diameter. The higher the pressure or the size of the specific part, the higher the category should be, which also has a repercussion on its cost (additional certification, even from external entities). The design pressure of HPs with propane may be below 25 bar, which means that the high categories of pressure vessels and piping could be easily avoided when designing the system.

CO_2 HPs operate at much higher pressures than propane HPs due to the properties of this refrigerant. The maximum allowable pressure is higher, and this could affect the category of the parts. However, the high density of CO_2 works in the favour of manufacturers, allowing for reduced components (volume and diameter) for the same flow rates.

Furthermore, **temperature requirements apply for the use of hydrocarbons**. Hot temperature sources present a potential for ignition, the risk of which should be minimised when using propane. Even if there are slight differences in the various standards covering this matter, the general idea is for the source's maximum temperature that can be reached in the event of leakage of any source reachable by the refrigerant in case of leakage to be lower than the auto-ignition temperature of the refrigerant minus 100 K (370°C in the case of propane) (EN 378-3:2016 and IEC 60335-2-40:2018).

There is much information on the different standards for the requirements for building safe vapour compression systems (HPs) with regard to different matters such as piping, measuring devices needed, safety devices, etc. Concerning protective devices, strong emphasis is put on preventing excessive pressure. The limits and other requirements for the different safety switching devices, pressure relief valves, use of bursting discs, etc., are clearly indicated (EN 378-2:2016).

The **necessity of refrigerant detectors** is also covered in the standards, depending on the charge, location, etc. **In the case of CO_2, the main concern is to avoid reaching the practical limit related to suffocation** (50 % of the toxicity parameters of CO_2 would be a suitable pre-set value for the detector). **In the case of hydrocarbons (propane), the main focus is to prevent any flammable/explosive mixture with air**. Thus, detectors must be activated whenever the refrigerant concentration in air exceeds 25 % of the lower flammability limit. Detectors must have an electrical signal that activates the alarm system and/or other emergency systems and stop the HP if necessary. The location of detectors will depend on the refrigerant density. Both propane and CO_2 are denser than air at atmospheric pressure and ambient temperature, and they tend settle on the ground, meaning that detectors should be located close to the floor of the room (EN 378-3:2016).

The relevant standards (EN 378-2:2016) cover how and which tests must be performed on units (HPs) before they are placed in the market. Some examples are strength pressure test, tightness test, function test (safety switching devices) and conformity test of installation. The required labelling and documentation that HPs need are also clearly listed (specific requirements apply to hydrocarbons).

4.2. EFFICIENCY

The basic testing (conditions, methodology, required conditions and accuracies, etc.) to determine the performance of HPs for heating and cooling at design capacity is covered, as is DHW production, with the specific tests and profile loads (see EN 14511:2018, EN 14825:2016 and EN 16147:2017).

The ‘eco-design’ EU directive (2009/125/EU) and product specific regulations (813/2013, 2016/2281) use the seasonal performance factor methodology to obtain the minimum required efficiencies that HPs must have if they are to be released on the European market. In the ‘eco-design’ product regulations there are also certain values of noise power level that cannot be exceeded by HPs that are put on the market. These limits depend on the rated HP capacity and location (indoors-outdoors), but range between 65 dB and 78 dB.

As far as the authors are concerned, there is a lack of standards on how to test the performance of HPs that operate with simultaneous loads (simultaneous space heating and DHW, space cooling and DHW, space heating and space cooling).

Another important aspect is labelling (directive 2010/30/EU and Regulation 2017/1369). HPs must have an energy efficiency label to be in the market. These labels allow consumers and installers to select a suitable/efficient product in an easy way and contribute to reducing the footprint of HPs in the energy consumption of Europe.

There are topics not directly related to HPs, but having a repercussion on the HP design. Examples of hydraulic systems are included in the standards (EN 15450:2007), as well as the requirements that shall be followed and load profiles to determine the capacity of the HP used in a certain installation/system.

In addition, both the topic of legionella and limitations/permissions that many European countries impose on the use of ground and groundwater as heat source and sink for HPs must be carefully considered for TRI-HP HPs. TRI-HP solutions should be designed to reach at least 60 °C. Disinfection at 70 °C could be an important factor for some sites (Norwegian regulation, for example). Regulations regarding legionella infestation have become stricter in recent years.

4.2. REGULATIONS

Limitations/permissions in many European countries impose to the use of ground and groundwater as heat source and sink for HPs. These limitations prevent/reduce the risk of contamination and overuse of groundwater and could favour the solutions suggested in TRI-HP project: dual-source/sink and ice-solar system. Some examples are EU's Water Framework Directive 2000/60/EC, Groundwater Directive 2006/118/EC, VDI 4640 (Germany), Water / Environmental legislation (Switzerland).

