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Social Acceptance of Renewable Energy Technologies for Buildings in the Helsinki Metropolitan Area of Finland

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Abstract

The application of renewable energy technologies (RETs) in the residential building sector requires acceptance of technical solutions by key stakeholders, such as building owners, real-estate developers, and energy providers. The objective of this study is to identify the current status of public perceptions of RETs that are available in the Finnish market and associated influencing factors, such as perceived reliability, investment cost, payback time, and national incentives. A web-based questionnaire was disseminated to the general public in the Helsinki Metropolitan Area (*n*=246). Social perceptions of building-integrated RETs were evaluated through integration of survey data and Stochastic Multicriteria Acceptability Analysis (SMAA), which was applied to analyse the robustness of the survey results. The SMAA demonstrated that Finnish residents exhibit broad acceptance of multiple options, rather than preference for a single RET. Solar technologies and ground source heat pumps were the most preferred options and evaluated as very reliable, whereas wind-based technologies and combined heat and power were ranked as the least popular. In general, respondents indicated a strong willingness to financially invest in RETs as a means to reduce their carbon footprint and preferred tax deductions as an incentive to invest in RETs.

Keywords

SMAA, Finland, Renewable Energy, Public Perceptions, nZEBs

1 Introduction

Finland provides 36.8% of total energy demand through renewable energy sources (Figure 1), ranking near the top among European Union (EU) Member States. In accordance with the EU 2020 target, Finland aims to raise the share of renewable energy to 38% by 2020 [1,2].

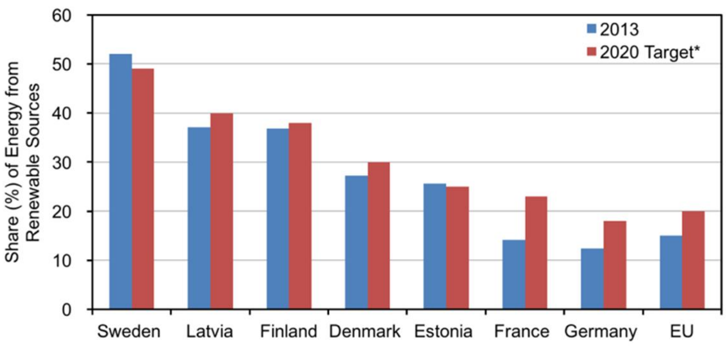


Figure 1 Share of renewable energy in the final consumption of energy in selected EU Member States as a percentage [1].

Improving the energy performance of both existing and future building stock has become essential to achieve EU climate and energy objectives. These targets are focused on public transport and building sectors, where the potential for energy savings is the greatest [3,4]. The EU has also set an ambitious target to increase the number of 'nearly Zero Energy Buildings' (nZEBs). Acknowledging the variations in building culture and climate throughout Europe, the European Building Legislation (EPBD) does not prescribe a uniform approach to nZEBs [5]. The current 'National Plan of Finland' [6] also intends to increase the number of nZEBs, but does not give detailed specifications. Nonetheless, definitions of nearly zero energy construction and associated specifications are underway.

Since 1983, the Ministry of the Environment in Finland (in Finnish: Ympäristöministeriö) has been responsible for leading national efforts on energy efficiency of buildings [7]. Directive 2002/91/EC of the European Parliament and of the Council on the Energy Performance of Buildings was issued on 16 December 2002, from which amendments were applied to both existing and new buildings [8]. During the past decade, numerous incremental improvements have been made in the National Building Code of Finland to set minimum levels of energy efficiency for new buildings [9].

The Helsinki City Council approved a new energy policy guideline in 2008 which specifies increasing the share of renewable energy from 4% to 20% by 2020 [10]. This commitment by the City Council is intended to cover all energy use in areas which fall under its jurisdiction (e.g. building sector). An important part of this commitment is to activate citizens to get involved in reducing their GHG emissions and developing measures for reduction [11].

Building owners and users represent the most critical stakeholders in determining the share of energy efficiency and renewable energy technology (RET) potential for buildings as renovations are made at their cost [12]. There are several barriers which may prevent an individual from seeking an environmentally friendly home, including: cost effectiveness of the investment, lack of attractive products and services, limited knowledge, priority for comfort, and other non-energy aspects [13–15]. A study on the acceptability of nZEB renovation strategies in Norway [13] found that social and economic factors, such as initial cost, payback time, and return on investment, could significantly affect the selection of the renovation option by the home owner.

There are only a few scientific studies presenting the key factors which influence societal acceptance of renewable energy-based heating and cooling technologies in the Nordic region. The objective of this study is to identify the current status of public perceptions of RETs currently available in the Finnish market and associated influencing factors, such as perceived reliability of RETs, investment cost, payback time, national incentives, and housing type. The RETs referred to in this study can be defined as a mechanism to generate renewable energy to either support net energy need in a building or to produce surplus energy to be stored or exported to the grid. A web based questionnaire was disseminated and received 248 respondents with a 21% response rate. Selected results of the survey study were analysed with Stochastic Multicriteria Acceptability Analysis (SMAA) to identify preference rankings of different RETs in the Helsinki Metropolitan Area (henceforth referred to as Helsinki) and to identify the associated uncertainty of the rankings. The results will support policy makers, technology providers, stakeholders in the energy and building sector, and building engineers to enable development and adoption of RETs for residential buildings, including nZEBs, in urban centres of Finland.

1.1 Attitudes and perceptions towards renewable energy in Finland

The attitudes of the Finnish public towards different energy sources were investigated in an EU study (as presented in Figure 2). In general, the public is in support of renewable energy sources [16]. Additionally, the Finnish Energy Industries have conducted annual surveys on the energy attitudes of the Finnish public since 1983 [17]. In 2006, 86% of the respondents agreed and 4% disagreed with the statement that climate change is a real and extremely serious threat that requires immediate actions. By 2014, only 75% agreed, which could mean that people are becoming immune to hearing about climate change. However, the climate change hypothesis is largely accepted by the residents of Finland.

A recent study found that residents in countries that express more environmental concerns related to energy use (e.g. Denmark, Finland, and Sweden) are also less optimistic about advancements in technology solving environmental problems in the future [12]. Another survey indicated that residents of Finland expect the public sector to be the forerunner for renewable energy production [18]. At the same time, one of the conclusions of a survey study conducted in 2007 was that Finnish residents believe their own individual consumer choices can be extremely significant in making a difference in the energy sector [19]. Our study focuses on specific RETs which have an established market in Finland and can be implemented in an nZEB or an environmentally-friendly home.

