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# Determining the factors of household energy transitions: A multi-domain study

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ABSTRACT

Energy transitions at the household level are important because there are so many households, and motives and barriers to these transitions processes are not well understood. The objective of this paper is to investigate explanatory variables of household energy transitions. We select papers investigating explanatory variables underpinning household energy transitions in three domains: adoption of solar photovoltaics (PV) in households, adoption/transition to sustainable residential heating systems (RHS) and adoption/transition to alternative fuel vehicles (AFVs). In all three domains the chosen literature employ a wide variety of quantitative analyses such as discrete choice models ranging from multinomial logit models and principal component analysis to qualitative assessment of the answers through inductive analysis. The explanatory variables are categorized in six superordinate explanatory variable categories of economic factors, environmental factors, personal preferences and values, social factors, household characteristics and market and policy factors. In total we identify 31 explanatory variables which have been investigated in the 38 articles chosen, falling under the six categories. Investment cost is an important explanatory variable for all three domains, but a policy variable such as government subsidy could mitigate the former explanatory variable. We propose a conceptual framework as an initial step towards understanding the interactions and impacts of the explanatory variables with each other.

## 1. Introduction

Loorbach et al. [1] give an in-depth analysis of the development of the field of sustainability transitions and its evolution over the decades. There are currently three approaches in studying transitions; socio-technical approach, socio-institutional approach and socio-ecological approach (for an in-depth description see Loorbach et al. [1]). All three perspectives ultimately aim to make sense of transitions, which is the process of change from one system state to another via a period of nonlinear disruptive change.

The energy transitions are essential to mitigate the GHG emissions from non-renewable energy sources. Yet, energy transitions in fields with fragmented energy use and GHG emissions are a decisive challenge since transitions need to happen in many small units, such as households, unlike large sinks of energy or sources of GHG emissions. In this paper, we define fragmented energy use as energy use which happens at a household level; small energy sinks dispersed in numbers. This sub-set of energy transitions brings out a dichotomy in the treatment of energy transitions and processes. Furthermore, energy transitions are socio-technical transitions, with wide-ranging changes in the elements of socio-technical systems. But they are the cumulative of households making changes. This dichotomy is at the core of the study we have undertaken here.

There is evidence pointing that household decisions regarding sustainable or 'green' energy transitions have a complex process behind them [2], due to the individual differences present when it comes to making decisions about investments.

Then, the understanding of the attributes and characteristics of the adopters or potential adopters, and the attributes and characteristics of the technologies become vital to understanding the transitions processes. Especially, given that the transitions have to happen in many different places it becomes important to know about the adopters or potential adopters, and to have knowledge about the barriers and motives stopping and aiding the transitions, respectively [3].

Despite the many different examples present when it comes to household level energy transitions, each of the different examples are vital to achieving sustainability and important in the context of climate change mitigation. There are published works looking at specific energy transitions at the household level, such as [4] for solar PV, and [5] for district heating.

Household energy transitions have been characterized as energy investment decisions by Kastner and Stern [3] where they investigate

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the ‘human factor’ behind energy investments in households, by defining ‘explanatory variables’ driving the decisions. Yet, they do not differentiate between the different domains of household energy transitions. There is no literature looking at multiple domains of energy use and their transitions which take place in households. In order to fill this gap, this study has selected three domains of energy transitions which take place in households: (1) adoption of solar Photovoltaic (PV) panels in households, (2) adoption/transition to sustainable residential heating systems (RHS) and (3) adoption/transition to alternative fuel vehicles (AFVs). These domains were specifically chosen because these transitions happen at a fragmented scale and the decision-making unit is generally a household. Simultaneously, they have a significant impact on the energy usage and GHG emissions.

Thus, the objective of this paper is to investigate the explanatory variables of household energy transitions under three different domains, and their linkages to household energy transitions processes and compare the explanatory variables' significance for the different domains.

In doing this, this paper answers the following questions:

- What are the explanatory variables underpinning the different household energy transitions processes?
- What are the commonalities and differences in the explanatory variables in the household energy transitions processes?
- Is it possible to formulate a conceptual framework to explain the explanatory variables and the interactions between them?

The rest of the article is organized thus: Section 2 explains the procedure adopted in this paper. Section 3 gives an overview of the selected literature and Section 4 discusses the findings from the literature under the three domains chosen for this study. Section 5 gives the pertinent discussion with respect to the findings and Section 6 concludes.

## 2. Methodological approach

The first step of the procedure, already mentioned in Section 1, is the selection of the three domains of household energy transitions. The study has been designed to be explorative. Explorative research can answer varied research questions such as “what”, “how” and “why” [6]. Most exploratory research focuses on analyses of secondary data. Thus, to explore the explanatory variables of the household energy transitions, the authors inductively analyse existing scientifically published papers dealing with these specific domains, using the method of Content Analysis (CA).

Content analysis is the analysis of the implicit or explicit content of any communicated material through classification, tabulation and evaluation of its key symbols and themes, in order to ascertain its meaning, according to Ref. [7]. Thus, in our study, to analyse which factors are important in the household energy transitions, we analyse the contents of scientific peer-reviewed literature dealing with household energy transitions. Hsieh and Shannon [8] show that there are three general approaches to CA such as conventional, directed and summative. In this study, we choose the directed CA approach. The CA process generally consists of the following steps; 1. Formulating a research question (in this case, what are the explanatory variables for household energy transitions?), 2. Selecting the sample (detailed in Section 2.1), 3. Detailing categories (detailed in Section 2.2), 4. Outlining and implementing the coding process (detailed in Section 2.4) and 5. Analysing the results of the coding process (Sections 3, 4 and 5).

### 2.1. Literature selection

Existing peer-reviewed scientific papers of recent times addressing the three domains are selected for this study. A hybrid selection method is used. First, a customary search with the search queries with strings “attributes” and “energy transitions”, in the “TITLE, ABSTRACT, KEYWORDS” category is carried out, and papers are selected after manual review of the abstract and main body of the paper. We used the search queries “characteristics” AND “energy transitions” and “motives and barriers” AND “energy transitions” to ensure that no additional papers were being excluded. Subsequently, a selection method loosely based on a snowball sampling method [9] is used to select other suitable papers not returned with the search results. These papers are cited by the papers chosen from the search query. We justify this relatively (relative to other systematized sampling methods) ad-hoc method for selecting the literature for this study since the purpose of this study is a not a rigorous literature review. Instead we have focused more on being consistent with what the selected papers have, that is, rigorously ensuring that the papers focus on the household energy transitions processes and the explanatory variables of the three energy transitions domains.

We have also made sure that the selected papers are limited to recent times (published within the last 15 years). The reason for limiting the papers read to recent times is that these technologies and transitions have undergone considerable metamorphoses and earlier papers may be irrelevant since the attributes of technologies which impact on the adoption decision and the associated adopters have changed. For example, in 2017 the attributes of electric cars and the reasons for adoption of them have changed from the year 2000. We justifiably presume that recent papers (primarily published within last 15 years) hold more relevance to this study and hence not choosing to include the earlier papers in the analysis is not going to result in a veritable loss of understanding.

In total 38 papers are chosen for the three domains, and they are spread among the domains thus: PV adoption in households represented by 15 papers, sustainable RHS represented by 13 papers and AFVs in personal cars represented by 10 papers. These papers have main research questions which scrutinize explanatory variables determining the reason for household energy transitions.

### 2.2. The selection of superordinate explanatory variable categories

These papers are analyzed for explanatory variables for the decision behind adoption or non-adoption of technologies which cumulatively amount to household energy transitions. The explanatory variables come in the form of attributes of the technologies, and characteristics of the decision-makers, and the barriers and motives present against and for adoption, respectively. Kastner and Stern [3] have presented six superordinate explanatory variable categories (SEVC), which are (i) demography, housing and location of residence, (ii) decision-maker disposition, (iii) beliefs about consequences for the household, (iv) beliefs about consequences beyond household, (v) social influences and (vi) policy measures and numerous explanatory variables which fall under the six categories.

An initial scanning of the chosen literature dealing with household energy transitions and energy investment decisions show us that the chosen literature categorize explanatory variables along the lines of economic factors, environmental factors, personal values and preferences, social factors, household characteristics and market and policy factors. Given the saliency of the categorization, we select these six categories as our SEVC. Thus, the SEVC chosen for this study are:

- Economic factors
- Environmental factors
- Personal values and preferences
- Social factors
- Household characteristics, and
- Market and policy factors

The selection of these six SEVC results in us carrying out a directed content analysis. Our analyses of the content of the chosen literature are framed by these six SEVC, and thus the content analysis is more targeted than analysing the content of all the articles without having any such pre-chosen SEVC. It also implies that we carried out the content analysis looking to categorize any explanatory variable that we came across under one of the six SEVC.

### 2.3. Coding process in the content analysis

We manually read and inductively analyse the papers for the explanatory variables and manually categorize them in the six SEVC and code them for factors listed as being critical for decision making associated with the transitions, and the important outcomes, for each of the selected domains of household energy transitions, and then discuss them in the subsequent sections. The raw data which came about as a result of the code implementation is given for the three domains in Appendix A.

### 2.4. Why a conceptual framework?

Many analysts use the terms ‘framework’, ‘theory’ and ‘model’ almost interchangeably according to McGinnis and Ostrom [10]. Furthermore, a framework provides the basic vocabulary of concepts and terms that may be used to construct the kinds of causal explanations expected of a theory, they posit. They also go on to add that frameworks organize diagnostic, descriptive and prescriptive inquiry. On the other hand, a theory posits specific causal relationships among core variables. In contrast to both a framework and a theory, a model constitutes a more detailed manifestation of a general theoretical explanation in terms of the functional relationships among the independent and dependent variables important in a particular setting [10].

A framework, among other things, is also capable of providing a metatheoretical language that can be used to compare theories. Simultaneously, Binder et al. [11] also define a framework as providing a set of assumptions, concepts, values and practices that constitute the way of viewing a specific reality.

With these pertinent definitions and explanations in mind, we think that a conceptual framework will serve the purpose of outlining the different explanatory variables available in household energy transitions literature under the superordinate categories. This conceptual framework would be general in a way, that many theories may potentially be used to explain the different variables included in the framework. Such a framework would serve as a heuristic tool to understand the different household energy transitions processes. Given the aim of understanding the decision variables in the three domains of energy transitions, a conceptual framework could be a method of categorizing and explaining the knowledge gained by the findings of the content analysis.

## 3. Overview of selected literature

The brief descriptions of the papers selected under the three separate domains of solar PV, sustainable RHS and AFVs, are presented in Tables 1–3, respectively. Of all the selected papers, most had national level focus, especially in the sustainable RHS and AFV domains. Of the selected papers, 10 papers had sub-national focus. In the solar PV domain, there were almost equal number of sub-national and national level focus in the selected studies (seven papers) (see Table 1). There are many reasons for this. One of them could be that the solar PV domain has had a presence in the literature going back decades, and hence sub-national level analysis and focus is more prevalent. Another could be that a sub-national focus is more relevant since solar PV is dependent on locality based natural resource (solar insolation) being available, among others. The testing of these reasons is beyond the scope of this paper. In some papers, the crux of the focus is a comparison between sub-national and national cases, such as in Refs. [12,13].

The papers use a wide variety of methods, which fall within the spectrum bordered by quantitative and qualitative at their two extremes, and the variety ranges from explorative case study [14] to assess the motivations to adopt solar PV, to a field survey using computer assisted interviews [15], and then to a national level survey of 5000 households [16] and to a choice modeling study from online survey respondents in Ref. [17]. An overwhelming majority of the studies have used choice studies as their method. While whom they questioned differed, most of their inputs into the methodology were the answers given to queries.

In the case of the type of analysis undertaken in the studies, in the sustainable RHS domain (see Table 2) and the AFV domain (see Table 3) there is more prevalence of quantitative analysis in the form of discrete choice modeling (multinomial logit models) and other statistical regression analysis. Approximately 95% of the studies used quantitative/statistical methods of analysis. On the other hand, in the papers of the solar PV domain, both quantitative and qualitative analysis methods are represented, by a split of 20% of inductive and abductive analysis and 80% of quantitative/statistical analysis. This in turn leads to the difference in the varied conclusions these studies come to, in their respective studies and impacts upon the different explanatory variables they consider.

