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Household Valuation of Electricity Attributes: Theory, Meta-analysis and Experimental Approaches

Adrián Ruiz Carvajal

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Adrián Ruiz Carvajal. Household Valuation of Electricity Attributes: Theory, Meta-analysis and Experimental Approaches. Economics and Finance. Université Grenoble Alpes [2020-..], 2022. English. NNT : 2022GRALE005 . tel-04089384

HAL Id: tel-04089384

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THÈSE

Pour obtenir le grade de

DOCTEUR DE LA COMMUNAUTÉ UNIVERSITÉ GRENOBLE ALPES

Spécialité : **Sciences économiques**

Arrêté ministériel : 25 mai 2016

Présentée par

Adrián RUIZ CARVAJAL

Thèse dirigée par **Stéphane ROBIN**

préparée au sein du **Laboratoire de'Économie Appliquée de
Grenoble**

dans l'**École Doctorale Sciences Economiques**

Household Valuation of Electricity Attributes : Theory, Meta-analysis and Experimental Approaches

Thèse soutenue publiquement le **10 octobre 2022**
devant le jury composé de :

Monsieur Cédric CLASTRES

Professeur des Universités, Université Grenoble Alpes (Président)

Madame Rodica LOISEL

Maître de Conférences HDR, IAE Nantes (Rapporteur)

Monsieur Yannick PEREZ

Professeur, CentraleSupélec, Université Paris-Saclay (Rapporteur)

Madame Valérie LESGARDS

Economiste, Electricité de France (Membre)

Monsieur Stéphane ROBIN

Chargé de recherche CNRS, Université Grenoble Alpes (Membre)



Remerciements

Je remercie chaleureusement mon directeur de thèse, Stéphane Robin, qui a été le premier à accepter ma proposition de recherche et m'a aidé à réussir ce projet dans l'académique et le personnel.

Je tiens à remercier aussi le jury, notamment Rodica Loisel et Yannick Perez pour avoir accepté d'être rapporteurs, Cédric Clastres et Frédéric Wurtz pour leurs commentaires à ce travail, et spécialement à Valérie Lesgards pour ses suggestions inestimables à la conception de l'expérience de terrain.

Je voudrais ensuite remercier les membres de l'association bien organisée des doctorants en économie de Grenoble Alpes (Labodega) qui m'ont donné leur vote de confiance et ont contribué aux activités de l'association : Rim Rejeb, Nahed Eddai, Luciana Braga, Rosy Fares et Paul Bettega.

Je remercie également tous les membres du GAEL qui m'ont assisté à surmonter les obstacles du quotidien, spécialement Céline Rival, Aurélie Level et Margaux Sinceux.

Je remercie enfin mes amis doctorants - et maintenant docteurs - qui m'ont aidé et fait compagnie pendant ce temps : Rim Rejeb (encore une fois), Luis Estevez, Wil Mournier et Penny Buckley.



Acknowledgements

I wish to take this opportunity to express my gratitude to my wife, without whose support and patience this work would not have been possible, and my three daughters who have been a continuing source of joy and exhaustion. To my mother for encouraging me to study a doctorate regardless of age or family responsibilities, and also my two brothers who have assisted in my absence.

My gratitude to the National Council for Science and Technology (*Consejo Nacional de Ciencia y Tecnología, Conacyt*) of the Mexican government, which granted – and extended – the scholarship that made these doctoral studies possible.

And because nobody can succeed alone, my gratitude to the three professors who provided letters of recommendation for this research: Hernando Romero Paredes Rubio (*Universidad Autónoma Metropolitana – Iztapalapa*), Augusto Sánchez Cifuentes (*Facultad de Ingeniería, UNAM*) and José Horacio Tovar Hernández (*Instituto Tecnológico de Morelia*). And to those that ignored my request: M. Kuhndt and R. R. Mazzoco.