5. MARKET BARRIERS

This chapter deals with market barriers for propane and CO_2 HPs and for ASHP, GSHP and solar-ice systems. The current knowledge on market barriers is based on experiences of TRI-HP partners, and participation in European H2020 projects such as Geotech[8] and Cheap-GSHPs[9]. One of the goals of the WP 2 "Social acceptance and barriers" will be to further investigate on market barriers. This will be reported in D2.2 "Barriers, hindrances and incentives towards the social acceptance of TRI-HP systems" that will be expected to be available by March 2021.

5.1. MARKET BARRIERS FOR PROPANE HEAT PUMPS

Market barriers for the expansion of propane HPs in apartment buildings mainly arise from safety issues, characteristics of propane, training needs and limitations on refrigerant charge:

- safety concerns regarding the high flammability of propane: hydrocarbons have been used for decades, but their medium and high flammability are still the main concern, although industry standards are very strict to avoid risks.
- additional manufacturing costs due to the characteristics of propane: however, today the technology is widespread and most components are available on the market. The extra costs associated with safety are to be kept low by promoting applications where they are offset by higher energy efficiency.

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[8] see http://www.geotech-project.eu/

[9] see https://cheap-gshp.eu/

- lack of knowledge and training needed for developers, installers and maintainers: there are some initiatives, such as the Real Alternatives project, which offers an e-learning platform and multiple resources to increase knowledge about alternative refrigerants in Europe (Real Alternatives 2019).
- limitations on refrigerant charge: systems with A3 refrigerants (the case of propane) and a charge up to 150 g (per refrigerant circuit) can be used without any restriction. This refrigerant charge restricts the capacity of propane HP units. If units are in ventilated enclosures, machinery rooms or rooms with a certain size (volume), it is possible to increase the charge safely (according to standards). An increase of the capacity value from 150 g to 500 g is foreseen, since this increase has been recently approved in the Standard IEC 60335-2-89 for commercial refrigerating appliances and ice-makers (IEC 2019), which are essentially HPs with a different focus.

5.2. MARKET BARRIERS FOR CO_2 HEAT PUMPS

Two main market barriers for CO_2 HPs have been identified:

1) From the manufacturers' point of view, the main barrier is (or was) costs, which is linked to the most representative property of this refrigerant: its low critical temperature. CO_2 HPs work mostly at transcritical, i.e. high pressure. On the one hand, this should increase the costs of the components used (more expensive materials with thicker walls). On the other hand, high pressure involves high volumetric capacity and reduces the size of components and piping, which in turn reduces costs. Thus, there is a compensation between pressure and size, so components for CO_2 units should not have higher costs than for other refrigerants, at least if sufficient production numbers are achieved (da Silva Lima and Thome 2014). Some manufacturers of CO_2 systems claim that these production figures have already been achieved, while other sources claim that this will happen as early as 2022 (Zolcer Skačanová and Battesti 2019). The smaller piping in CO_2 systems and the use of copper alloys such as K65 (even for the high-pressure side) lead to further cost savings.
2) The lack of training and knowledge about CO_2 vapour compression systems is another barrier. The transcritical operation of CO_2 in HPs was in the past a large technical barrier due to reduced performance and safety. Nowadays this is different. The new technologies applied to these systems allow them to have efficiency comparable to equivalent units running with hydrofluorocarbons. In addition, the gliding temperature at high pressure (transcritical) is optimal for DHW generation, which is the main purpose of the CO_2 HPs in the TRI-HP project.

5.3. MARKET BARRIERS FOR DUAL-SOURCE HEAT PUMPS

One of the HPs developed within the project will use a dual-source, i.e. a combination of ASHP and GSHP. Hereafter, the main market barriers identified for both HP systems are presented.

There are several market barriers for the application of GSHPs for both single family houses and apartment buildings. Some of them are inherent to the existing building stock, where refurbishment plans can cause their own problems. Some of the identified barriers include:

- limited space requirements (indoor and outdoor) for the HP and the borehole for multi- and single-family-houses (especially in densely populated urban areas)
- the necessity to find an agreement among households to substitute the central heating system in apartment buildings
- regulations, laws and permissions for ground use differ from country to country and from area to area depending on the geological, hydrogeological and soil pollution conditions

- faulty installations and wrong settings of the HPs
- low energy classification for the existing building stock which can:
  - involve a considerable thermal requirement provided by GSHPs and therefore a large surface area needed for the ground heat exchangers
  - lead to low efficiency of the system due to the high temperatures of the circulating fluid; low efficiency of GSHP can reach to working costs comparable with the working costs of natural gas boilers reducing in that way the convenience of the investment
  - lead end-users to other measures, such as improving insulation
- lack of knowledge or environmental awareness among end-users
- absence of appropriate financing schemes for end-users
- considerable cost of a GSHP solution with respect to alternatives, mainly ASHP; for end-users, the medium-long term savings depend very much on the number of operating hours of the system