The time perspective that has been considered in this analysis of the selected papers are dichotomously limited to either ex-ante or ex-post time perspective. There is both ex-ante and ex-post time perspectives represented.

The stakeholder perspective representation is not so straightforward. As with the existence of sub-national focus of the studies, in the solar PV adoption domain there is a wider representation of the stakeholders, including adopters, non-adopters along with solar PV installers [18], and bottom-up initiatives (BUIs) [4] and related actors. On the other hand, in the sustainable RHS and the AFVs example, there is a preponderance to limit the studies to adopters, non-adopters and potential adopters. Again, as ventured before, this could be because of the maturity of the study of diffusion of solar PV in the scientific literature.

In addition to this, there are some specificities in the papers selected in the domains that need to be highlighted before proceeding with the rest of the findings. In both the solar PV domain and in the sustainable RHS domain, most studies have dealt with individuals who own their own homes and individuals living in detached houses. This has been a limitation to stop the variability that might arise in the results due to the lack of decision-making power if the surveyed individuals are not home owners. In studies where the surveyed individuals do not live in their own homes, that they do not own their homes have been cited as reason or barrier for not implementing a solar PV or sustainable RHS system. Likewise, not living in a detached house has also been cited as a reason or barrier for not implementing a solar PV or sustainable RHS system.

## 4. Findings: the explanatory variables underpinning transitions

Table 4 gives the explanatory variables under the SEVC ***(or from herein explanatory variable categories (EVC))*** of the literature selected in the three domains (economic factors, environmental factors, personal values and preferences, social factors, household characteristics, and market and policy factors). Table 4 gives the number of papers (as a number and a percentage) with the designated explanatory variables in each domain of the transition.

There are many commonalities between the explanatory variables of the three domains. Among economic factors, the total initial investment (or the upfront investment) is considered a significant factor by a majority of the literature in the three domains. In the case of the sustainable RHS domain, the annual cost is an explanatory variable under the EVC of economic factor in the decision leading to the transition.

In terms of environmental factors, GHG emissions or pollution mitigated was an important explanatory variable included in a significant

**Table 1**
The descriptive facts about the selected papers on Solar photovoltaic (PV) adoption.

| | Title | Geographical focus | Theory used | Data collection | Type of analysis | Time and stakeholder perspectives |
|---|---|---|---|---|---|---|
| 1 | Consumer attitudes towards domestic solar power systems [19] | National | Diffusion of Innovations Theory | Kelly's Repertory Grid. 100 adopters of solar PV, and 1000 adopters of different energy measures | Statistical analysis: bi-polar descriptor pairs | Ex-post. Both early adopters and early majority. |
| 2 | Explaining interest in adopting residential solar photovoltaic systems in the United States: Toward an integration of behavioural theories [20] | Sub-national | Diffusion of Innovations Theory, Theory of Planned Behaviour, and Value-Belief-Norm theory. | Survey data; 1161 participants through a web form | Statistical regression analysis | Ex-ante time perspective. Non-adopters of Residential PV systems. |
| 3 | Household level innovation diffusion model of photo-voltaic (PV) solar cells from stated preference data [21] | Sub-national | Diffusion of Innovations Theory | Discrete choice experiment 298 completed questionnaires | Statistical analysis; Hypothesis testing | Ex-ante research. Adopters and potential adopters. |
| 4 | Local factors driving the diffusion of solar photovoltaics in Sweden: A case study of five municipalities in an early market [18] | Sub-national | – | 1. Internet search queries, 2. Semi-structured interviews 3. Surveys, mail questionnaire | Statistical and quantitative analysis. | Ex-post. Adopters, utilities, and retailers |
| 5 | Motivations and barriers associated with adopting microgeneration energy technologies in the UK [22] | National | – | Literature review of 18 articles | Abductive analysis | Ex-post. Adopters and non-adopters |
| 6 | Motivators for adoption of photovoltaic systems at grid parity: A case study from Southern Germany [14] | Sub-national | Diffusion of Innovations Theory | Explorative case study, Interviews and observation | Inductive analysis of the interviews | Ex-post. Adopters of solar PV and the local solar company and its employees. |
| 7 | Motives for and barriers to household adoption of small-scale production of electricity: examples from Sweden [23] | National | Multi-level perspective, Niche-regime-landscape interactions | In-depth semi-structured interviews | Inductive analysis of the interviews | Ex-post and ex-ante. Regime and niche actors. |
| 8 | Peer effects in residential solar photovoltaics adoption—A mixed methods study of Swedish users [24] | Sub-national | – | Survey questionnaire (postal); follow-up semi-structured telephone interviews | Quantitative (statistical) analysis and qualitative inductive analysis. | Ex-post. Adopters |
| 9 | Prediction of photovoltaic and solar water heater diffusion and evaluation of promotion policies on the basis of consumers' choices [25] | Sub-national | Bass Diffusion model. | Choice experiments, and conditional logit model. | Quantitative and statistical analysis. | Ex-ante research. Potential adopters. |
| 10 | Residential consumers' experiences in the adoption and use of solar PV [26] | Sub-national | Diffusion of Innovations Theory | In-depth semi-structured interviews | Qualitative and explorative analysis. Inductive analysis. Thematic analysis. | Ex-post perspective. Early adopters and early majority |
| 11 | Photovoltaic diffusion from the bottom-up: Analytical investigation of critical factors [4] | National | Decision-making using SWOT and AHP. | Mixed design methodology; First SWOT analysis and then AHP analysis | Inductive analysis of literature and Delphi method (expert analysis) | Ex-post Stakeholders are members and other key-actors of BUIs. |
| 12 | Stimulating the diffusion of photovoltaic systems: A behavioural perspective [12] | National and sub-national | – | Survey questionnaire | Statistical and quantitative analysis of survey results | Ex-post. Adopter. |
| 13 | The adoption of PV in the Netherlands: A statistical analysis of adoption factors [27] | National | Diffusion of Innovations Theory and Technology Acceptance Model (TAM) | Questionnaire interview via the Internet of 1371 people. | Descriptive and inductive analyses, quantitative statistical regression-based analysis. | Ex-post. Adopters, non-adopters and potential adopters. |
| 14 | The diffusion of microgeneration technologies – assessing the influence of perceived product characteristics on homeowners' willingness to pay [15] | National, Ireland | Diffusion of Innovations Theory. | Computer-assisted telephone interviews | Hypothesis testing | Ex-ante. Adopters and potential adopters |
| 15 | Willingness-to-pay for renewable energy: Primary and discretionary choice of British households for micro-generation technologies [28] | National | Stated Preference Theory | 1279 computer assisted personal interviews | Both conditional, and mixed logit models | Ex-ante perspective from potential adopters |

**Table 2**
The descriptive facts about the selected papers on the adoption of sustainable residential heating systems (RHS).

| | Title | Geographical focus | Theory used | Data collection | Type of analysis | Time and Stakeholder perspectives |
|---|---|---|---|---|---|---|
| 1 | Adoption of innovative heating systems—needs and attitudes of Swedish homeowners [29] | National | Concept of Attitude-Practice gap. | Two surveys, baseline survey and re-survey, of 50 and 1500 respondents, respectively. | Statistical analyses and a battery of tests | Ex-ante and ex-post. Adopters and non-adopters |
| 2 | An adopter-centric approach to analyse the diffusion patterns of innovative residential heating systems in Sweden [30] | National | Systems of Innovations. | Two surveys, baseline survey and re-survey, of 50 and 1500 respondents, respectively. | Statistical analysis, both manual and using software, significance testing. | Ex-ante and ex-post. Adopters and non-adopters |
| 3 | Determinants of households' space heating type: A discrete choice analysis for German households [31] | National | – | Discrete Choice framework to panel data | Multinomial logit approach, statistical analysis. | Ex-post. Adopters and non-adopters |
| 4 | Diffusion of renewable heating technologies in households. Experiences from the Norwegian Household Subsidy Programme [32] | National | Theory of Household Energy Behaviour, Energy Paradox and Theory of Planned Behaviour. | Survey questionnaire of 896 households. | Hypothesis testing. A multivariate regression analysis | Ex-post. Adopters. |
| 5 | Homeowners' preferences for adopting innovative residential heating systems: A discrete choice analysis for Germany [16] | National | – | Representative and self-administered national survey of 5000 households. | Discrete choice model in the form of a multinomial logit model. | Ex-post. Adopters |
| 6 | House owners' perceptions and factors influencing their choice of specific heating systems in Germany [5] | National | – | Nation-wide written survey of 4500 house-owners | Multinomial logistic regression analysis. | Ex-post time perspective with adopters of wood-pellet systems. |
| 7 | Household preferences of hybrid home heating systems – A choice experiment application [33] | National | – | Surveys | Choice experiment and then a mixed logit model | Ex-post and ex-ante. Adopters and potential adopters |
| 8 | Households' heating investments: The effect ofmotives and attitudes on choice of equipment [17] | National | – | Choice modeling from online surveys of 1860 respondents. | Both logit estimation and mixed logit estimation. | Ex-post. Adopters. |
| 9 | Influencing Swedish homeowners to adopt district heating system [34] | Sub-national | Theory of Innovations Diffusions. | Two surveys, baseline survey and re-survey of 700 homeowners | Statistical analysis, both manual and using software, significance testing. | Ex-ante, and ex-post, Adopters and non-adopters. |
| 10 | Motivational factors influencing the homeowners' decisions between residential heating systems: An empirical analysis for Germany [35] | National | – | National self-administered survey of 2440 households | Principle Component Analysis and Cluster Analysis. A multinomial logit model predicting adoption behaviour. | Ex-post. Adopters |
| 11 | No pipes in my backyard? Preferences for local district heating network design in Germany [36] | Sub-national. | – | First a focus group study of seven people and then choice-based conjoint analysis of their discussion | Inductive bottom-up analysis for the focus group study. Goodness of fit and Hierarchical Bayes for the conjoint analysis. | Ex-ante. Potential adopters |
| 12 | Stated preferences of Finnish private homeowners for residential heating systems: A discrete choice experiment [37] | National | Characteristics Theory of Value and Random Utility Theory. | Questionnaire survey of 1008 house-owners | Multinomial logit model analysis, and then implicit tradeoffs | Ex-ante. Adopters and non-adopters |
| 13 | Switching from fossil fuel to renewables in residential heating systems: An empirical study of homeowners' decisions in Germany [38] | National | Elements of rational decision-making and emotional characteristics. | Questionnaire survey of 1125 house-owners. | Statistical regression analysis. | Ex-post. Adopters. |

**Table 3**
The descriptive facts about the selected papers on the adoption of AFVs.

| | Title | Geographical focus | Theory used | Data collection | Type of analysis | Perspectives |
|---|---|---|---|---|---|---|
| 1 | Adoption barriers for electric vehicles: Experiences from early adopters in Sweden [39] | National | – | A paper survey sent out to 402 respondents. | Quantitative analysis of the responses | Ex-post. Adopters. |
| 2 | Barriers to wide spread adoption of electric vehicles: An analysis of consumer attitudes and perceptions [40] | *Not mentioned* | – | An internet survey of 408 respondents | Chi-square test statistical analysis. | Ex-ante and ex-post; Technology enthusiasts and potential adopters |
| 3 | Effectiveness of incentives on electric vehicle adoption in Norway [41] | National | – | Secondary data | Statistical regression analysis | Ex-post analysis and adopter perspective. |
| 4 | How might potential future plug-in electric vehicle buyers differ from current "Pioneer" owners? [13] | National | – | 3-part mixed mode survey.<br>1. a web-based questionnaire of 1754 households<br>2. a mail-out and web-based survey package<br>3. web-based survey of stated choice experiments and design space exercises. | Discrete choice model analysis - multinomial logit model. | Ex-post. Adopters and potential adopters |
| 5 | Incentives for promoting Battery Electric Vehicle (BEV) adoption in Norway [42] | National | | A survey of 3400 residents. | Statistical analysis. | Ex-post. Adopters. |
| 6 | The dynamics of purchasing an electric vehicle – A prospective longitudinal study of the decision-making process [43] | National | Bramberg's Stage model with 4 stages: pre-decisional, pre-actional, actional and post-actional. | A web-based survey administered to 113 participants. | Econometric and quantitative analysis | Ex-ante. Potential adopters |
| 7 | The impact of car specifications, prices and incentives for battery electric vehicles in Norway: Choices of heterogeneous consumers [44] | National | Econometric choice models. | | Random Coefficient Discrete Choice Model (BLP) | Ex-post. Adopters. |
| 8 | Who will buy electric vehicles? Identifying early adopters in Germany [45] | National | – | Secondary data, and an online questionnaire survey taken by 25000 households. | Total Cost of Ownership analysis | Ex-ante and ex-post. Adopters and potential adopters |
| 9 | Willingness to pay for electric vehicles and their attributes [46] | National | – | Internet based survey applied with 3029 respondents. | A latent class random utility model | Ex-ante. Potential adopters |
| 10 | Willingness-to-pay for alternative fuel vehicle characteristics: A stated choice study for Germany [47] | National | – | Nation-wide web-based stated preference Discrete Choice Experiment (DCE) with 711 respondents. | Statistical inferential analysis | Ex-post. Adopters and non-adopters |