Abstract

Accelerating the transition toward renewable energy sources is widely believed to be essential to mitigate greenhouse gas emissions, local air pollution and other negative environmental and social impacts. The residential sector plays an essential role as the largest electricity consumer in many countries and a bellwether of economic and social stability, yet despite the entry of numerous new 'green' electricity suppliers into the market its uptake continues to fall short of national and international targets. This thesis examines the preferences of households regarding different 'types' of electricity based on their hedonic attributes, which by definition cannot be observed nor measured at the point of consumption.

The thesis is divided into four chapters, each of which treats a different aspect of electricity valuation. The first chapter explores how individuals make decisions to better understand *why* they value some attributes more than others. This review of theories and models from various disciplines intends to bridge the shortcomings of neoclassical economics, which has struggled to explain altruistic behavior or consider the fact that much behavior is irrational, detrimental to the individual or simply driven by emotion or habit. A scheme is also presented to suggest how the various models from neoclassical and behavioral economics to psychology and sociology can complement one another.

The second chapter presents the results of a discrete choice experiment to elicit individual preferences when choosing between different types of electricity and modes of supply. Installing a solar photovoltaic (PV) system, joining an energy community, consuming higher shares of green electricity and having more self-sufficiency were all deemed to be desirable characteristics that commanded a price premium, whereas increasing the share of electricity that is sourced locally appeared to carry a penalty. This is by no means the first study that has found negative values for certain hedonic attributes, as is explained in the following chapter.

The third chapter shows how this experiment is but one among many, and conducts a meta-analysis of willingness to pay (WTP) for green electricity to lend coherence to the otherwise disparate findings in the literature. No survey-specific variable or group of variables was found to produce consistently accurate predictions of WTP across different countries and years, despite numerous attempts to fit the data using different models. Nevertheless, random effects models performed better than fixed effects models overall, suggesting that the results reported in the literature reflect a diversity of underlying true preferences.

Finally, the fourth chapter provides an example of how the individual surplus associated to the consumption of hedonic attributes can be pooled and shared within an energy community, a novel structure that allows households to capture more of the value of distributed energy resources.

Together, these four chapters present a coherent narrative of the present, past and future of hedonic attribute valuation in the electricity sector.

Résumé

L'accélération de la transition vers des sources d'énergie renouvelables est largement considérée comme essentielle pour atténuer les émissions de gaz à effet de serre, la pollution atmosphérique locale et d'autres impacts environnementaux et sociaux négatifs. Le secteur résidentiel joue un rôle essentiel en tant que plus grand consommateur d'électricité dans de nombreux pays et garant de la stabilité économique et sociale, mais malgré l'entrée de nombreux nouveaux fournisseurs d'électricité « verte » sur le marché, son adoption reste en deçà des objectifs nationaux et internationaux. Cette thèse examine les préférences des ménages concernant différents « types » d'électricité en fonction de leurs attributs hédoniques, qui par définition ne peuvent pas être observés ni mesurés au point de consommation.

La thèse est divisée en quatre chapitres, chacun traitant d'un aspect différent de la valorisation de l'électricité. Le premier chapitre explore la façon dont les individus prennent des décisions pour mieux comprendre pourquoi ils accordent plus d'importance à certains attributs qu'à d'autres. Cette revue de théories et de modèles de diverses disciplines vise à combler les lacunes de l'économie néoclassique, qui a eu du mal à expliquer les comportements altruistes ou à considérer le fait que de nombreux comportements sont irrationnels, préjudiciables à l'individu ou simplement motivés par l'émotion ou l'habitude. Un schéma est également présenté pour suggérer comment les différents modèles allant de l'économie néoclassique et comportementale à la psychologie et à la sociologie peuvent se compléter.

Le deuxième chapitre présente les résultats d'une expérience à choix discret pour connaître les préférences individuelles lors du choix entre différents types d'électricité et modes d'approvisionnement. L'installation d'un système solaire photovoltaïque (PV), l'adhésion à une communauté énergétique, la consommation d'une plus grande part d'électricité verte et une plus grande autosuffisance étaient toutes considérées comme des caractéristiques souhaitables qui commandaient une prime de prix, tandis que l'augmentation de la part d'électricité d'origine locale semble porter une pénalité. Ce n'est en aucun cas la première étude qui a trouvé des valeurs négatives pour certains attributs hédoniques, comme cela est expliqué au chapitre trois.