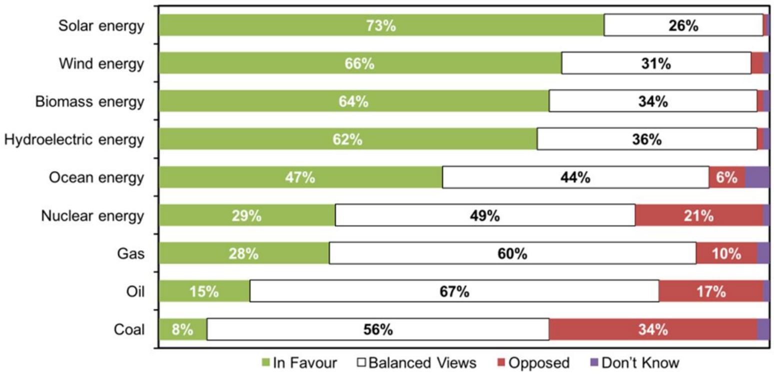


Figure 2 Attitudes and perceptions of residents of Finland (in favour, balanced views, opposed, and other) towards different energy sources [16].

1.2 Incentives to promote RETs and energy efficiency in Finland

Often in environmental law, incentives are divided into tax-based, economic, volunteer-based, or eco-labeling. Finland has primarily used tax incentives to promote wind energy and other renewable electricity until 2010. Finland had no obligations or binding recommendations for power companies to promote energy production from renewable energy sources [20]. Economic incentives were lacking to encourage wood pellet use for thermal energy production. Recently, Finland's energy taxation and subsidies have been developed to promote GHG reduction, energy efficiency, and the use of renewable energy. In order to promote electricity generation based on renewable sources, Finland introduced a feed-in tariff system operating on market terms replacing partially the tax subsidies and some of the investment subsidies for electricity generation. In 2010, the feed-in tariff system entered into force offering electricity users to pay the difference between the market price and the feed-in tariff if the market price is below the agreed feed-in tariff [21]. The feed-in tariff system developed mainly to promote electricity production from wind power and biogas, however, it also involved other renewable sources.

Beside the above incentives, building regulations were developed in 2010 requiring additional energy efficiency measures, such as additional insulation and tighter building envelope, to be applied in new construction. Recently, regulations and guidelines codes for Indoor Climate and Ventilation of Buildings (Building Code D2), Energy Management in Buildings (Building Code D3), and Calculation of Power and Energy Needs for Heating of Buildings (Building Code D5) were revised and reformed and have been under force from July 2012.

For buildings requiring renovation, energy subsidies for the improvement of energy efficiency and changes in heating systems were granted for residential buildings, mainly for apartment blocks and terraced houses. Refurbishments of energy systems in detached houses became eligible for improved domestic help credits. Moreover, grants for energy improvements in detached houses were used as a supplementary aid for low-income households.

In Finland (2006), renovation investment was estimated to be roughly half of the total construction investment. Residential buildings account for half of the renovation activities and their share is expected to increase as the stock built in 1960–1970 will soon come to an age requiring renovation. The renovation investments for 2006–2015 are estimated to be around €1,800 million per year. Due to subsidies and ownership structures, renovation activities in the rental sector are likely to be higher than in the owner-occupied sector [22].

1.3 Social acceptance

Societal acceptance is a major concern in energy policy and in the marketing of new innovative solutions. Social acceptance is a dynamic process rather than a static feature of a technology [23]. Societal acceptance is not merely a dichotomy, but can range from active support to active resistance. A study by Devine-Wright [24] argues that there is little clarification in research as whole about what is meant by public acceptance or public resistance and how these relate to the unit of analysis. It is commonly assumed that "public attitudes" need to change to make more radical scenarios about the implementation of RETs feasible. There is hence a need to for more systematic research on public acceptance driven by coherent theoretical frameworks drawn from psychology and other social science disciplines, explicit definitions of concepts, the use of innovative methodological tools, and a greater emphasis upon symbolic and affective aspects [25].

Socio-political acceptance, community acceptance, and market acceptance of energy-efficiency and RET solutions have been distinguished in [26]. Two kinds of market acceptance were identified by [12] as "acceptance in principal" and "acceptance in actual adoption and use." Based on this classification, acceptance 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 [27]. For instance, in [18], it is presented that 53% of Finnish interviewees accept in principle that it's important to develop the RETs at the moment. However, only 43% of the sample expressed their acceptance in 'actual adoption and use' to take practical steps for renewable energy developments, e.g. installing solar panels on their roof.

It is debated that most empirical research on the public's acceptance of various RETs uses a quantitative or market research type of methodology and is, hence, not informed about the underlying social or psychological processes [24]. To measure context-based social acceptance, many indicators can be used, such as the socio-economic background, age group, political beliefs, and attitudes of the participants [18,28]. There is a need for an abrupt change in public attitudes with respect to energy use [29]. In our study, we focus on market acceptance of RETs by the general public as the key stakeholder. Such studies are necessary to go beyond case studies or national opinion polls and offer the possibility to assess to what extent differences in governance, demography, and culture are reflected in different public beliefs about energy issues in general [30].

2 Methodology

2.1 Survey design and questionnaire

Respondents for this study were residents of Helsinki. In the questionnaire they were classified into stakeholder groups of researchers, energy company employees, industry, real estate developers, and others. During the study phase, teams of researchers were consulted periodically in working group meetings, including experts from field of social sciences and energy technology, to assist in the formulation of a web-based questionnaire survey. The questionnaire survey was prepared in three stages, where the first stage focused on identifying key topics, questions, and multiple choice formulations to achieve the tangible results (in both English and Finnish). The second stage involved a pre-test field survey (n=24) conducted at central locations in Helsinki city centre (Kamppi) in order to understand the common problems in understanding the survey questions and their multiple choices addressed by the respondents. This was done to identify the difficulties that a larger number of audiences might encounter when answering the survey online, resulting in implementation of minor changes, such as using simplified words. The third stage resulted in the development and implementation of an improved web-based questionnaire (Table S1) which was disseminated through social media channels in the Helsinki Metropolitan Area (Fall 2014-Winter 2015, n=246).