**Table 4**
The explanatory variables and their spread in the literature under the three domains.

| Explanatory variable categories | Explanatory variable | Number of papers with the explanatory variables (in numbers and percentages) | | | | | |
|---|---|---|---|---|---|---|---|
| | | Solar PV domain | % | Sustainable RHS domain | % | AFVs domain | % |
| Economic factors | Total initial investment | 10 | 67% | 12 | 92% | 5 | 50% |
| | Payback period | 4 | 27% | 3 | 23% | 3 | 30% |
| | Value added to the property | 4 | 27% | 1 | 8% | 0 | 0% |
| | Savings over time | 4 | 27% | 4 | 31% | 2 | 20% |
| | Annual cost | 2 | 13% | 9 | 69% | 1 | 10% |
| Environmental factors | GHG emissions/pollution reduced | 8 | 53% | 6 | 46% | 4 | 40% |
| | Environmental friendliness | 3 | 20% | 5 | 38% | 3 | 30% |
| Personal values and preferences | Attitude to risk (risk-taking or risk averse) | 4 | 27% | 0 | 0% | 0 | 0% |
| | Need for energy independence | 4 | 27% | 5 | 38% | 2 | 20% |
| | Positive attitude towards climate change | 3 | 20% | 6 | 46% | 2 | 20% |
| | Openness to change | 3 | 20% | 2 | 15% | 3 | 30% |
| | Required ease of installation and operation | 6 | 40% | 8 | 62% | 4 | 40% |
| | Willingness to pay | 4 | 27% | 0 | 0% | 3 | 30% |
| | Social altruism | 1 | 7% | 0 | 0% | 0 | 0% |
| Social factors | Peer effects and social influence | 8 | 53% | 7 | 54% | 2 | 20% |
| | Availability of information | 5 | 33% | 4 | 31% | 3 | 30% |
| Household characteristics | Type of house | 1 | 7% | 6 | 46% | 4 | 40% |
| | Ownership of house | 2 | 13% | 6 | 46% | 0 | 0% |
| | Age | 1 | 7% | 6 | 46% | 4 | 40% |
| | Gender | 1 | 7% | 6 | 46% | 4 | 40% |
| | Household size | 1 | 7% | 6 | 46% | 4 | 40% |
| | Region | 1 | 7% | 4 | 31% | 0 | 0% |
| | Income | 0 | 0% | 6 | 46% | 4 | 40% |
| | Ethnicity | 0 | 0% | 0 | 0% | 1 | 10% |
| | Usage patterns | 0 | 0% | 0 | 0% | 6 | 60% |
| Market and policy factors | Utility to buy surplus | 5 | 33% | 0 | 0% | 0 | 0% |
| | Tax breaks, incentives and grants | 7 | 47% | 4 | 31% | 5 | 50% |
| | Government policy stability | 3 | 20% | 2 | 15% | 0 | 0% |
| | Fuel (electricity) prices, future and current | 2 | 13% | 6 | 46% | 3 | 30% |
| | Influence of market players | 3 | 20% | 4 | 31% | 3 | 30% |
| | Availability of fuel/charging | 0 | 0% | 2 | 15% | 5 | 50% |

number of studies in all three domains. This finding could be because we have chosen papers from the last 15 years, and the connection between pollution and GHG emissions and energy use have been stressed very much in the years the literature are from. Nevertheless, this is important, since the scientific field of energy investments and transitions in households considers that GHG emission mitigation and pollution mitigation are important factors in the transitions process.

In terms of differences, household characteristics are considered important in the sustainable RHS and AFV domains, while in the solar PV domain, they are not deemed important. This is significant, since it implies that household characteristics are not important to the installation of solar PV in households.

In our study, we have considered willingness to pay (WTP) as an explanatory variable belonging to the category of personal values and preference rather than an economic factor, since it mostly depends on what a household believes a technology is worth rather than what it is actually worth.

The explanatory variables of peer effects and social influence are in the solar PV domain, while surprisingly they are deemed insignificant in most of the literature in the AFV domain (two out of 10). Here, social influence and peer-effects are also considered as the recommendation and advice given by amateurs and professionals alike.

The subsequent sub-sections will deal with the explanatory variables for each domain and assess what were found to be significant.

### 4.1. The solar PV domain

In the solar PV domain, as mentioned before, along with adopters and non-adopters, other actors have also been asked questions regarding the diffusion of solar PV (in three out of 15 studies).

In all the papers studied the economic variable category is important, either as an attribute of the technology, or as a barrier. Studies often include different costs, instead of classifying all different costs as one. For instance economic factors contain the explanatory variables annual savings, payback period, affordable technology and appreciating asset (home/house) in Ref. [19], in addition to the investment cost. Likewise [21] divides cost further into total initial investment, cost of connection to the national grid, and payback period, while [22] identifies upfront cost and payback period as barriers to adoption of solar PV. In terms of outcomes, 12 papers agree that the initial cost of installation and the payback period of the solar PV system are critical factors against the adoption of the solar PV system. In studies [22,23,25,27,28], initial or capital costs are cited as the foremost barrier or attribute against the adoption of solar PV.

In explaining the adoption of solar PV through the personal values and preferences EVC [20] uses the Value-Belief-Norm theory. Here, values are termed as consisting of bio-spheric and social altruism along with self-interest and openness to change. On the other hand [15] deconstructs beliefs as attitudes, which contain concerns about costs, perceived riskiness along with the belief of how the adoption would personally benefit the individual, among others. Motives for acting can be personal norms on issues such as energy and climate change. Per this explanation, beliefs and norms are subject to change when influenced by external factors, but the values are held deeply within.

The personal preference and values EVC being important is also reflected in the willingness to pay (WTP) findings from some of the papers. The WTP is considered in comparison to the conventional electricity supply options or the status quo. The [28] finds that respondents were willing to pay five times less than actual capital costs for solar PV systems, while [15] also finds that the respondents were willing to pay significantly less than the actual market price. They also found that while the product complexity was not a barrier, more than environmental benefits, the independence and energy security given by the solar PV system mattered more to the respondents. This is also found in quite a few other papers studied in this analysis. Both [22,23] find that security of supply and protesting against the big energy companies was an important motive for adopting solar PV, in the UK and Sweden, respectively.

Simultaneously, six of these studies concluded that the existence of subsidies, grants, and knowledge about these subsidies or grants were great motivators of the adoption of the solar PV system, along with savings on electricity or energy bill [27]. These are defined as the explanatory category of policy and market factors.

Along with the subsidies and grants, the explanatory variables of main grid's electricity prices, and feed-in-tariffs (FITs) are clear motivators for the adoption of solar PV as pointed by Ref. [14] along with purchase rate of surplus electricity. But, it is important to note that these policy and market related explanatory variables interact with the economic factors, and the annual reduction of energy cost, as noted in Ref. [25].

There is some ambivalence with regards to the environmental factors and the entailing explanatory variables of that EVC, and their relevance to the adoption of the solar PV system. In the study by Ref. [4] the contribution to environment and climate protection has been listed as a strength of the solar PV generation unit, which aids in the adoption; nonetheless [20] concludes that the personal norms of energy and climate change consciousness decrease when factors such as cost become important. In fact, while [22] points out that environmental reasons were the biggest factor in the adoption of solar PV, the cost was a bigger barrier in stopping the adoption among UK residents. On the contrary [26], finds that environmental reasons were the least important in adoption, but the energy and related cost savings were the most important reason for adoption of solar PV in Queensland, Australia.

In terms of social factors, there are some interesting links and strains that are worth looking at. While looking at peer effects in the adoption of solar PV [24], concludes that the findings show that peer effects work as they should in the Swedish societies. The active engagement of current adopters with potential adopters works to remove the barriers associated with trialability and low observability. The peer effects of friends were observably better than the peer effects of unknown people. Furthermore [12] finds that local information meetings reduced the technical barriers related to the adoption of solar PV, along with the positive influence of energy advisors, who are current adopters of solar PV systems.

The household characteristics EVC did not play a significant role in the adoption process of solar PV systems in the selected literature. More information regarding the important explanatory variables for the selected literature and the significant outcomes are given in Table A1 in Annex A.

### 4.2. The sustainable RHS domain

The economic explanatory variables were important in the decision to adopt sustainable RHS in the papers analyzed in this study. Like in the solar PV domain, different costs are considered in the papers, such as annual cost of heating [29,30], investment cost [33], economic return on investment [32], and payback period [35].

But, along with cost, indoor air quality of the RHS chosen was also as important. The [17] found that after reduction of heating costs, the biggest motive for replacing or buying a new RHS was to improve indoor air quality, and improving local air quality also ranked higher than improving GHG emissions. This falls under the explanatory variable of GHG emissions/pollution reduction.

The EVC of household characteristics was given prominence in the domain of sustainable RHS, as opposed to the solar PV domain. Likewise, socio-demographics of the respondents and decision-makers also gained importance in the eyes of the researchers of the selected papers. There was significant correlation found between age of the decision-maker (or in the case of this domain, the house owner), the university degree, income and the presence of children and the chosen RHS [5,34]. There was a positive correlation noted between the age and the selection of oil based RHS reported by Ref. [16] in Germany. Likewise, age of the occupants also influenced their non-decision to change, especially if they could not recuperate their investment in their lifetime, as reported by Ref. [30]. So, this implied that older homeowners were likely to continue with their oil based RHS.

Likewise, all else being equal, one additional member in a house lead to an “oil and solid based” RHS as reported by Ref. [31], along with bigger houses likely to not be heated by electric heating (both heat pump and resistance heaters). For the adoption of New and Renewable Energy (NRE) Heating methods, such as ground heat pumps, the investment subsidies were important as found in both [16,35], which falls under the EVC of market and policy factors. Along with this, the availability of fuel, and supply of fuel were also important in the sustainable RHS domain, which falls under the market and policy factors explanatory variable category.

Another important aspect to note is that indoor air quality and heat related, and non-heat related comfort was ranked higher than the GHG emissions, in terms of motivating factor. There is also a difference between the adoption of RHS in rural and urban areas in southern Germany, as reported by Ref. [31].

There is no conclusive finding with regards to the peer and network effects in terms of the RHS, which fall under the EVC of social factors. While [29,34] find that information regarding the different RHS helps in adopting the sustainable RHS, there are some papers which dispute this with their findings. For example [38] reports that there is no significant switching probability related to peers and peer effects. Nonetheless, the positive effect of energy advisors on the non-adoption of resistance and oil-based RHS has been found in Refs. [16,38]. More information regarding the critical explanatory variables for the selected literature and the significant outcomes are given in Table A2 in Annex A.

### 4.3. The AFVs domain

The AFV domain is assessed through the 10 selected papers. We consider only two AFVs in the selection of papers, namely, Battery Electric Vehicles (BEVs) and biogas cars.