Some measures to address and overcome market barriers to the application of GSHP in the building sector could include the following:

- connection of single family and apartment buildings through thermal energy networks, connected to ground heat exchanger fields, located in appropriate available areas; the HPs can be placed either near the ground heat exchanger field or inside the buildings
- hybridization of GSHP and ASHP systems
- development of new financing schemes for activation of energy efficiency projects by clusters of end-users
- increasing economic grants for energy rehabilitation projects in apartment buildings
- certification of processes as a prerequisite for financial incentives (e.g. when replacing oil, gas or electric heating systems)
- training of installers (fitters, plumbers and other intermediaries) and promotion by local authorities
- lower drilling costs and deeper boreholes solutions

On the other hand, ASHP systems common in Southern Europe and in moderate climates in general are less efficient than GSHP. However, they are undoubtedly cheaper and can provide some allocation of RE as well. In addition, they are a good solution for densely populated urban areas and can be easily combined with PV and ST collectors. They thus represent an alternative for building refurbishment projects.

One of the market barriers identified for ASHP in single family houses, apartment buildings and singular or historical buildings is the reticence of the end-users and architects to the external unit and more concretely to its fan. This is due to the noise generated and to the visual impact. Sound prevention reports are limiting, costly and time-consuming. In the case of GSHP, this is minimized by the ability to install the entire system inside the building. Owners and architects of single-family buildings are usually not in favour of ASHP outdoor units. In the case of installing an ASHP, they try to reduce its visual impact by trying to camouflage it.

For both small and large projects, the integration of GSHP and ASHP could be a good solution to reach a compromise between investment and energy efficiency for the end-user.

5.4. MARKET BARRIERS FOR SOLAR-ICE SYSTEMS

Solar-ice systems are becoming popular in some central European countries, such as Germany and Switzerland. Apparently, one of the reasons for the initial market push of the solar-ice systems was the fact that ground water protection laws played an important role. This forced engineers to look for solutions that could be as efficient as GSHP, but would not be affected by existing legal protection of ground and water in some regions (Carbonell et al. 2017). As stated before, the aesthetics of heat exchangers on the façade and the noise of the fans are common barriers for ASHPs. First commercial solar-ice systems were those provided by Isocal and Consolar. However, currently other companies such as Energie Solaire SA and EWJR AG are active in the Swiss market.

A main market barrier for solar-ice systems is lack of available space. The ice storage can be installed either in the cellar or in the ground. The main difference is that installing the ice storage in the ground allows for significant heat gains in winter. When the ice storage is installed indoors, the lower heat gains via the storage walls in winter have to be compensated by a larger storage volume (or a larger collector area). However, a lack of available ground space or possibly lower costs for installing the storage in the basement could make this option more attractive. This depends very much on a case-to-case basis and is particular important for densely populated urban areas.

Several demonstration projects in Switzerland that do some kind of monitoring show that today's efficiency is not as high as it was initially foreseen and/or the cost are higher than GSHP systems. The reason of the low performance is most likely due to the under-sizing of the ice storage volume in some cases, i.e. well below the recommended range between 0.4 to 0.6 m^3/MWh of yearly heat demand, and due to the low use of solar direct heat in other cases (Carbonell et al. 2019). Today, there is a clear evidence that using solar direct heat is necessary if high system efficiencies are to be obtained. Both, the low storage volume and the low use of solar direct heat are typically options chosen to reduce cost and to be cost competitive with other solutions, but their effects on yearly efficiency were not fully assessed on those demonstration projects. However, further investigations are necessary to gain knowledge about the reasons of the gap between simulations and real performance. It could well be that the performance gap in building demands is part of the problem, since solar-ice systems use a combination of collector area and ice storage volume to supply heat to the HP. If the demand in winter is higher than initially foreseen, the system can run into back-up (typically electric rods) more often than foreseen which reduces the yearly energetic efficiency.

The increase of HP efficiency and the reduction of investment costs by 10% compared to GSHP and solar-ice systems without super-cooling with the same system efficiency are among the TRI-HP targets that are expected to reduce some of the market barriers of solar-ice systems.

6. Summary and conclusion

Based on a comprehensive literature review, key social barriers (including market barriers and hindrances resulting from standards and regulations) that could affect the acceptance of RE H/C systems were identified in the previous chapters. Barriers, as the term is used here, should be understood as any kind of obstacles, caveats and reservations to adoption of RE H/C systems, e.g. private investment or use (cf. Reddy 2013; Wolsink 2019). In the project's sense, this means that TRI-HP solutions are actively accepted, i.e. adopted in apartment buildings.