2.1.1 Case description

The Helsinki Metropolitan Area is divided into four sub-regions, including Helsinki, Vantaa, Espoo, and Kauniainen, with a total population of 1.4 million inhabitants and 746,280 household units, of which 31% are rented [31,32]. Types of residential housing include block of flats, detached and semi-detached houses, attached houses, and other buildings and nearly all are supplied with basic amenities [33,34]. Residential housing accounted for approximately 20% of the final energy consumption in 2013. As presented in Table S2, the three largest sources of heating are district heating, wood, and electrical heating [35]. Helsinki is an established global leader in district heating (DH), operating five combined heat and power (CHP) plants, with greater than 90% efficiency, and an advanced large scale heat pump station capable of producing simultaneously district heating and cooling. The DH provider (Helen Oy) serves 400,000 customers and provides 93% of city’s heated space. Consequently, Helsinki is equipped with approximately 1,200 kilometres of underground DH pipes, making it one of the largest DH networks in the world. The city itself provides an interesting platform to study why the general public would have an interest to invest in RETs for space heating and domestic hot water, which is available for 67 €/MWh in 2015 [36].

2.2 Multi criteria Decision Problem

Stochastic Multicriteria Acceptability Analysis (SMAA) was applied to the results from segment 4 of the survey (see Table S1). A total of 8 alternative RETs that are available in Finland were considered in the survey, as listed in Table 1 with their abbreviations. The respondents were asked to rank their preference from 1 to 8, where the most favourable technology was ranked as 1 and the least favourable as 8. Respondents were organised into respondent groups based on how they choose to categorise their profession. The respondent groups correspond to criteria in multicriteria analysis (G1-G5). This was deliberate to separate the opinion from the ‘Others’ category, defined as a resident of Finland. Some of the respondents had answered the survey incompletely, and these responses were therefore removed from the analysis, as shown in the 'Removed' column in Table 2.

Table 1 RET as choices for ranking the preferred alternative and the abbreviation used

	RET alternative provided for ranking	Abbreviation
1	Solar electricity by photovoltaic cells	SOLAR
2	Ground source heat pump	GSHP
3	Solar heat for space heating and domestic hot water	SHEAT
4	Combination of a solar thermal system for space heating, domestic hot water, and electric power	SHEATP
5	Combined heat and power production based on renewable biomass such as wood chips, etc.	CHPR
6	Small scale wind turbine	WINDS
7	Combined heat and power production based on community waste	CHPW
8	Roof mounted small scale wind turbine	WINDR

Table 2 Categories of respondent groups

Criteria as represented in SMAA	Categorisation of respondents based on their profession	Number of respondents in each criteria	Percentage of Responses Removed	Percentage of Responses Used in SMAA
G1	Industry employee (any field)	56	12.5%	87.5%
G2	Energy company employee	8	12.5%	87.5%
G3	Researcher/Scientist (any field)	61	13.1%	86.9%
G4	Real estate developer in Finland	8	12.5%	87.5%
G5	Others	113	15%	85%
Total		246	13.8%	86.2%

A typical way to analyse survey results is to use the average of a data set to derive results. Table 3 shows the average of the rankings that different respondent groups have given to the RET alternatives. The standard deviations for the average rankings were in the range 1.2 to 2.8, which indicates significant uncertainty in the results caused by disagreement between the respondents. Therefore, computing results based only on averages will not indicate the reliability of the overall ranking. Also, using standard deviations to assess the robustness of the results is not sufficient, because standard deviations do not carry information on the dependencies of the uncertainties. For example, respondents who prefer technology A may systematically also prefer technology B and disfavour technology C. In general, such multi-dimensional and potentially non-linear dependencies can be considered in statistical analysis only by using a simulation approach. For this reason, we use the simulation based SMAA method to evaluate the robustness of the ranking. SMAA can be used with arbitrary probability distributions for modelling both independent and dependent uncertainties in criteria measurements, but it is also possible to use sample data directly in the simulation. The article [37] compares using the criteria sample directly with applying a multivariate Gaussian distribution to represent dependent uncertainties in SMAA. In this study, we extended the sample-based approach into a two-phase sampling technique, as described later.

Table 3 Averages of the rankings given by respondent groups to RET alternatives

RET Alternative	G1	G2	G3	G4	G5
SOLAR	3.59	3.43	3.53	3.86	3.03
GSHP	5.31	4.71	5.21	4.43	5.02
SHEAT	5.59	5.14	5.25	5.43	5.42
SHEATP	3.98	4.14	3.51	3.71	3.23
CHPR	4.04	4.14	3.72	4.86	3.59
WINDS	4.86	4.86	4.21	4.43	4.93
CHPW	2.92	4.29	4.70	3.71	4.34

2.3 Application of SMAA

SMAA is a multicriteria decision support method for problems that involve significant uncertainty or imprecision in criteria measurements and decision makers' preference assessment [35, 36]. SMAA considers simultaneously the uncertainty in all parameters. Therefore, SMAA is particularly useful for robustness analysis of different multicriteria decision models [38, 39]. SMAA was initially developed to support various public environmental decision problems, such as relocating the Helsinki cargo harbour [40], developing the Kirkkonummi general plan [41], and siting waste treatment plants [42]. A recent application was the evaluation of sustainable heating choices for a new residential area in Loviisa city, Finland, that provides an overview of the background and application of SMAA [43].

The multicriteria problem is represented as a matrix $\mathbf{x} = [x_{ij}]$ of criteria measurements, where index i refers to alternatives and j refers to criteria. In the current problem, the measurement matrix contains 8 rows for the RET alternatives and 5 columns for the stakeholder groups corresponding to criteria. The criteria are combined together by a utility or value function $u(\mathbf{x}_i,\mathbf{w})$, which computes for each alternative an overall utility value u_i based on criteria measurements and subjective weights w_j of the decision maker. The utility function is scaled so that 1 is the best (ideal) value and 0 is the worst value. The most commonly used type for the utility function is the additive form that computes the overall utility as a weighted average of the partial utilities:

$$u_i = u(\mathbf{x}_i,\mathbf{w}) = \textstyle\sum_j w_j\, u_j(x_{ij}). \quad (1)$$

Here $u_j(x_{ij})$ are the *partial utility functions* for criteria, and their purpose is to map the criteria measurements to the interval [0,1], where 1 is the best value. The weights are normalised so that they are non-negative and their sum is 1. This means that the *set of feasible weights* is defined as:

$$\mathbf{W} = \{\mathbf{w} \in \mathrm{R}^n \mid w_j \geq 0 \text{ and } \textstyle\sum_j w_j = 1\}. \quad (2)$$

SMAA is designed to assist in problems where both criteria measurements and weights can be imprecise or uncertain. Any uncertain or imprecise information is represented by stochastic variables with suitable probability distributions: $f_X(\mathbf{x})$ for criteria measurements and $f_W(\mathbf{w})$ for weights. The distributions can be independent or multi-dimensional joint distributions, according to needs. For example, ordinal criteria can be represented by a special kind of joint distribution, as explained later.