The EVC of economic factors consisted of upfront cost, and costs savings from AFVs, especially in the case of BEVs. But, in all the papers, these different costs have been considered in conjunction with the different subsidies and grants available in the different cases, which again reinforces the link the market and policy factors have with the economic factors. For example [42], has considered reduction of fixed costs and reduction of use costs as two dependent variables, with the investigated factors being different incentives such as exemption from purchase tax, exemption from Value Added Tax (VAT), vehicle license fee reduction, exemption from road tolling, free parking, bus lane access and free ferry tickets. Also, the [13] has listed the purchase price premium as a factor in their stated choice experiment, along with weekly fuel cost savings. In fact, the cost efficiency AFVs provide is cited as a motivation to adopting them in both [13,39] along with the environmental benefits. But, as mentioned before, the incentives play a big role in factors affecting the adoption. For example [42], found that for 80% of the adopters, incentives from purchase tax and VAT were important. But the same study for Norway, shows that 16% of the respondents found none of the incentives important.

But, in terms of the barrier to adoption, driving range and other technical specifications were a bigger reason than the premium price, which fall under the EVC of personal preference and usage, and specifically the explanatory variable of pattern of usage. For example, in Ref. [40] respondents said that the driving range was their biggest concern about adopting an BEV, followed by bigger cost and charging infrastructure or lack thereof. But in this case, the charging or fueling availability falls under the EVC of market and policy factors, since the inclusion of charging and fueling stations are influenced by the policies and market factors.

The household characteristics of the surveyed respondents are paid attention to in the selected papers, and the findings from these papers suggest that there is significant correlation towards the age, income, gender and university education of the decision-makers. The [39] finds that males between ages 40–45 are likely to adopt BEVs, and higher income and higher education also increase the likelihood of adoption. But, [40] found there is no significant relationship between income and interest in BEVs. In Ref. [13] the authors find in addition to being male and educated, the early adopters of BEVs have charging access at home and they tend to own their single family detached houses, compared to "mainstream" buyers, that is buyers who buy after the early adopters. While [44] finds that households with higher incomes are less sensitive to the price of BEVs, they also find that establishing charging stations is the most effective way of increasing the adoption of BEVs.

Additionally [43] divides the critical factors along three different stages in the decision-making process, one of which is the pre-actional stage. In this stage attitude and knowledge about the car were important factors. Also [45] found that users with greater affinity to BEVs were less likely to live in cities and had greater environmental awareness and had greater technical affinity as well. This is in conflict with the findings from Ref. [39], where they found that in Sweden, the three largest cities had higher adoption of BEVs. More information regarding the critical explanatory variables for the selected literature and the significant outcomes are given in Table A3 in Annex A.

## 5. Analysis and discussions

In this explorative study, we have not attempted to come to any quantitative conclusions regarding the explanatory variables and their significance to the household energy transitions processes. The main reason for this is the non-uniformity of the studies that were selected for the analysis. For example, in the solar PV domain, the study of [19] deals with responses of 1161 participants, while [23] deals with responses of 20 participants. It is not scientifically sound to quantitatively compare the outcomes from these studies with respect to the factors of energy transitions because they have very different study methods and sample sizes, not to mention different contexts of geographical location and method of analysis. No significant quantitative comparisons or conclusions can be made with realistic levels of confidence and hence we refrain from doing so.

At the same time, as we have noted before, even though the EVCs are delineated to give a structure to the analysis, in reality, even within our analysis we find that explanatory variables have connections, interactions and impacts on each other. While the EVC themselves have interactions with each other, as we have shown with the market and policy factors interacting with the economic factors, the individual explanatory variables also interact with other explanatory variables.

We think it is important to consider the impacts and connections these explanatory variables have with each other, even if not analytically, then at least conceptually. So, we propose a new conceptual framework to map the different explanatory variables covered in our study to overcome the differences in sample sizes, among others, and to conceptually visualize the connections between the explanatory variables.

### 5.1. The proposed conceptual framework to map the explanatory variables

Smith et al. [48] propose a systematic framework for understanding different transition contexts and associated governance implications. Their framework of regime transformation is a function of three factors. The latter two are: the degree to which the resources required for effective regime transformation are available either within or beyond the members of the incumbent regime; and the extent to which responses to these pressures are coordinated in a coherent fashion across the regime members. They go on to define transition contexts as a function of resource locus and the steering of adaptive response, to prescribe idealized transition contexts and, subsequently, the different types of governance of transitions.[1] Thus, the two extremes of resource locus are internal and external, and the two extremes of steering of adaptive response are high coordination and low coordination. Thus, if fitted in a horizontal and vertical axis, the transition contexts fall under four quadrants.

Smith et al. have used these definitions to formulate their framework for a multitude of reasons, some of which are: system level change is brought about by the coordination and steering of many actors and resources, so coordination and steering become important; the resources and sharing of resources is essential for system level change, and thus where the resources are located become vital.

We use the same logic to formulate our conceptual framework. The focus in this study has been household energy transitions, and thus, the household energy transitions are akin to transition contexts. We define the explanatory variables of the household energy transitions as being functions of locus of the variable and external influence on the variable.

Thus, our framework is built on the placement of the explanatory variables on these two axes. The first axis is the origin and situation of the explanatory variables, with respect to the household. The two extremities of this axis are "internal" and "external". For ease of analysis, this framework considers or places most factors on the two extremes. Thus, they can be considered as either "internal explanatory variable" or "external explanatory variable". The next axis on the framework is whether the variables are subject to change under external influence. This axis has two extremities, namely "not subject to change" and "subject to change". For the sake of clarity only the dichotomies (that is, internal and external, subject to change and not subject to change) are considered in this framework for now. The reason for formulating the framework this way is because these two measures represented in the axis are assumed to be important to the decision leading to the energy transition, as postulated by Smith et al. [48]. The origin or situation of the variable and how the variable changes under influence are important in understanding how the variable affects the decision-making in the energy transition process.

The linearized 2-dimensional representation of the framework is given in Fig. 1, stylized by us. Furthermore, the internal attributes can be divided into two categories based on whether they are subject to change under external influence. The internal variables which are not subject to change under external influence are named "intrinsic" variables in this framework. The internal attributes subject to change are given the same self-explanatory name.

The same division is done for the external factors as well. The external factors which are subject to change are termed "micro external factors" and external factors not subject to change under external influence are termed "macro external factors".

Here, the terms "micro" and "macro" need to be clearly identified and their boundaries and terms of reference need to be articulated. The terms micro and macro are entirely case-dependent, and are termed with respect to the scope of the analysis (or categorization). If the scope of the analysis were sub-national, then where the external influence comes from would determine if it is micro or macro influence. Whether the influence is micro and macro is also determined by whether the scope has any reciprocal impact on the influence.

The explanatory variables extracted from the papers and listed in Table 4 are mapped onto the matrix representation of the framework. The mapping is done by evaluating the said variables on where they fit in terms of the quadrants of Fig. 1.

The proposed conceptual framework (seen in Fig. 1), for lack of a better way of representation, are presented statically, but the maps do not necessarily remain static. In the domains chosen in our paper, some explanatory variables impact upon other variables, within the different categories. This creates dynamics within the different factors or even within the categories, which are ideally captured in a dynamic map

[1] Details of the quadrants, and the framework are given in Smith et al. [48].

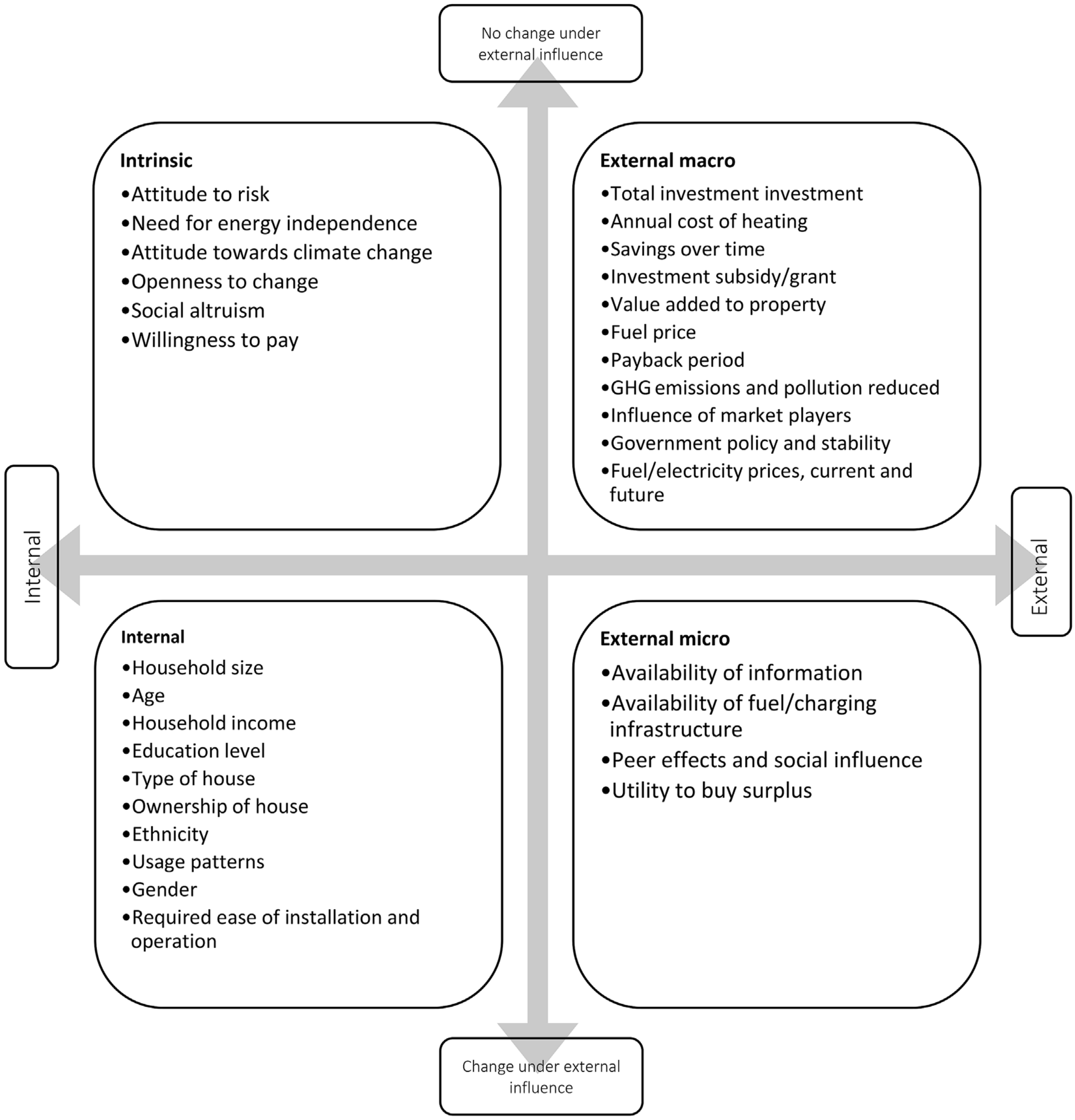


**Fig. 1.** The mapping of the explanatory variables on the proposed conceptual framework.

[49]. The same way, with time, the variables are expected to change places. Situating the identified variables on an axis with the locus determined by their place with respect to the household and the change experienced by external influence helps visualize and place the dynamics better than the categorizations conventionally preferred. This framework can be a useful starting point to building causal loop diagrams (CLDs) and for further studies, with respect to the impact on the behaviour of the variables with specific influences. An example of the dynamicity is how external micro and macro factors influence on the internal factors and shift them beneficially towards adoption. These dynamics will be useful to transitions policy-makers and even potential adopters to know.

Another necessity for such a descriptive framework is that it can act as a knowledge classificatory system in the context of household energy transitions, as shown in Ref. [50]. The authors have intentionally chosen the framework to be descriptive, rather than prescriptive (showing how it is done, rather than how it should be done, as detailed in Ref. [10]) to encourage the use of this framework to organize concepts around household energy transitions.