Le troisième chapitre montre comment cette expérience n'est qu'une parmi plusieurs et mène une méta-analyse du consentement à payer (CAP) pour l'électricité verte afin de donner une cohérence aux résultats par ailleurs disparates de la littérature. Aucune variable ou groupe de variables spécifique aux enquêtes n'a été trouvé pour produire des prévisions précises et cohérentes du CAP dans différents pays et années, malgré de nombreuses tentatives d'ajustement des données à l'aide de différents modèles. Néanmoins, les modèles à effets aléatoires ont obtenu de meilleurs résultats que les modèles à effets fixes dans l'ensemble, ce qui suggère que les résultats rapportés dans la littérature reflètent une diversité de véritables préférences sous-jacentes.

Enfin, le quatrième chapitre donne un exemple de la façon dont le surplus individuel associé à la consommation des attributs hédoniques peut être mis en commun et partagé au sein d'une communauté énergétique, une nouvelle structure qui permet aux ménages de mieux capter la valeur des sources d'énergie distribuées.

Ensemble, ces quatre chapitres présentent un récit cohérent du présent, du passé et de l'avenir de l'évaluation des attributs hédoniques dans le secteur de l'électricité.

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General Introduction

The environmental and social dimensions of development have risen in the international policy agenda to parallel economic imperatives ever since the publication of the landmark Brundtland Report in 1987 (World Commission on Environment and Development, 1987). Today, more than thirty years after its publication, its central message on the importance of balancing environmental, social and economic imperatives continues to shape development goals at all levels.

The energy sector is central in the transition toward a model of development that balances economic growth with environmental and social imperatives. Renewable energy sources are widely believed (United Nations, 2021) to be best positioned to mitigate the negative effects of climate change, local air pollution and in general accelerate the shift toward a more sustainable society. Raising the share of renewable or 'green' electricity that is produced and consumed worldwide remains an international priority, especially after the steep cost reductions they have experienced in recent years and more favorable laws and financial incentives in numerous countries (Wolske et al., 2017). As the cost of solar photovoltaic (PV) and energy storage systems has declined in recent years relative to other sources of supply their adoption has also become more widespread.

However, despite years of progressive increases in renewable energy deployment energy-related emissions reached a new record high of 36.3 gigatons, due in part to the post-pandemic economic recovery. Of this, the largest increase took place in electricity and heat production, which accounted for 46% of the global increase in emissions, of which 36% from coal (IEA, 2022). More recently security and inflation concerns have gained prominence in Europe, prodding authorities to prioritize more reliable and diversified energy supplies rather than cleaner ones, at least in the short-term (European Commission, 2022).

Households continue to play an essential role in the energy transition through their consumption patterns and purchase decisions, as has been recognized by policymakers interested in incentivizing the orderly deployment of renewables (Goulden et al., 2014; Sintov and Schultz, 2015; Verbong et al., 2013; Wolsink, 2012). At the European level they accounted for 26% of final energy consumption in 2019, of which electricity represented 25%, a figure that is expected to double by 2030 (Eurostat, 2021). Energy, and especially electricity, is closely embedded in modern lifestyles and continues to play an essential role to improve peoples' quality of life to the extent that its absence has given rise to the notions of energy scarcity and poverty (Dussud et al., 2017). The liberalization of electricity markets that began in the late 1990s has allowed the entry of numerous new suppliers - some of them 'green' - widening the choices available to residential consumers. In France, for example, consumer demand for more differentiated energy products has allowed 23 such suppliers to serve around 30 percent of households, compared to a single one a couple of decades ago. At the same time, the relaxation of national regulatory frameworks has allowed households to invest in solar PV systems for self-consumption, increasing capacity roughly four-fold since the previous network rates (TURPE 5) were published in 2017 and reaching a total capacity of 223 MW (57,000 installations) at the end of 2019 (*Consultation publique n°2020-007 du 19 mars 2020 relative à la composante de soutirage des prochains tarifs d'utilisation des réseaux publics d'électricité « TURPE 6 »,* 2019). Collectively known as Distributed

Energy Resources (DERs), these systems were initially conceived as a backup rather than primary energy source, but have more recently seen wider adoption as part of the primary energy supply in many households fueled by economic considerations and mounting concerns over greenhouse gas emissions (Soshinskaya et al., 2014).