The information collected in surveys is uncertain for several reasons. The respondents who chose to answer the survey assumingly had an interest in the topic and therefore may not form an unbiased sample of the general population. Also, any subjective information collected from the general public will be imprecise or uncertain and may change with time. For this reason, we applied SMAA for analysing the robustness of the respondents' preference rankings.

Different kinds of preference information are represented by a suitable joint distribution for the weights. In this study, the analysis was conducted with absent preference information. Absent weight information is represented by a uniform distribution in **W**, which means that any feasible weight vector is considered equally probable. In the current problem with 5 stakeholder groups representing criteria, this means that there are five non-negative weights, which are constrained only by $w_1+w_2+w_3+w_4+w_5=1$. On average, the responses of each stakeholder group will receive equal weight. However, the analysis will consider all possible combinations of weights for different stakeholder groups, both for cases where only the responses of each single group are given all the weight, and everything in between.

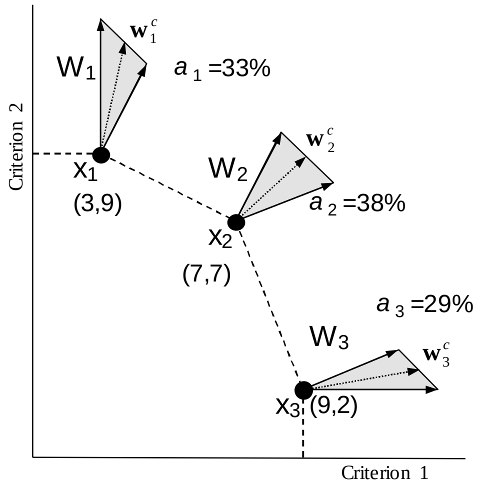


Figure 3 Acceptability indices ($\boldsymbol{a}_i$) in case of two criteria and three alternatives - central weight vectors ($\mathbf{w}_i^c$) for alternatives are drawn as dotted arrows

Based on the decision model and distributions for criteria and preference information, SMAA computes a number of descriptive measures for the alternatives. The main measures are the following:

- The *acceptability index* a_i is a measure for the variety of different weights that make an alternative most preferred, i.e. how widely acceptable the alternative is. Zero acceptability index means that the alternative is *inefficient*, i.e. no weights make it most preferred. **Figure 3** illustrates the acceptability indices in the case of three alternatives ($\mathbf{x}_1$, $\mathbf{x}_2$, $\mathbf{x}_3$) and two criteria to be maximised. Each of the three alternatives can be considered the best one subject to *favourable weights*, which are plotted as sectors ($\mathbf{W}_1$, $\mathbf{W}_2$, $\mathbf{W}_3$) at each alternative. The acceptability indices (a_1, a_2, a_3) are the relative sizes of these sectors.

- The *rank acceptability* index b_i^r is a measure for the variety of different weights that place an alternative on rank r. In other words, the rank acceptability index generalises the acceptability index for ranks other than the first one. The rank acceptability indices give a rough ranking for the alternatives and can be easily visualised by a 3-dimensional column chart.

- The *central weight vector* $\mathbf{w}_i^c$ is the centre of gravity of the weights that are favourable for an alternative, i.e. make it most preferred. The central weight vector describes typical weights that support choosing an alternative and they can be presented to the decision makers in order to help them understand how different weights correspond to different choices. In **Figure 3** the central weight vectors ($\mathbf{w}_1^c, \mathbf{w}_2^c, \mathbf{w}_3^c$) are illustrated as arrows at the centre of the favourable weight sectors.

- The *confidence factor* p_i^c is the probability for an alternative to obtain the first rank when its central weight vector is chosen. It measures how robust a choice for the first rank an alternative is if the central weight vector is chosen. If the confidence factors for all alternatives are low, it means that the criteria measurements are not accurate enough to discriminate the alternatives robustly. In such a situation, collecting more accurate preference information is not sufficient: instead the criteria should be measured more accurately.

SMAA measures can be computed efficiently using numerical Monte Carlo simulation. Therefore, the method does not require any simple function shapes for the decision model or criteria and weight distributions. Instead, any function shapes and also direct sampled data can be used to represent the problem specifically. In each simulation round, criteria measurements and weights are generated randomly from their corresponding distributions and alternatives are ranked based on their utilities. During the simulation, statistics are collected to compute the measures. A sufficient number of simulation rounds is between 10,000 and 100,000 [44].

Criteria measurements can be cardinal or ordinal in SMAA. Ordinal measurement means that there is information only about the preference order of the alternatives with respect to the criterion, but no knowledge as to how much better one alternative is in comparison to the others. In this study, only ordinal criteria were used, because the survey respondents were asked to give a preference order for the alternatives. Asking the great audience to quantify the strength of their preferences numerically was considered too difficult in this survey.

Ordinal criteria measurements are treated during the simulation by mapping the different ranks of the alternatives to random cardinal values in the range [0, 1], so that these values are consistent with the specified ranking. For example, if a respondent has ranked three alternatives on ranks (1, 2, 3), consistent cardinal values for these alternatives would be (1, z, 0), with any random value for z between 0 and 1. For details of this process, see [45].

Traditionally in SMAA, ordinal criteria have been measured by a team of experts, who agree on a complete or partial ranking for the alternatives. However, in this study a large set of respondents from five different stakeholder groups provided their individual rankings, making it impossible to form a consensus ranking. For this reason, a new way to treat the ranking information was developed:

- The opinions of each respondent group were treated as one ordinal criterion. In this way, the influence of one respondent group does not depend on the number of respondents in that group. This was considered necessary because there was a great variation in group size (7 real estate developers versus 113 others), but we did not want to give more or less weight to any particular group.
- Furthermore, a two-phase sampling technique was developed to treat each ordinal criterion. In the first phase, a random respondent from the group is selected. In the second phase, the traditional SMAA mapping technique is applied to convert the selected respondent’s ranking into a cardinal value.