### *5.2. The commonalities and contrasts between the three domains as analyzed by the proposed conceptual framework*

This section delves deeper into the commonalities and contrasts touched briefly in the previous sections.

Firstly, even with specific local incentives identified, which is not present in the papers studied in the other two domains, none of the papers analyzed for the AFV example have investigated micro external explanatory variables such as peer effects or the availability of information (either through energy advisors or through local action). Given the extensive changes to the local landscape which will happen with the transition to the AFVs, such as charging infrastructure or new biogas filling station infrastructure, we would expect the consideration of peer effects, which are present in the other two domains. This opens new avenues of queries as to why the AFV transition studies lack this point of view. One reason could be that while the other two examples entail longer-term investments (average life of a solar PV panel and a heating system are in the order of 20–30 years), the investment in a car has a lower turnaround time. But, despite this, the infrastructure investments at a local and a national level for AFVs are still longer term and thus transitions to AFVs would entail similar considerations as the other two domains.

Another inexplicable finding from the comparison of the cases is the willingness-to-pay (WTP) studies done in both the solar PV and the AFV domain. The order of initial investment and the differential in the initial investment is of a similar order of magnitude for the acquisition of a solar PV panel and an AFV car, respectively. Yet, there are critical differences in the WTP of the two energy technologies. Findings from the papers show that in the case of the solar PV domain, the respondents are willing to pay about five times less than the actual price of the technology [28], where as they were willing to pay more for battery electric vehicles [47]. While the reason for this not apparent, it can be ventured that this disparity in the WTP could be because of certain intrinsic values of the respondents and how they view the two different transition technologies and the non-rationality aspect of decision-making when it comes to different energy transitions. Another hypothesis could be the perceived savings from running costs of AFVs is higher than the savings from solar PV panels, and thus the WTP is higher for AFVs, compared to solar PV.

Another commonality which should be noted is that the internal factors are the most in terms of numbers in all three domains. While this by itself is not a significant finding, it does lead to some interesting observations. If one discounts the cost factor, the most barriers also arise from internal explanatory variables. Simultaneously, certain variables, such as peer-effects and local information channels may be effectively used to dispel the barriers linked to internal factors such as required ease of installation and operation. There is evidence of this in the solar PV domain, as shown by Refs. [23,24]. Yet, there is ambiguity with regards to this in the sustainable RHS domain. While some studies note that the neighborhood peer-effects are important, some say there is no link between the rate of adoption and this. Governmental subsidies and grants, which fall under the external macro categories, are also generally effective in overcoming other external macro variables such as savings and costs.

## 6. Conclusion

We have looked at the explanatory variables investigated in the household energy transitions literature. We have analyzed papers which fall under three distinct domains of household energy transitions: (1) adoption of solar photovoltaic (PV) panels in households, (2) adoption/transition to sustainable residential heating systems (RHS) and (3) adoption/transition to alternative fuel vehicles (AFVs). The papers dealing with the three domains of energy transitions in the last 15 or so years have been selected and inductively analyzed.

In all three domains, the chosen literature employ a wide variety of quantitative analysis such as discrete choice models ranging from multinomial logit models and principal component analysis, to qualitative assessment of the answers through inductive analysis.

The explanatory variables are placed in six SEVC of economic factors, environmental factors, personal preferences and values, social factors, household characteristics, and market and policy factors. In total we identify 31 explanatory variables, falling under the six categories, which have been considered in the 38 selected papers.

In all three domains, economic factors are important. While in the solar PV domain, investment cost is the most important factor (barrier), in the sustainable RHS case, it is the investment cost and the household characteristics category, such as the variables house type, size of the house, household size etc. which are important. In the AFVs domain, along with investment cost, it is also the usage pattern explanatory variables, such as driving range and market and policy category variables, such as charging and refilling infrastructure that are important.

After our analysis, we surmise that explanatory variables have an impact on each other. Often these interactions are not captured in the literature. As a first step towards conceptually assessing the interactions between the explanatory variables, we propose a conceptual framework, whereby we place the explanatory variables according to their position in terms of their situation, with respect to the household (whether internal or external) and whether they are subject to change under external influence. Thus, the explanatory variables are divided as intrinsic, internal, external micro and external macro variables.

We find that household characteristics fall under internal variables, are highest in number, and are mostly applicable to the literature in the sustainable RHS and AFV domain. On the other hand, we also find that external macro variables such as subsidies and grants have an impact on initial investment costs. External micro variables such as peer-effects and available information also impact upon the internal variables such as need for ease of use and installation. We see the conceptual framework as the first step towards meaningfully analysing the interactions and feedbacks between the explanatory variables in household energy transitions and gaining a deeper understanding of the household energy transitions processes.

## Acknowledgements

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## Appendix A. List of explanatory variables for the three domains selected in this study

Table A.1
The list of explanatory variables in the solar PV case.

| | Title | Outcomes | List of critical factors |
|---|---|---|---|
| 1 | Consumer attitudes towards domestic solar power systems | Early adopters viewed payback period as a negative characteristic, implying it was high. The early majority cared and felt positively about the environmental aspects of the solar PV. The early majority also felt negatively about the grants. | The list of critical factors is taken from the pair-wise descriptors which are used by the authors.<br>1Economic factors - Generating savings, adding value to the property, affordable technology, grant availability, payback period, appreciating asset, improves the value of the house.<br>2Environmental factors: Clean, reduces carbon emissions, reduces pollution<br>3Social factors: safe form of power generation, widespread in the future, develop in the future<br>4Individual preferences: home improvement, maintenance free, attractive, simple to install, systems are hidden, effect on visual landscape, comprehensive solutions, acts all the time, provides a visual statement of beliefs |
| 2 | | | |

(continued on next page)

Table A.1 (*continued*)

| | Title | Outcomes | List of critical factors |
|---|---|---|---|
| | Explaining interest in adopting residential solar photovoltaic systems in the United States: Toward an integration of behavioral theories | The explaining effect of personal norms decrease as cost and other proximate factors become important.<br>•People higher in novelty seeking have higher chances of adopting.<br>•Environmentally minded households are prone to adopting it.<br>•Potential adopters need information from trusted sources, of the personal benefits of adopting solar PV.<br>•There are significant benefits to leveraging existing social networks to promote solar PV. | The factors critical to solar PV adoption can be explained in terms of Value-Belief-Norm:<br>The critical Values can be given as:<br>•Biospheric altruism,<br>•social altruism,<br>•self-interest,<br>•traditional values and<br>•openness to change<br>Awareness of consequences of climate change<br>Personal norms to act can also be a motive, on issues such as<br>•energy<br>•climate change.<br>Beliefs/Attitudes which are motives are<br>•personal benefits,<br>•relative advantage,<br>•environmental benefits,<br>•riskiness,<br>•cost concerns,<br>•trialability.<br>External influences are observability, PV marketing, trust in PV industry, and trust in social network. |
| 3 | Household level innovation diffusion model of photo-voltaic (PV) solar cells from stated preference data | The expected utility of a solar PV panel was closely related to the cost of installation, energy cost saving, increase in emissions, payback time, export reward (FIT) and inflation of fossil fuel and tax incentives.<br>Younger households with higher awareness and less sensitivity to price/cost are more likely to adopt.<br>There is also a positive impact on the energy cost saving, export reward and adoption rates through positive word of mouth (WOM). | Drivers:<br>1Cost related: Total initial investment including installation and connection to national grid & payback period<br>2Environmental benefits: Saving in carbon emission, energy cost saving<br>3Market development and policy: Tax incentives and grants, Export rewards as per micro-FIT program and possibility of government policy changes about green energy technologies<br>4Demand inducing: yearly inflation on fuel cost, % of local households already adopted one of these technologies. |
| 4 | Local factors driving the diffusion of solar photovoltaics in Sweden: A case study of five municipalities in an early market | Local channels of information were deemed slightly more important than common non-local information channels. In terms of the utilities and retailers, having a vision and ambition is important. | For private people and households:<br>1Local channels of information<br>2Peer-effects, both passive and active, also talking to people from PV retail outlets or utilities,<br>3Knowing someone personally, who is attached to a solar PV utility.<br>4Having a utility buy the surplus electricity.<br>5nformation meetings and seminars.<br>For utilities:<br>1Having a CEO with a clear vision,<br>2Having a salesman with good contacts to sell |
| 5 | Motivations and barriers associated with adopting microgeneration energy technologies in the UK | •Reducing the payback period is possible with Feed-In Tariff (FIT), increasing electricity and energy cost and reduced capital costs.<br>•Also, there is a gap between the levelized cost of electricity of solar PV and the willingness to pay (WTP) for solar PV electricity.<br>•Resale-ability of the house was a concern, the effect on property/house prices being ambiguous.<br>•The environment is normally the biggest reason for people investing in microgeneration, yet cost reasons trump the environmental benefits.<br>•Having an affinity towards innovative products and being seen as 'green' is also important for some people'.<br>•Security of supply - this relates to perceived self-sufficiency and being less susceptible to price fluctuations.<br>•Lack of confidence in the system's ability to perform as promised. Performance and reliability were significant barriers.<br>•The inconvenience caused by the major modifications needed to the electrical systems is a barrier. Of course, this can be overcome by warranties and other assurances.<br>•The negative impact on the residence and use of space.<br>•Also, there is no correlation with age and adoption of likelihood. But house ownership is a precursor to installing solar PV panels. | Barriers to adoption<br>1Upfront cost and payback period.<br>2Lack of confidence in the system's ability to perform as promised.<br>3The inconvenience caused by the major modifications needed to the electrical systems is a barrier.<br>4The negative impact on the residence and use of space.<br>Motivations for adoption<br>1The environment<br>2Security of supply - this relates to perceived self-sufficiency and being less susceptible to price fluctuations. |
| 6 | Motivators for adoption of photovoltaic systems at grid parity: A case study from Southern Germany | Since the FIT has decreased, the adoption has decreased, but it might pick-up with the subsidy scheme for storage batteries, thus providing the incentive to be self-sufficient.<br>Independence from utility and uncertainty regarding the increase in electricity prices are the main drivers for adopters | *List of critical factors (motivations) are separated into three categories.*<br>1Policy measures: The FIT, but since grid parity this is not the main motivation, and FIT has decreased. Also, the |

(*continued on next page*)

 

Table A.1 (*continued*)