For the sake of clarity and in line with relevance for the whole TRI-HP project, key barriers put forward most frequently are compiled and categorised as follows into three groups: (1) economic-financial barriers, (2) barriers regarding practical implementation and feasibility, and (3) psychological and social barriers. A further distinction can be made between the different perspectives of interest groups, for which certain barriers appear more or less relevant, and which can be roughly summarised to demand-side or supply-side barriers (cf. Enviros Consulting Limited 2008a, 2008b). While the supply-side involves all TRI-HP stakeholders in the implementation, such as planners, manufacturers or craftsmen, the demand-side is more closely related to the use of the technology and thus includes end-users and house owners (cf. Chassein et al. 2017; Chassein and Roser 2017). In the following table 3 all three groups of barriers are applied to a selection of central stakeholders on the supply side.

	end-users	planers, installers	operators
1) economic-financial barriers			
- *high costs (manufacturing, investment or installation)*	x		
- *long payback periods*	x		
- *lack of financial support and subsidies (especially, but not exclusively, for low income households)*	x		
- *landlord-tenant-dilemma in apartment houses*	x		
- *lack of access to capital for private investors, difficulties or unwillingness to get a grant or a low interest loan*	x		
- *unstable and unreliable financial support system from an investors' perspective*	x		
- *low margins*		x	

	end-users	planers, installers	operators
2) barriers regarding practical implementation and feasibility			
- *immaturity of technology and its susceptibility to errors*	x	x	x
- *lack of adequate space for roof panels (both ST and PV) and storages*	x		
- *availability of aquifers for GSHPs and permission to use them*	x	x	
- *lack of local operation, maintenance and service culture*	x	x	x
- *lack of standards, procedures and guidelines, e.g. for HPs, in terms of durability, reliability, and performance*		x	x
- *low energy classification for the existing building stock*		x	x
- *requirement for rooms, e.g. ventilation*	x		
- *labelling*	x	x	
- *lack of experience, skill and training, e.g. in plumbing firms, especially when different types of cooperation are necessary*	x	x	
- *lack of certifications for qualified installers and other professionals*	x	x	x
- *regulatory policies, bureaucratic complexities and related delays, varying by country, technology and building type*	x	x	
- *stakeholders with power have no interest in their promotion and adoption (e.g. no cooling needed or wanted yet)*	x	x	
3) psychological and social barriers			
- *low importance given to RE generation and consumption*	x	(x)	(x)
- *bounded rationality among all stakeholders*	x	x	x
- *mistrust in reliability and concerns of security of technology*	x	x	x
- *lack of awareness, (access to) information and understanding of technology (complexity)*	x	(x)	x

	end-users	planers, installers	operators
- *social practices, everyday routines, lifestyles and behavioural preferences (inertia)*	x	(x)	x
- *long and discouraging processes due to regulations and bureaucracy*	x	x	
- *intangible costs, i.e. additional time for collecting information, consultation, unexpected problems, temporary relocations*	x		
- *perception of technical risks, environmental impacts and safety, e.g. for GSHPs*	x		
- *aesthetics, poor usability and noise of the technology, e.g. for ASHPs*	x		
- *loss of control, privacy and trust (smart control)*	x		
- *minor step-by-step adjustments are preferred to major changes of entire systems*	x		
- *disruption and hassle factor, especially for existing buildings*	x		
- *no support and promotion by installers or maintenance personnel*	x		
- *no neighbour, family member or friend having TRI-HP system*	x		

Table 3: Key barriers (own compilation)

These findings show that non-technical factors play an important role for the acceptance of RE H/C systems and must be seriously taken into account in the further development of the project. These include economic as well as non-economic factors, like socio-cultural issues as well as the importance of local contexts and social practices. Furthermore, the compilation of empirical examples has shown that the respective individual technologies that are part of the TRI-HP systems have their own issues and that these issues can vary from stakeholder to stakeholder and from country to country. A gender analysis shows that gender has an influence on the perception, purchase and use of RE H/C systems. Gender aspects are highly relevant for the TRI-HP project and should be considered in order to enhance the acceptance of RE H/C technologies. The reviews on standards, regulations and market barriers points to further issues that are to be respected in this regard.

This report provides a first overview on relevant topics and issues related to RE H/C systems in general. How these barriers are assessed by users, installers and other professional middle actors and how they can be addressed and overcome in the development of the TRI-HP system will be further determined through in-depth interviews and stakeholder workshops in WP 2.3 and WP 2.4. These expected results will culminate and be discussed further in Deliverable 2.2, which is expected to be available by March 2021, and Deliverable 2.3, which is expected to be available by September 2021. Both Deliverables will also take future trends into account, such as the increasing demand for cooling technologies in a warmer world.

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Appendix: Overview of standards, regulations and norms

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TRI-HP PROJECT

Trigeneration systems based on heat pumps with natural refrigerants and multiple renewable sources

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