3 Results and Discussion

The survey was made short (estimated completion time of 15 minutes) and relatively simple to increase the probability of receiving an increased number of respondents. A total of 246 people responded to the online survey, with a response rate of 21%. The results and discussion of the survey are presented in section 3.1. The results of the SMAA, which are the main outcome of this study, are presented in section 3.2.

3.1 Survey results

This section explains the survey results from segment 1, 2 and 3 of the questionnaire (Table S1). Table 4 presents the respondents' background information, indicating that two-thirds of the sample population live in the urban area of Helsinki and 80% have a college or advanced degree.

Table 4 Background information of the respondents

Sort	Response choice	Share of respondents (%)
Gender	Male	52.4
	Female	47.6
Age	< 30 years	34.2
	> 30 years	65.8
Education	High school	18.3
	Bachelor's Degree	32.1
	Master's Degree	39
	Doctoral Degree or Licentiate	8.9
Occupational Status	Employed	68.4
	Unemployed	9
	Student	27.5
Location	Suburban area	29.1
	Urban area	66.4
	Other	4.5

Decisions on investment cost for RETs are made to reduce the life cycle cost of a building, although higher energy efficiency may not result in increased value of the property [46].

Table 5 illustrates respondents' opinion on climate change and their occupational status in comparison with associated investment amount in RETs for an environmentally friendly home. Willingness to pay for RETs has been discussed by many studies and has been correlated to socioeconomic characteristics, including education, interest in environmental issues, and knowledge of RETs [47–50].

77% of the respondents who selected that they wish to save environmental and energy resources are willing to invest their money (in any monetary amount > 1,000€) in RETs, with 43% are willing to invest over 6,000€ in RETs. Among those who selected 'they care, but cannot do anything alone' in regard to climate change, 56% are willing to invest (in any monetary amount > 1,000€) in RETs and 26% are willing to invest over 6,000€ in RETs. This suggests that people are generally open to invest in either case. 21 respondents indicated that they feel climate change does not affect them personally or that they do not care about climate change. Among these respondents, only three intend to invest (in any monetary amount > 1,000€) in RETs. 11% of all respondents selected the investment bracket of 11,000 to 21,000€ and twelve respondents listed that they are willing to invest greater than 21,000€. Nearly one third (32%) of all respondents indicated that they would consider investing in RETs. Monetary amounts listed in the 'Other' category typically included investment amounts of several hundred euros. These results suggest that Helsinki residents are generally concerned about climate change and are willing to, or will consider in the future, investing in RETs as a means to reduce their carbon footprint.

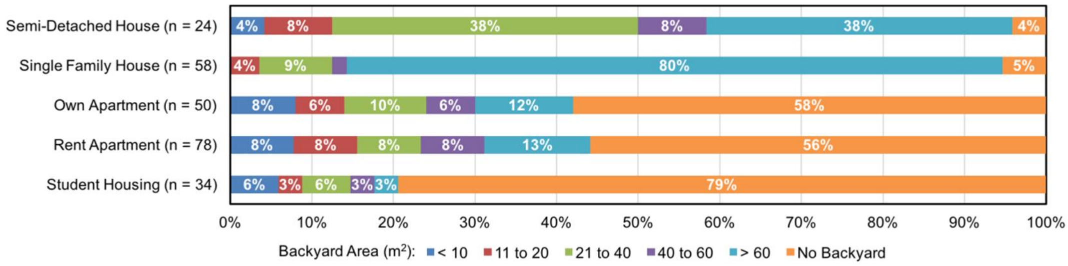
Table 5 Opinion on climate change and occupational status vs. willingness to invest in RETs

Opinion on climate change / Investment amount	1,000 – 5,000 €	6,000 – 10,000 €	11,000 - 20,000 €	> 21,000 €	I will consider it	Other, please specify
1: I want to save environmental and energy resources	52	33	22	11	34	2
2: I care, but I feel I cannot do anything alone	18	12	4	-	24	3
3: It does not affect me personally	2	-	-	-	10	-
4: I do not care	1	-	-	-	6	2
5: Other	3	1	-	1	4	-
Occupational status						
Employed	44	39	23	9	48	4
Unemployed	6	2	1	1	12	-
Student	29	8	3	2	21	4

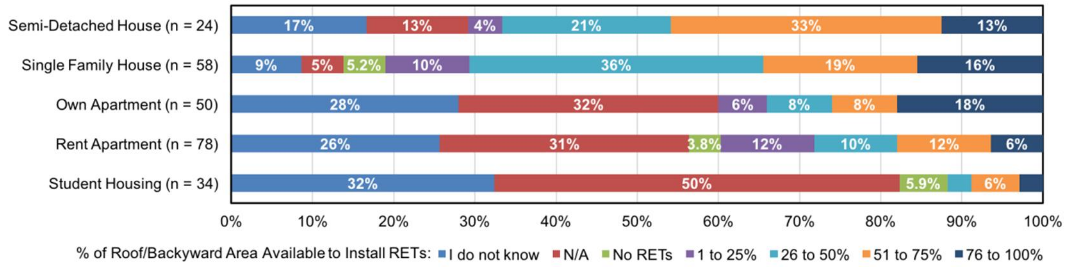
Decisions to invest in RETs were also found to be influenced by occupational status. Hast et al. (2015) found that financial affordability has greater influence on consumer choice over environmental reasons [51]. In our study, 68% of respondents reported to be employed, 27% as students, and 9% as unemployed. Among those who are employed, 69% are willing to invest (in any monetary amount > 1,000€) in RETs and 37% are willing to invest over 6,000€. A significant fraction of students (63%) are willing to invest over 1,000€ in RETs. Although unemployed, 45% of these respondents are willing to invest over 1,000€ in RETs. Occupational status among Helsinki residents appears to primarily influence investment decisions beyond 6,000€, with all respondents, regardless of employment status, indicating a desire to invest.

The respondents represent a diverse collection of housing types, as shown in Figure 4. The backyard area (Figure 4a and percentage of the backyard and roof area one would make available to install RETs (Figure 4b), is largely dependent on housing type. Occupants who rent or own an apartment or live in student housing have limited ownership of exposed backyard space, whereas the majority of respondents who live in single family or semi-detached homes have access to over 10 m^2 of space. The latter group of respondents show a much greater interest in utilizing this space to install RETs (over 60% willing to use over 26% of available space), such as photovoltaic panels, than the former group, who are not able to or unsure about their ability to install on-site RETs.