| | Title | Outcomes | List of critical factors |
|---|---|---|---|
| | | adopting solar PV. Also, formal and informal peer effects play a role. The solar companies act as change agents, while providing effective communication and influencing the peer-effects as well. | expected higher electricity prizes. Subsidy schemes for batteries.<br>2Adopters: improved natural environment, and gain independence. Positive influence of peer effects. Protesting nuclear power.<br>3Local solar companies: acting as change agents and networking peer effects of solar companies, also providing effective communication |
| 7 | Motives for and barriers to household adoption of small-scale production of electricity: examples from Sweden | In the households that adopted the solar PV system, most did so that it gave them a 'good conscience'. The investment is symbolic, wanting to represent a 'green way of life', and an ecological lifestyle. The investment also makes sense since the adopters live in rural areas where self-production makes sense, financially.<br>For households still deliberating about the investment, the environmental aspect is central to their decision.<br>For households who rejected the adoption, the environmental reasons were important, but the barriers were too big, especially the financial barriers. | *Motives for adoption*<br>1Concern for the environment and lifestyle harmonization<br>2Own production to act and to set an example for others<br>3To protest energy companies or the "Big Brother" society<br>4Own production to become independent<br>5Financial reasons<br>6Technological reasons<br>*Barriers to adopting*<br>1Investment cost and production efficiency<br>2Grid companies and regulations as a hindrance<br>3Technology and installation |
| 8 | Peer effects in residential solar photovoltaics adoption—A mixed methods study of Swedish users | In Sweden, in the study conducted, the function of peer effects appears to have been a confirmation that it worked as it should, rather than give unexpected insights. Also, peer effects of friends are larger than with unknown neighbours. It has removed the barriers with respect to Trialability and low observability. Also, just seeing was less important for adoption than interpersonal contact. Thus, just seeing a solar PV panel did not lead to a non-user contacting a user. | *Significant number of people who had contacted neighbours who had PV felt that had reduced their uncertainty about buying solar PV.*<br>*It made them think that it was*<br>1technically reliable,<br>2gave a positive image of PV,<br>3it would work in Sweden's climate<br>4was a low-risk investment and 5. made them adopt it earlier than otherwise. |
| 9 | Prediction of photovoltaic and solar water heater diffusion and evaluation of promotion policies based on consumers' choices | Subjectively, people chose solar PV over solar heating systems.<br>Reducing the initial cost has a more profound effect on the WTP rather than reducing the operation and maintenance cost (through FIT). | List of critical factors examined<br>1initial installation cost<br>2subsidy for installation<br>3purchase rate of surplus electricity<br>4annual reduction of energy cost<br>5annual $CO_2$ emissions reduction<br>6number of installed units. |
| 10 | Photovoltaic diffusion from the bottom-up: Analytical investigation of critical factors | There is a clear distinction made by the founding members of the Bottom-up Initiative (BUI) and the energy experts as to which strength is important. Founding members say energy and climate benefits, whereas energy experts say financial attractiveness. | The Strength of PV BUIs:<br>1Financially attractive investment for participants,<br>2Contribution to environment and climate protection,<br>3Reduced dependence on imports of fossil fuels.<br>The Weaknesses of BUIs:<br>1Great effort regarding establishment of initiative,<br>2Uncertainty concerning the business model,<br>3Not economically viable without subsidies.<br>The Opportunities to BUIs:<br>1Further reduction of PV costs compared to other energy sources,<br>2Increasing awareness of PV BUIs among the population,<br>3increasing importance of PV BUIs in political strategies.<br>The Threats to BUIs:<br>1Resistance by the dominant players in the energy sector to transition to renewables,<br>2Uncertain economic and political conditions,<br>3Legal and financial uncertainties related to the electricity grid. |
| 11 | Residential consumers' experiences in the adoption and use of solar PV | •There was conscious and positive behavioural change in the lower FIT group.<br>•The environmental motivation was the least important reason. Economic motivators, and the money accruing or the benefit was the biggest reason.<br>•Communication channels, both formal and informal, were clear social motivators. | Motivations:<br>1Economic motivators: this was two-fold, both to save on the electricity bill as well as the FIT.<br>2Social motivators: information channels, both formal and informal (friends, relatives and family) played an important role. Formal channels consisted of advertising and information from well-established major utility firms.<br>3Environmental motivations: these were the least discussed.<br>4Behavioural change: in the people using different rates of FITs. |
| 12 | Stimulating the diffusion of photovoltaic systems: A behavioural perspective | •Reducing the complexity of the decision and expert-support at the decision-making stage are very important in increasing adoption.<br>•People in possession of a PV panel may function as advisors. Adopters of solar PV panels have higher education and a higher income than an average person. | Motives for purchasing a PV system<br>1 . Contribution to a better environment<br>2. Grant/subsidy<br>3. Increasing the value of my home<br>4. The central organisation of the request for the grant<br>5. Independence from electricity supplier<br>6. Discussion with other owners convincing |

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Table A.1 (*continued*)

| | Title | Outcomes | List of critical factors |
|---|---|---|---|
| | | •The adopters were very aware of the problem with respect to the environment, as opposed to an average person.<br>•Environmental benefits and grants were the most important motives for adoption, among the high involvement and low involvement group, respectively.<br>•The network effects were more important for the low involvement group.<br>•The info-meeting reduced the perception of technical barriers<br>•After the info meeting a significant sub-set of people changed their minds about the barrier of the solar PV installation.<br>•People who knew others with solar PV stated that was an important motivation for adopting as opposed to people who did not know anyone with solar PV.<br>•Information and instruction meetings had a strong positive effect on the diffusion of PV systems | 7. Decorative value of the house goes up 8. Neighbours buying PV systems<br>9. Technical support offered by the municipality |
| 13 | The adoption of PV in the Netherlands: A statistical analysis of adoption factors | •The adopters have higher income than the non-adopters.<br>•There is a higher probability of a stacked house occupant not adopting.<br>•House improvements and subsidies are decisive factors for adoption, along with stories from the media. For most non-adopters, the investment costs must drop significantly for them to consider adopting.<br>•Environmental benefits of solar energy are not a predictor of adoption.<br>•Social influence is not a significant factor for adoption.<br>•Knowledge of grants have a positive effect on the adoption. | Motives for adoption:<br>1savings on electricity bill,<br>2cost efficient system,<br>3self-sufficient,<br>4less environmental impact,<br>5quality of the system,<br>6innovative system,<br>7visual representation and 8. easy to install.<br>Barriers:<br>1. investment is too high,<br>2. not a home-owner,<br>3. energy yield is too low,<br>4. fear of gaining promised efficiency,<br>5. living in an apartment,<br>6. not interested,<br>7. difficult to install,<br>8. visual representation,<br>9. fear of subsidy adjustments,<br>10. plans to move.<br>Explanatory variables for adoption are classified as<br>•relative advantage,<br>•complexity,<br>•social influence, and<br>•knowledge about costs and grants. |
| 14 | The diffusion of microgeneration technologies – assessing the influence of perceived product characteristics on homeowners' willingness to pay | In the case of Solar PV: mean WTP was 6207,8 Euro which is significantly lower than the market price (at the time of publishing).<br>Also, the WTP is not based on rational decision-making, since the payback period is lower compared to solar thermal systems (which had a WTP which was closer to actual market price).<br>For solar PV, the independence matters more than the environmental benefits.<br>The habits and routines are not affected that much, but social risks are a problem but performance risk is not a problem.<br>Cost related to compatibility is not a problem either, complexity is not a problem either. | 1Perceived relative advantages: Environmental friendliness; independence<br>2Perceived compatibility: Habits and routines<br>3Perceived trialability<br>4Perceived complexity<br>5Perceived initial cost<br>6Compatibility-related costs<br>7Perceived Risk: social risk; performance risk<br>8Subjective norms and subjective knowledge.<br>Some other characteristics controlled are: age, gender, social class, type of house ownership, household size, region (urban or rural) and knowledge. |
| 15 | Willingness-to-pay for renewable energy: Primary and discretionary choice of British households for micro-generation technologies | The WTP for solar panels were almost five times less than actual capital costs. Also, consumers' time horizon for cost is generally 3 to 5 years. Consumers were WTP almost 3 Great British Pounds (GBP) in capital costs to reduce annual fuel bills by GBP 1.<br>Who suggested solar PV did not matter, but if two people (like friend, and plumber) were to suggest, then the likelihood increased significantly. | 1capital cost<br>2annual energy saving<br>3maintenance cost<br>4who was it recommended by. |

Table A.2
List of explanatory variables in the sustainable RHS case.

| Number | Title | Outcomes | List of critical factors |
|---|---|---|---|
| 1 | Adoption of innovative heating systems—needs and attitudes of Swedish homeowners | •Annual cost of heating increased in importance and was placed first as an attribute, followed by functional reliability and investment cost. | Attributes:<br>1.Annual cost of heating,<br>2.Functional reliability, |

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Table A.2 (*continued*)

| Number | Title | Outcomes | List of critical factors |
|---|---|---|---|
| | | •But, in the resurvey indoor air quality overtook investment cost and was in 3rd place.<br>•Also, GHG emissions, even though not that important, was given higher importance in the resurvey.<br>•In the baseline survey, respondents thought that oil boilers were the worst performing.<br>•In terms of socio-demographic factors, respondents in the age group 36-45 were likely to install a New and Renewable (NRE) heating system.<br>•With increasing age, they were less likely to install.<br>•Also, external factors such as investment subsidy, increased price of oil and electricity, and marketing campaigns has improved attitudes towards IHS. | 3.Investment cost,<br>4.Indoor air quality,<br>5.Security of fuel supply,<br>6.System automation,<br>7.Environmental benignity,<br>8.Increased market value of home,<br>9.Low GHG emissions,<br>10.Time to collect information |
| 2 | An adopter-centric approach to analyze the diffusion patterns of innovative residential heating systems in Sweden | •For the uptake of district heating and bed rock or ground heat pump, the investment subsidy was important. But people with resistance heaters said that the investment subsidy was of little importance.<br>•Older owners are less likely to install a new heating system if they do not expect to recoup the investment during their occupancy.<br>•As household income increases, the proportion of respondents planning on investing increases.<br>•Installers/vendors and interpersonal sources were the two most important sources of information.<br>•Heat pump and district heating would be the highest recommended types of heating systems.<br>•In terms of system related factors, annual cost of heating was the most important factor in both the baseline survey and the re-survey. Functional reliability was second, investment cost third and indoor air quality fourth.<br>•In terms of system related factors, heat pump was best for annual cost of heating, district heating was best for functional reliability, resistance heater was best for investment cost, and district heating was best for indoor air quality in the baseline survey.<br>•In the re-survey, heat pumps were best for indoor air quality. Also, heat pump was adjudged best for environmental benignity as well.<br>•For market value of a home, heat pump was best. | Sections questions were posed on,<br>Section A.<br>1.Satisfaction with the existing heating system,<br>2.plans for installing a new system,<br>3.sources of information,<br>4.the level of importance of the package offered by the municipality owned company and<br>5.the investment subsidy, and the type of system recommended.<br>Section B. Question relating to specific heating systems,<br>1.vendor availability,<br>2.monetary savings.<br>Section C. General importance of heating system-related factors:<br>1.annual energy cost of heating,<br>2.investment cost,<br>3.environmental benignity.<br>Section D. Importance of factors listed in Section C.<br>Section E. Questions on energy and environment.<br>Section F. Socio-economic variables.<br>System related factors (Section C, previously)<br>1.Annual cost of heating,<br>2.investment cost,<br>3.market value of the house,<br>4.technical/functional reliability,<br>5.level of comfort (indoor air quality/level of automation),<br>6.environmental benignity,<br>7.GHG emission,<br>8.security of fuel supply,<br>9.Time required to gather information. |
| 3 | Determinants of households' space heating type: A discrete choice analysis for German households | Dwelling attributes:<br>•it is an important determinant of residential heating type, except for electric heating, which can be explained by the fact that electric heating is very flexible.<br>•The period of building seems to affect most heating types, but not some.<br>•Gas is a more attractive option for row houses than detached houses, and the opposite is true of oil burners.<br>Household level variables:<br>•income significantly affects the heating appliance type. Its influence is positive on gas, but negative on oil, solid and "oil and solid" systems.<br>•An additional member significantly raises the probability of an "oil and solid" system, all else being equal.<br>•Electric heating is negatively related to larger households and small children. Higher education tends to pick gas.<br>Regional level variables:<br>•rural households are partial towards oil and solid systems.<br>•Also, negatively related to gas.<br>•In West Germany oil is less common and gas is a more common option, and vice versa for East Germany. | Building type:<br>1.What type of housing: detached houses and row houses.<br>2.Vintage class of house: before 1948, 1949 - 1971, 1972 - 1990 and 1991 - 2003.<br>Socio-economic effects:<br>1.Presence of a child,<br>2.educational attainment,<br>3.average household income. |
| 4 | Diffusion of renewable heating technologies in households. Experiences from the Norwegian Household Subsidy Programme | •The only economic variable with significance was the price for electricity, which indirectly influences the return on investment.<br>•A strong significance was found on the technical quality of the product.<br>•A positive relationship was found between indoor air quality and positive perception about the investment. | Independent variables:<br>Technical use-related variables:<br>1.comprehensive evaluation of the technical quality of equipment;<br>2.satisfaction with service and availability from vendor;<br>Economic and market conditions:<br>1.economic return, on investment<br>2.electricity price,<br>3.ease of access to wood pellets, |

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Table A.2 (*continued*)

| Number | Title | Outcomes | List of critical factors |
| --- | --- | --- | --- |
| | | | 4.perception of actual price of pellets compared to the expected price<br>Attitudes, norms, motivations for investment:<br>1.want to reduce expenses for electricity,<br>2.contribute to reduced national electricity use,<br>3.contribute to more sustainable energy use,<br>4.want to try out new heating technology,<br>5.possibility of receiving a subsidy,<br>6.improve indoor climate, improve heating comfort,<br>7.recommended by a friend or colleague,<br>8.technical interest, and<br>9.environmental consciousness.<br>Reported/perceived indoor environment and heat comfort:<br>1.heat comfort,<br>2.non-heat comfort,<br>3.cleanliness,<br>4.evaluation of indoor climate and heat comfort after installation.<br>Demographical factors:<br>1.income,<br>2.education, number of persons in household,<br>3.gender of respondent.<br>The house related factors:<br>1.living area in square meter,<br>2.single or multiunit. |
| 5 | Homeowners' preferences for adopting innovative residential heating systems: A discrete choice analysis for Germany | •Socio-demographic variables are important determinants, especially income, age and university degree.<br>•Income is positively correlated to gas with solar thermal RHSs and heat pumps, while negatively correlated to oil with solar thermal RHSs and wood pellet RHSs.<br>•Age is positively correlated with oil, so that older respondents prefer oil as opposed to gas.<br>•Home characteristics are also important, as newer homes have gas-fired RHS, while the probability of oil-fired and solid fuel RHS are higher in older homes.<br>•Home size is important.<br>•Also, having spoken with energy consultants has a negative correlation with oil-fired RHS. Spatial characteristics are found to be highly significant too.<br>•In terms of RHS-specific attributes, the grant has a positive impact on wood pellet RHS and negative impact on heat pumps.<br>•It seems that respondents include or exclude certain costs in their decision-making process.<br>•There is also evidence that homeowners stick to an RHS system they know already. Also, they are resistant to changing their habits and behaviours. | Explanatory variables:<br>Socio-demographic:<br>1.age,<br>2.household income,<br>3.educational status,<br>4.family size,<br>5.children present in the house.<br>Home characteristics:<br>1.floor size,<br>2.vintage class,<br>3.home type,<br>4.available infrastructure; spatial characteristics:<br>1.administrative unit,<br>2.urban/rural,<br>3.climate zone,<br>4.east/west Germany,<br>5.north/south Germany;<br>RHS-specific attributes:<br>1.environmental benefits,<br>2.comfort,<br>3.energy supply security,<br>4.recommendation,<br>5.cost aspects,<br>6.financial grant. |
| 6 | House owners' perceptions and factors influencing their choice of specific heating systems in Germany | Unimportant/insignificant factors in experience of the product:<br>•Ecology,<br>•supply of the fuel,<br>•information,<br>•individual contact, and •kind of fuel. | Characteristics of consumer:<br>1.ecological attitude (determined as 5 cluster groups),<br>2.experience of the product (before and after purchase, through Principal Component Analysis;<br>Before purchase factors:<br>1.kind of fuel,<br>2.delivery of fuel,<br>3.information,<br>4.comfort,<br>5.economy,<br>6.subsidies and ecology;<br>After purchase factors:<br>1.convenience,<br>2.supply of the fuel,<br>Purchase risk (measured as the number of information sources),<br>Socio-demographic factors<br>1.size of household,<br>2.number of children,<br>3.age,<br>4.education,<br>5.monthly income<br>The kind of product is measured through characteristics of the product (measured as a quotient) and consumers' evaluation of different quality (measured for NG, crude oil, |

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Table A.2 (*continued*)

| Number | Title | Outcomes | List of critical factors |
|---|---|---|---|
| | | | electricity, firewood, wood pellets and for price estimations of these energy sources).<br>Situational conditions such as social surroundings through heating system of the neighbour, and opinion of family members are critical factors as well. |
| 7 | Household preferences of hybrid home heating systems – A choice experiment application | •Respondents favoured ground heat and district heat over other systems.<br>•The interaction between household income and choice of system were significant.<br>•The choice of ground heat pumps was higher with higher income.<br>•Higher age levels increase the choice of electric storage systems. | The list of critical factors in the choice experiment:<br>1.the type of supplementary heating systems,<br>2.investment cost,<br>3.operating cost including annual electricity/fuel consumption and maintenance costs,<br>4.comfort of use (effort needed for faultless operation),<br>5.environmental friendliness.<br>Also, controlled for some socio-demographic factors such as:<br>1.age,<br>2.household size,<br>3.gender,<br>4.household's income,<br>5.education,<br>6.living environments (urban or rural),<br>7.whether a forest is owned. |
| 8 | Households' heating investments: The effect of motives and attitudes on choice of equipment | The motives for heating investment:<br>•To reduce heating costs<br>•to improve indoor air quality,<br>•to replace broken appliance,<br>•to modernize equipment,<br>•to save time and effort in heating,<br>•to improve local air quality,<br>•to reduce GHG emissions,<br>•the previous one did not look good,<br>•to increase house sale value. | Perspectives and attributes on:<br>1.appearance,<br>2.efficiency,<br>3.cost,<br>4.time to operate,<br>5.environmental impact |
| 9 | Influencing Swedish homeowners to adopt district heating system | 1.The marketing campaign and the package offered by the company, and the investment subsidy were effective in creating a need for a IHS.<br>2.There is significant negative relationship between the age and investment decision. The respondents of age group 36-45 were most likely to invest.<br>3.As household income increases, the probability of investing in an IHS increases, in the initial survey, but no such correlation in the baseline survey.<br>4.In the baseline survey, installers and vendors were the most important source of information, along with interpersonal sources. In the re-survey, as well. Also, information meetings and house visits were important as well.<br>5. In the baseline survey, order of decreasing importancea. annual cost of heating,b. investment cost,c. functional reliability,d. indoor air quality.<br>But in the resurvey, investment cost lost importance, and indoor air quality gained importance. Also, system automation and GHG emissions also gained importance. | Section A.<br>1.Satisfaction with the existing heating system,<br>2.plans for installing a new system,<br>3.sources of information,<br>4.the level of importance of the package offered by the municipality owned company and the investment subsidy, and<br>5.the type of system recommended.<br>Section B. Question relating to specific heating systems,<br>1.vendor availability,<br>2.monetary savings.<br>Section D. Importance of factors listed in Section C.<br>Section E. Questions on energy and environment.<br>Section F. Socio-economic variables.<br>System related factors (Section C, previously)<br>1.annual cost of heating,<br>2.investment cost,<br>3.market value of the house,<br>4.technical/functional reliability,<br>5.level of comfort (indoor air quality/level of automation),<br>6.environmental benignity,<br>7.GHG emission,<br>8.security of fuel supply,<br>9.Time required to gather information. |
| 10 | Motivational factors influencing the homeowners' decisions between residential heating systems: An empirical analysis for Germany | •Wood pellet adopters care more about cost, and gas-ST care less.<br>•Newly built houses care less, but bigger homes care more about costs.<br>•General attitude is similar across all adopters.<br>•The grants were important for Oil with ST and wood pellets.<br>•Threats from outside feature prominently among the Renewable Heating System (RHS) adopters.<br>•Adopters of newly built homes care about ease of use and comfort than already existing homes. The influence of peers is not significant. | **Adoption motivations**<br>***Cost aspects***<br>1.total costs,<br>2.current fuel price,<br>3.expectations of future fuel price,<br>4.maintenance costs,<br>5.expected payback period,<br>6.initial purchase cost<br>***General attitude towards the RHS***<br>1.Quickness of getting accustomed<br>2.comparative advantage,<br>3.giving recommendations,<br>4.extra work<br>5.ease of use,<br>***Government grant***<br>1.grant availability,<br>2.possibility of non-availability<br>***Reactions to external threats*** |

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Table A.2 (*continued*)

| Number | Title | Outcomes | List of critical factors |
|---|---|---|---|
| | | | 1.environmental or energy supply security considerations,<br>2.independence from fluctuating fuel prices,<br>***Comfort considerations***<br>1.low effort with fuel acquisition,<br>2.low maintenance requirements,<br>3.improvement in home value<br>***Influence of peers***<br>1.number of people known with similar RHS,<br>2.recognition from others,<br>3.other peoples' influence,<br>4.opinion of peers |
| 11 | No pipes in my backyard? Preferences for local district heating network design in Germany | •The energy source was the most important attribute, regardless of the pricing, followed by geographical network design and finally security of supply.<br>•When costs were not considered, biogas and geothermal heat were preferred energy sources.<br>•When costs were considered geothermal became preferred, and NG was preferred over biomass.<br>•Overall high security of supply was preferred and mixed structure was preferred in the network design. | For the focus group discussion:<br>Costs<br>1.investment and maintenance costs and<br>2.supply security related to prices and costs in the future,<br>•environmental factors such the possible use of multiple renewable energy sources,<br>•network design, such as the time it would take to install the pipes in the backyard,<br>•trust and maturity of technology,<br>Another issue discussed was community and organizational factors. For the conjoint analysis:<br>1.geographical network design,<br>2.security of supply<br>3.energy source<br>All three attributes were also assigned a cost factor (investment, maintenance and operating costs). |
| 12 | Stated preferences of Finnish private homeowners for residential heating systems: A discrete choice experiment | •Investment and annual operating costs are statistically significant factors for all heating systems.<br>•The required effort parameter only affects solid-wood fired systems.<br>•The choice of wood pellet heating decreased with respondent's increasing age. | The pre-determined attributes:<br>1.investment cost<br>2.annual operating cost<br>3.CO2 emissions,<br>4.fine particle emissions<br>5.required own work. |
| 13 | Switching from fossil fuel to renewables in residential heating systems: An empirical study of homeowners' decisions in Germany | •The motivation to deal with external threats like independence from fossil fuels and environmental contribution, and RHS related knowledge are significant drivers for the change.<br>•A higher preference for comfort makes the homeowner stick to fossil fuel RHS. Also, if the current status quo is to be maintained, then change to renewable RHS is low. Thus, homeowners are likely to stick to a system.<br>•No statistically significant results for grant, and peers.<br>•The size of the house has a positive effect on the switching probability. Home-age has a negative effect on the same probability.<br>•Homes in rural areas and south of Germany are more likely to switch. The socio-economic characteristics are less relevant for the switch to renewable RHS.<br>•Reasons for non-adoption: Homeowners don't switch to oil/gas with solar thermal support because of the dependence on oil/gas. Also, high fuel costs and total costs. Resistance factors not connected to this only play a minor role.<br>•The barriers against HPs are psychological barriers, where they feel they can't get used to the habit/norm. Also, lack or confusion about the technical knowledge, they confuse it with electric resistance heaters. Also, energy advisors' advice against this system.<br>•For wood pellet RHS, functional barriers related to usage and risk. This includes the lack of necessary skills. Also, high in effort and maintenance costs. | Motives:<br>Socio-demographic characteristics:<br>1.income,<br>2.age (age of the homeowner),<br>3.university (whether the owner has a university degree),<br>4.female (homeowner is female);<br>Attributes of the home:<br>1.size,<br>2.age of the home,<br>3.whether a parallel retrofit was done,<br>4.which region of Germany;<br>Motivational factors and knowledge:<br>1.cost considerations,<br>2.status quo (present situation)<br>3.perceived compatibility with ease of use,<br>4.habits, norms and ability to understand,<br>5.relevance of the capital grant,<br>6.reaction to (threats) such as environmental protection and independence from fossil fuels.,<br>7.comfort considerations,<br>8.influence of peers, and RHS-related knowledge.<br>Barriers: Functional barriers:<br>1.ease of use, ease of explanation to others,<br>2.low effort,<br>3.eco-friendly RHS,<br>4.low energy consumption,<br>5.more independent from oil and NG,<br>6.investment cost of RHS,<br>7.price after the grant,<br>8.maintenance costs,<br>9.current fuel price,<br>10.expected future fuel price,<br>11.total cost of the RHS,<br>12.regulatory constraints,<br>13.constraints related to the property,<br>14.infrastructural constraints,<br>15.financial scope for RHS,<br>16.payback period,<br>17.low fault liability;<br>Functional barriers: Changing habits, advice from peers, advice from experts. |

Table A.3
List of explanatory variables in the AFVs case.