Only eight respondents selected that they do not wish to install any RETs on their property (roof or backyard). Thus, it can be concluded that the prevalence of the not in my backyard (NIMBY) mind-set is very small among the surveyed Helsinki residents. The NIMBY hypothesis has been discussed and debated in several studies [52,53] and can be described as a form of local opposition to a facility siting [54]. This has been a prevalent subject to study, especially in the case of on-site and off-site wind farms in a community setting [52,55], suggesting people accept RETs as long as they are not located in their own back yard [26].



4a



4b

Figure 4a. Backyard area (in m^2) and **4b**. percentage of roof and backyard area one would make available to install RETs, both as categorized by respondent housing type.

As presented in Table 6, in order to reduce the carbon footprint of their homes, 37% of the respondents would prefer to reduce their current heating and electricity consumption by use of automated control devices, whereas 58% of respondents would prefer to produce energy from renewable energy sources. Among those that selected both of these options, 54% of the respondents have opted for energy efficiency renovations, such as overhauling of heating, ventilation, and air conditioning systems and efficient windows to improve the building performance their current home. Operational energy appears to be the most important aspect for the design of buildings that are energy efficient throughout their life cycle [57]. By extensive refurbishment, it is possible to surpass the performance of new building designs based on perception of building occupants [58]. The renovation of older buildings can result in 30-40% saving in energy consumption [10]. Another example of home owners being proactive in taking steps to implement sustainable home energy technologies is presented by [56], where the study reported 192 heat pump and wood pellet burning systems inventions by home owners in Finland between 2005-2012.

Table 6 Selected questionnaire responses

Question	**Options**	**% Selected**
Payback time for the financial investment in RETs *n* = 244	5 years	36.5%
	10 years	36%
	15 years	13.9%
	20 years	4.9%
	30 years	1.2%
How much extra would you invest for an environmental friendly home *n*=246	From 1,000 to 5,000 Euro	29.7%
	From 6,000 to 10,000 Euro	18.3%
	From 11,000 to 20,000 Euro	10.2 %

	Above 21,000 Euro or more	3.3%
	I will consider it	31.3%
Preference in order to reduce environmental footprint of your home (multiple selection)	Reducing your heating/electricity consumption (less comfortable conditions)	37.6%
	Producing energy from renewable energy sources (additional investment)	58.8%
	Renovation (HVAC, efficient windows, materials) to improve building performance	53.9%
Preferred incentives by the respondents (multiple selection)	Feed in tariff	34.4%
	Tax deductible	61.9%
	Investment grant	47.1%

In a consumer stated preference survey study by Menegaki (2011), the absence of subsidies and regulatory requirements are observed in most European countries [59]. Tuominen et al. (2012) studied the barriers related to regulations and interviewed the stakeholders. For Finland, the lack of subsidies for energy efficiency of residential buildings was reported by the interviewed stakeholders [60]. In this study, one-third (33.6%) of respondents indicated that they were aware of the Finnish government investment grant for RET implementation.

When evaluating the preferred type of incentives, 61% of the respondents would invest in RETs if it would become tax deductible, 47% showed preference for availability of an investment grant, and 34% of the respondents chose feed in tariff (see Table 6). In the Finnish context, the effectiveness of the feed-in-tariff as an incentive towards n/NZEB has been investigated in for a single family house and an office building, respectively[61,62]. The current feed-in tariff scheme for wind power has come to a closure, as it is no longer considered cost-effective and market oriented [63]. This scheme was for rather large scale generation facilities with minimum nominal capacity of 0.5 MVA, making it inaccessible for very small scale production.

Ahvenniemi et al. (2013) reported the trends and influencing factors of the low-energy building market situation involving forty real estate industry experts in eight northern European countries. It was found that an additional investment cost is a large hindrance for low-energy construction businesses. Approximately half of these experts believe that tax deduction could support in covering the additional investment costs. Whereas, tenders or subsidies as a support mechanism was observed only by 10% [64]. Approximately one-third of respondents in our survey were satisfied with a 5-year payback time, another one-third selected 10 years, with the remaining respondents preferring a 20 to 30-year payback time.

Willingness to pay was observed to be mostly dependent on the cost instead of preference or reliability for a specific RETs, as discussed by [12,47–51]. It is difficult to explicitly differentiate between the preference and the reliability for a RET. Reliability can include factors such as ease of use and continuous supply of energy requiring no effort from the end-user. Preference (as evaluated with SMAA in the following section) is a matter of choice and can be defined as "*a rank of importance of the dimensions over which the product is defined*" which can be based on popularity, cost, competing energy providers, sizing of the unit, and many other factors [65]. Through our survey, we also evaluated how people perceive the reliability of the eight RETs when compared to preferences. Figure 5 shows the number of respondents who identified the RET as being reliable and its associated ranking (1-8) concurrently. Both SOLAR and GSHP were perceived as the most reliable of the eight RETs. WINDR, WINDS, CHPW, and CHPR were comparatively less reliable as evaluated by the respondents.

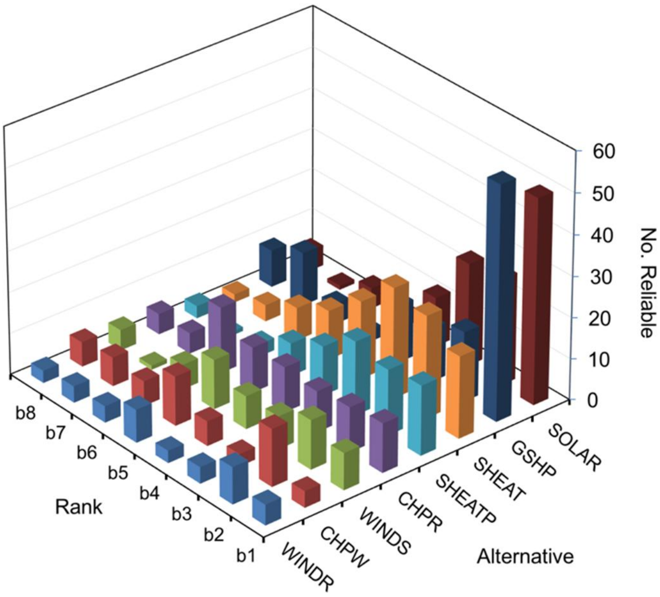


Figure 5 Number of respondents who identified the selected RET as being reliable and its associated ranking by the respondent (1-8).

3.2 SMAA results

SMAA was applied to the results of survey segment 4, as previously discussed. The respondents were asked to choose the stakeholder group they belong to as presented in Table 2. Some of the answers were incomplete, i.e. the respondent had answered only a part of the question. For example, some respondents only ranked one or a few best alternatives in segment 4 of the survey (see Table S1). Such responses were removed from the SMAA analysis, since it was difficult to derive a complete or even partial ranking of RETs from incomplete information. In some cases, the respondent had ranked a few best and a few worst alternatives; in that case we assumed that the non-ranked alternatives were considered intermediate, and were assigned a 'middle rank' of 5 among the 8 alternatives. Table 2 shows each respondent group and the number of removed responses per category.

It can be seen that the number of real estate developers and energy company respondents are relatively low in comparison with other respondent groups; however, in general, they are likely to be more informed of the practical implementation of these technologies in the building sector when compared to other groups. For this reason, the responses of all stakeholder groups have been considered equally important in SMAA, regardless the size of the group.

Figure 6 is illustrates the rank acceptability indices for different alternatives according to SMAA. They reveal the share of possible weighting among respondent groups that make an alternative most preferred (b^1) or place it on any subsequent rank ($b^2 \ldots b^8$). The alternatives in the figure are sorted according to their first rank acceptability index. We can see that SOLAR is the most widely acceptable solution for the first rank, with GSHP second. This is followed by SHEAT, SHEATP, CHPR, WINDS, CHPW, and WINDR as last. The top alternatives also have high acceptability for the second and third ranks (b^2, b^3), which means they are widely accepted for the best ranks. In contrast, the three last alternatives (WINDR, CHPW, WINDS) have high indices for the lasts rank, which means that they are inferior choices when subjected to many possible opinions.

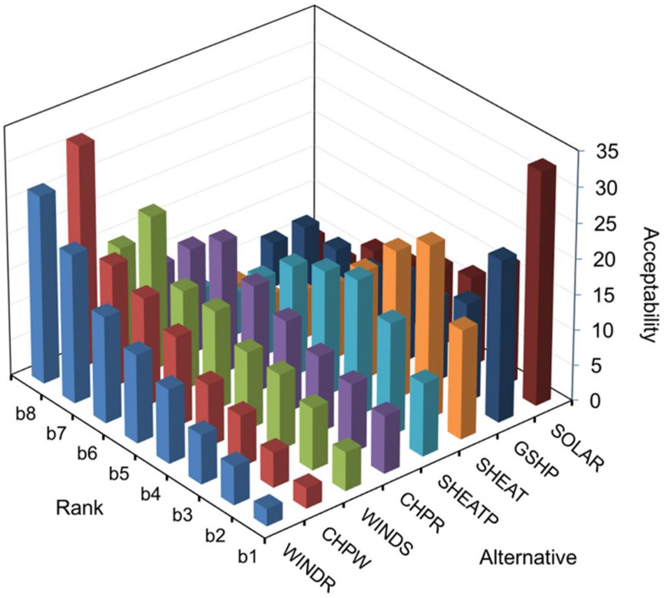


Figure 6 Rank acceptability indices for RET alternatives, showing the variety of possible preferences that place alternatives on different ranks. Alternatives are sorted according to their first rank acceptability index.

The central weight vectors are illustrated in Figure 7 and are also shown in Table 3 for RET alternatives as selected by the respondent groups. They reveal how the opinions of different respondent groups should be emphasized in order to make the alternative most preferred. The SOLAR, SHEAT and SHEATP alternatives remain the steady choices among all respondent groups. Also, the second most preferred alternative GSHP is supported uniformly. CHPR is supported by emphasizing the opinions of people employed at energy companies (G2) and placing less weight on the others group (G5). The central weights for the last three alternatives, WINDS, CHPW, and WIND show great variation among the respondent groups. This variation may be due to the relatively small number of respondents selecting one of these alternatives as the most preferred one. CHPW is favoured by emphasizing the opinions of real estate developers (G4) very highly, and placing minimal weight for the respondent groups industry (G1) and others (G5). Interestingly, the central weight profiles for WINDS and WINDR are almost opposite (Figure 7). It is difficult to identify a clear reason for such opinions. It is possible that the differentiation between the WINDS and WINDR alternatives was not clarified well enough in the questionnaire.

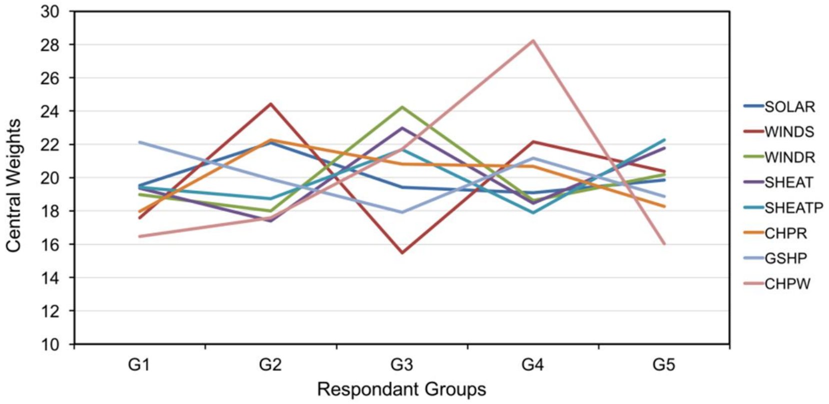


Figure 7 Central weights for alternatives by respondent groups.

Table 7 Confidence factors and central weights for alternatives.

Alternative	Confidence factor	Central weights							
		b^1	b^2	b^3	b^4	b^5	b^6	b^7	b^8
SOLAR	39	33	17	13	11	9	8	4	5
GSHP	24	23	14	12	13	10	11	11	6
SHEAT	20	15	24	21	15	11	7	4	3
SHEATP	11	10	16	19	18	16	11	6	4
CHPR	7	8	10	11	13	15	19	15	10
WINDS	4	5	9	11	11	14	14	22	15
CHPW	3	3	5	7	9	13	15	17	31
WINDR	1	2	5	7	10	12	15	21	26

Table 7 presents the confidence factors for the alternatives (probability to be most preferred when the central weight vector is chosen). The confidence factors for all alternatives, even for the top alternatives, are quite low. This means that the survey responses are uncertain and it is impossible to determine the best alternative, even if precise weights for the different stakeholder groups were specified. If a single alternative was to be chosen, the confidence factor in statistical/scientific contexts should be about 90-99%, and in a decision making situation with subjective information, it should be more than 50%. In this study, we are not choosing a single best alternative. Instead we have identified a ranking, which reveals multiple best (most preferred) alternatives. For this reason, the precise order of the top alternatives is not critical.