| Number | Title | Outcomes | List of critical factors |
|---|---|---|---|
| 1 | Adoption barriers for electric vehicles: Experiences from early adopters in Sweden | Outcomes of socio-demographic characteristics:<br>•mostly male between the ages of 40-45 with a predominant right-skew towards younger ages have AFVs<br>•higher income is reported along with higher levels of education.<br>•mostly families with 2 kids or 4 kids use EVs.<br>•Stockholm, Goteborg and Skåne have higher ownership of electric vehicles.<br>Secondly, outcomes of the questions about the EV drivers' motivations:<br>•most of the EVs are used for personal travel.<br>•most of the owners of EVs had two cars in their household, but most said that they would definitely consider using only the EV in the future.<br>•most are satisfied with their EVs as well.<br>With regards to motivation to buy:<br>•regardless of the gender, environment and cost efficiency was chosen as the two main reasons.<br>Driving patterns:<br>•mostly reported driving distance is between 30 to 100 kms a day.<br>•the mostly used charging location was home.<br>•majority of the car owners charge their cars during night time. | Questions were posed along four main themes.<br>Personal and household characteristics:<br>1.age,<br>2.gender,<br>3.place of living,<br>4.type of home,<br>5.composition of the household (number of children and ages)<br>6.educational level of the members and average income<br>***EV drivers' motivation***<br>Main reason for purchasing the electric vehicle a. environment<br>b.cost efficiency<br>c.safety,<br>d.design,<br>e.incentives,<br>f.others (new design and technology)<br>3.is the EV used as main vehicle or a secondary vehicle?<br>4.if they have an ICE vehicle, will they consider using the EV in the future,<br>5.what is the main use of the EV,<br>6.level of satisfaction with their EV<br>7.the way the EV users pay for charging.<br>***Driving and charging patterns:***<br>1.driving distance per day;<br>2.what time of the day is the vehicle charged,<br>3.typical place of charging,<br>4.what are the improvement suggested for the driving infrastructure? |
| 2 | Barriers to wide spread adoption of electric vehicles: An analysis of consumer attitudes and perceptions | •Males have had more experience with EVs than females, on average.<br>•There were significant differences in interests in EVs based on gender, education and age.<br>•There were no statistically significant differences in interest based on income.<br>•Most associations with EVs were about environment, battery performance and charging, efficiency, high purchase cost, fossil fuels, alternative energy and the future, in that order.<br>•Battery range limitation was cited as the biggest concern, followed by high cost and charging infrastructure.<br>•There is a lack of understanding of safety of EVs among the respondents. | Survey consisted of 4 parts:<br>Part 1:<br>1.gender,<br>2.age,<br>3.ethnicity,<br>4.occupation,<br>5.education and<br>6. household income,<br>Part 2: Perceptions and attitudes towards EV attributes:<br>1.decrease/eliminate use of gasoline,<br>2.less maintenance,<br>3.less emissions,<br>4.looks/style, comfort;<br>Part 3: Environmental and sustainability issues perceptions<br>Part 4: Changes desired in the EV technology regarding biggest concerns:<br>1.high cost,<br>2.battery range,<br>3.safety,<br>4.reliability,<br>5.charging infrastructure. |
| 3 | Effectiveness of incentives on electric vehicle adoption in Norway | •The regional sales per capita data have a good fit with the chosen independent variables, but the municipal data do not have such a good fit and are more complex.<br>•The tolls and bus lanes were not very significant, and there was some correlation between the number of charging stations in the private EV sales data.<br>•In terms of municipal level sales data, the number of vehicle kilometers (kms) travelled has a significant effect on the EVs sold. If the car travels higher than 100 kms, then the possibility of EV sales goes down, in that municipality. | List of critical factors includes the three local incentives that are assessed:<br>1.toll roads,<br>2.proximity to a city and<br>3. bus lane availability.<br>Along with this,<br>1.the area's unemployment rate,<br>2.median household income,<br>3.average vehicle kms travelled,<br>4.number of EV charging stations,<br>5.the presence of tolls,<br>6.the presence of bus lanes,<br>7.and the area bordered by a major city (the last 3 as a binary). |
| 4 | How might potential future plug-in electric vehicle buyers differ from current "Pioneer" owners? | •The pioneers are male, educated, and have more charging access at home, tend to own their single family detached houses, compared to mainstream buyers. | List of factors in the PEV state choice experiment:<br>1.purchase price premium, |

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Table A.3 (*continued*)

| Number | Title | Outcomes | List of critical factors |
| --- | --- | --- | --- |
| | | •The pioneers have more familiarity with a variety of plug-in electric vehicle (PEV) cars, compared to the mainstream buyers.<br>•The pioneers prefer Battery electric vehicles (BEVs), but the mainstream buyers prefer plug-in hybrid electric vehicles (PHEV) and PEVs.<br>•In the multinomial logit model, it was revealed that among the mainstream buyers, BEV was the least preferred vehicle.<br>•The mainstream buyers are willing to pay an extra 744 Canadian dollars (CAD) for a PHEV but would have to be compensated over 10 000 CAD to purchase a BEV. But with Level 2 home charging access, they are willing to pay CAD 3 311 for a PEV.<br>•Outcomes show that the Pioneers are more open, more altruistic and less egoistic than the early and late mainstream buyers. The early and late mainstream buyers have more in common with each other than with the pioneers. | 2.weekly fuel cost (savings),<br>3.electric-driving range,<br>4. home recharge access, and<br>5. recharge time.<br>Along with this,<br>1.environmental friendliness of the respondent,<br>2.technology orientation,<br>3. lifestyle choices and<br>4. environmental concern (using New Environmental Paradigm scale) |
| 5 | Incentives for promoting Battery Electric Vehicle (BEV) adoption in Norway | •Results show that incentives from purchase tax and VAT are critical for the purchase decision for more than 80%.<br>•Exemption from road tolling and reducing the vehicle licensing are critical to half the sample and the rest of the incentives are critical only to particular samples.<br>•Significantly, 16% of the respondents find none of these incentives critical.<br>•Men, likely above 45 respond to RFC. Also, the primary targets live outside the city.<br>● Also, income levels do not predict belonging to this group RFC. RUC influence people with a college degree lower income groups and respondents living in or near the city of Trondheim. | This study investigates 7 different incentives:<br>1. exemption from purchase tax,<br>2. exemption from VAT,<br>3. vehicle license fee reduction,<br>4. exemption from road tolling,<br>5. free parking,<br>6. bus lane access and<br>7. free ferry tickets.<br>In the regression analysis, dependent variables are:<br>1. reduction of fixed costs (RFC),<br>2. reduction of use costs (RUC) and<br>3. priority to infrastructure (bus lane) (PRI).<br>Independent variables are:<br>1. gender,<br>2. age,<br>3. education,<br>4. personal income,<br>5. place of residency, and<br>6. recent ownership. |
| 6 | The dynamics of purchasing an electric vehicle – A prospective longitudinal study of the decision-making process | ● Goal intention is influenced the most by positive emotions and awareness of need.<br>● Behavioural intention is influenced the most by attitude and knowledge about car types.<br>● Planning ability influences the most in the actional stage. | Critical factors can be gauged per the three different stages: ***pre-decisional; people in this stage were asked questions about their:***<br>1. goal intention,<br>2. positive emotions,<br>3. personal norm,<br>4. social norm<br>5. responsibility<br>6. awareness of need,<br>***Pre-actional; people in this stage were asked questions about***<br>1. behavioural intention<br>2. attitude,<br>3. perceived behavioural control,<br>4. knowledge about electric car models.<br>***Actional stage questions were***<br>1. implementation intention,<br>2. planning ability,<br>3. knowledge about car availability. |
| 7 | The impact of car specifications, prices and incentives for battery electric vehicles in Norway: Choices of heterogeneous consumers | ● Higher Battery Electric Vehicles (BEV) prices may hinder adoption but not significantly.<br>● BEV technology improvements correlates positively with BEV adoption.<br>● Consumers with higher income tend to be less price-sensitive.<br>● The heterogenous weight of toll waivers and charging stations is higher than bus lane access.<br>● Bus lane access is significant only in 25 municipalities.<br>● Establishing charging stations is the most efficient way of increasing BEV adoption. | The hypothesis is that BEV consumers make choices of BEV products based on individual utilities that consist of three parts:<br>● utility of product specifications,<br>● utility of money and<br>● utility of municipal incentives.<br>1. Utility of product specification is given by vehicle technology,<br>2. utility of money is given by price and<br>3. municipal incentives are given by bus lane access, toll waiver, charging stations, and personal feature is given by income. |
| 8 | Who will buy electric vehicles? Identifying early adopters in Germany | ● Users with greater affinity to EVs are less likely to live in cities.<br>● Actual users and users likely to buy are male, live in smaller towns and multi-person households and work full time.<br>● Attitudinally, people with affinity towards EVs stated that it was important for them to drive a car less impactful to the environment. Also, they have more technological affinity to innovations and give less importance to comfort. | Socio-economic variables:<br>1. gender,<br>2. age,<br>3. education,<br>4. income,<br>5. household size,<br>6. location.<br>Attitudinal variables: |

(*continued on next page*)

Table A.3 (*continued*)

| Number | Title | Outcomes | List of critical factors |
|---|---|---|---|
| | | | 1. environmental awareness,<br>2. technical affinity,<br>3. and attitudes towards the symbolic meaning of electric cars and cars with other propulsion technologies. |
| 9 | Willingness to pay for electric vehicles and their attributes | The variables increasing the chances of orientation of EV:<br>● being younger or middle age,<br>● having a college degree or higher,<br>● expecting higher gasoline prices in the next 5 years,<br>● having made a shopping or lifestyle change to help the environment in the last 5 years,<br>● likely to buy a hybrid vehicle in the next purchase,<br>● having a place to install an EV electrical outlet at home,<br>● likely to buy a small or medium sized car on their next purchase,<br>● having a tendency to buy new products that come to the market,<br>● taking at least one driver per month longer than 100 miles.<br>Driving range, fuel cost savings and charging time lead in importance to respondents. | Questions on four categories:<br>1. background questions on car ownership and driving habits,<br>2. description of conventional EVs followed by two choice questions,<br>3. description of vehicle-to-grid EV followed by two choice questions,<br>4. series of attitudinal and demographic questions.<br>The attributes tested in the choice experiment are:<br>1. price relative to your preferred GV,<br>2. driving range on full battery,<br>3. time it takes to charge battery for 50 miles of driving range,<br>4. acceleration preferred to your preferred GV,<br>5. pollution relative to your preferred GV,<br>6. fuel cost. |
| 10 | Willingness-to-pay for alternative fuel vehicle characteristics: A stated choice study for Germany | There are six classes of consumers with varying degrees of importance given to the different motivational factors.<br>The six groups are:<br>**AFV aficionado** who are partial to the AFVs, compared to the other classes. The charging time and incentives show a moderate impact on them.<br>**Car dependents** who are older less environmentally aware more educated buyers of bigger cars, and have stronger preference for larger driving range, larger fuel availability and shorter recharging time.<br>**Fuel cost savers** for whom fuels costs are more important, along with purchase price, CO2 emissions and driving range and non-monetary incentives.<br>**CFV (conventional fuel vehicle) buyers** are more swayed by government incentives.<br>**PHEV enthusiasts** prefer mostly PHEVs.<br>**Purchase price sensitives** who are persuaded by the purchase price.<br>Willingness to pay (WTP) individuals are willing to spend Euros 1056 for a fuel cost reduction of 1 Euro per 100 km, euros 7175 and euros 5925 for a vehicle tax exemption and the permission to use bus lanes and park free of charge, respectively.<br>Also, pay between euros 14 to 1432 for the abatement of 1% of the vehicles CO2 emissions, euros 12 to 25 for an additional km of driving range, euros 60 to 296 for increasing fuel availability by 1%, and between euros 5 to 194 for one minute shortening of the battery recharging time. | Important features:<br>1. purchase price<br>2. fuel cost,<br>3. $CO_2$ emissions,<br>4. driving range,<br>5. fuel availability,<br>6. refueling time,<br>7. battery recharging time,<br>8. policy incentives (1. no vehicle tax, 2. free parking and use of bus lanes) |

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