SMAA results clearly indicate that solar energy technologies were the most pronounced choice of the respondents. The top alternatives for solar power, ground source heat pump, solar heat and combined solar heat & power were widely acceptable either for the first rank, or for the top ranks. Ground source heat pumps are energy efficient techniques and common in Finland, which may increase their acceptability. Solar energy, and in particular photovoltaic panels, is a very highly advertised and widely implemented technology in some European countries, such as Germany and Denmark. This, together with recent development of lower prices for photovoltaic panels, has positively influenced the popularity of solar power in Finland. Many studies have indicated that when comparing knowledge levels of RETs, most of the public is aware of solar and wind technologies [66,67]. For Finland, as estimated by [68], solar thermal and solar photovoltaic can marginally improve the share of renewable energy sources in primary energy consumption by only 0.3% and 1%-point at maximum, respectively. Solar power is not a complete solution at Finnish latitude and climate conditions. At best, it is only a partial solution for nZEBs due to non-coincidence between supply and demand.

It needs to be augmented by storage techniques, renewable-based combustion, and power transmission across borders. Yet respondents designated it as both a reliable and preferred RET, as presented in Figure 5 and Figure 6.

Renewable-based combined heat and power (CHPR) is a very efficient technique to simultaneously produce heat, power, and cooling from scarce resources. CHPR and CHPW remained the least opted for among the respondents. The reasoning behind this result could be based on the fact that end users, in general, are not very involved in Finland; these alternatives are large scale plants owned by big companies. Micro-scale CHPR and CHPW production units are not common in Finland because the investments are relatively high and the return is low [69,70]. Another reason for low acceptance of CHPW could be due to an infamous waste incineration plant near the city centre which polluted its surroundings [71]. This plant was shut down in 1983 due to citizen movement. Current waste incineration technology does not cause similar emissions. As an example, a new solid waste CHP plant in the neighbouring city Vantaa opened in 2014 by Vantaan Energia. The plant is able to produce 920 GWh of district heat per year, which is 30% of the heating needed for the city of Vantaa. This plant operates with 20% reduction in CO_2 emissions and 30% less fossil fuels [72]. In Finland, the majority of the fuel mix used in CHP plants is based on fossil fuels, including coal and natural gas [73], nevertheless, there is potential to switch the fuel type towards renewables.

3.3 Study limitations

The questionnaire excluded advanced heat pump solutions for combined district heating and cooling systems, options of investment potential in community-based RETs, and other off-site energy generation approaches (e.g. hydroelectric, nuclear). It was also noted from the feedback of respondent groups that our questionnaire did not ask about the monetary value of previously made investment by the respondent in RETs. However, this information was captured in segment 2 of questionnaire as presented in Table S1, where the respondents were asked to choose the installed heating system in their home.

When assessing the survey critically, it should have provided better numerical assessment of the alternatives based on price per capacity or equipment instead of a lump sum amount of RETs. This is recommended for the future studies when assessing the willingness to invest, however, the pricing is complicated to estimate because of numerous types of technologies and technology providers. The survey data and SMAA only reflect preferences for the eight RETs listed, and thus, social perceptions of renewable energy sources not explicitly mentioned in the survey could not be evaluated. Lastly, the study did not consider perceptions of energy performance certificates for buildings in Finland. The certificates selectively target certain renewable energy production methods at the building- and community-level, and thus, may influence one's preferences for a RET [74].

4 Conclusions

This study presents the public perceptions of RETs in the capital region of Finland and uses SMAA for analysing the robustness of the respondents' ranking of preferred RETs. In this study, a large set of respondents from different stakeholder groups (e.g. industry, energy, general public) provided their individual rankings. Because forming a consensus ranking was impossible, we developed a novel way to treat the ranking information. The opinions of each respondent group were treated as a criterion. Then a two-phase sampling technique was applied to convert the respondent's survey answers into ordinal criteria measurements. This approach was successful by giving balanced weight to each respondent group regardless the number of respondents in each group.

The results show wide array of variance between the preferred choices by the respondents. The key finding of this study is that multiple different RETs are preferred, implying that we are not limited to the preference of only one or two RETs (e.g. photovoltaic panels), and rather have a spectrum of options that are acceptable as a top choice to consumers. The diversity of Finland's energy production has always been a strength, however, small-scale energy production can have a significant impact on overall energy production [29].

Because the public has dissimilar opinions on the preference ranking of RETs, choosing only one or two RETs to promote energy efficiency will not necessarily yield wide implementation. The political implication of this study is that the government should subsidise implementation of different RETs in a balanced manner, allowing people to choose, based on their preferences, perceptions of reliability, and local conditions, the most suitable technologies for their home.

Respondents indicated a strong willingness to invest in RETs, with 43% selecting to invest over 6,000€. Investment decisions were influenced by the respondent's opinion on climate change and their occupational status, with employed residents who wish to save environmental and energy resources demonstrating strong support for RETs in monetary amounts greater than 6,000€. Housing type also influenced the fraction of available backyard and roof area one would be willing to utilize for on-site RETs. The majority of Finnish residents living in single family homes and semi-detached homes indicated a strong support for installing RETs on their property (using greater than 25% of available area) and NIMBYism was not found to be prevalent among the sample population, with only eight respondents indicating they do not wish to install RETs on their roof or in their backyard. Respondents were in favour of receiving financial incentives, including tax deductions and investment grants, to support investment in RETs. 57 respondents ranked GSHP as the most reliable RET and 50 ranked SOLAR as the most reliable. Conversely, less than 10 respondents ranked either WINDS or WINDR as the most reliable.

In most cases, community level solutions for RETs can be more efficient than building specific solutions for several reasons, such as increased shared storage capacity, non-coincidence of power and heat loads, more professional supervision and management, and more flexibility to choose ideal location for production and promote idea of energy positive neighbourhood [75]. To promote growth of RETs, larger individual owner based subsidies should be introduced, especially for the detached houses which are not connected to a district heating network. These detached houses can then follow examples of renewable energy load matching as presented by Cao et al. (2013), for the case of a non-existent grid where energy is produced by photovoltaic panels and micro-wind turbines and stored in energy storage systems [76].

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