If the energy transition relies to a large extent on the procurement decisions of individuals and households, eliciting and understanding their preferences is essential for drafting sound public policies and designing attractive new products (Goulden et al., 2014; Sintov and Schultz, 2015; Verbong et al., 2013; Wolsink, 2012). Within the boundaries set by regulators consumers can decide if an electricity offer counts as ‘green’ or ‘clean’ based on the environmental and social impacts of its generation technology, even when these attributes are not observed, measured nor explicitly verified at the point of consumption (Yang et al., 2015a). In this thesis the term *hedonic attributes* has been chosen to describe them.

Unveiling individual preferences has traditionally relied on stated and revealed preference methods, which present their own advantages and drawbacks. Overall, the evidence they provided has challenged many of the assumptions taken for granted by neoclassical economics, which has struggled to predict or explain the presence of altruistic behavior or consider the fact that much behavior is irrational, detrimental to the individual or simply driven by emotion or habit. This has forced researchers to draw from other disciplines including psychology, sociology and other behavioral sciences. This thesis has strived to capture and convey this trans disciplinaryity.

The thesis is structured in four chapters, each of which treats a different aspect of electricity valuation. The first chapter explores how individuals make decisions, as this provides the basis to understand *why* they value some characteristics or ‘attributes’ more than others. The second chapter describes an experiment to elicit individual’s preferences when choosing between different types of electricity and modes of supply. The third chapter broadens the reader’s perspective by showing how this experiment is but one among many similar studies, and how meta-analyses can lend coherence to otherwise disparate findings from the literature. Finally, the fourth chapter provides an example of how the individual value produced from consuming electricity attributes can be pooled and shared within an energy community, a novel structure that allows households to capture more of the benefits of distributed energy sources. Together, they present a coherent narrative of the present, past and future of hedonic attribute valuation in the electricity sector.

— THE PRESENT —

Chapter 1. Theories of Behavior and the Value of Hedonic Attributes

The objective of this chapter is to better understand individual preference and choice, and more precisely to shed light on the processes behind consumers' valuation of electricity and its attributes. To do so, it presents different answers to the question *How do individuals formulate their (consumption) decisions?* The answers are presented in the form of frameworks or models of behavior drawn from various disciplines and theories developed since the mid XX century. They each try to account, as much as they can, for the observed discrepancy between what people say and what they actually do – a gap that has also affected the adoption of renewable energy at the household level. A consolidated scheme that integrates the various models and frameworks is the main original contribution of this chapter.

Chapter 2. How French Households Value their Electricity Supply Choices

The objective of this chapter is to empirically uncover *How households value the hedonic attributes of electricity?* To elicit individual preferences a discrete choice experiment was conducted in a sample of local residents (heads of household) from the French region of Auvergne-Rhône-Alpes (ARA) in early 2022. The offers presented varied by source (grid, solar PV or energy community) and in their combinations of hedonic attributes, which could include different percentages of green (renewable) energy, local generation and autonomy (self-sufficiency). The reader is guided through the design, testing and implementation of the experiment, as well as the processing of the data using statistical methods. The results are framed in terms of respondents' willingness to pay (WTP) for specific attributes, expressed as a percentage or money premium in their monthly bills.

The motivations behind this chapter include the lack of studies on WTP for green electricity in France, an examination of the interactions between attributes which is often overlooked in existing studies, and the need for more granular information on preferences to inform decision makers in the public and private sectors. Overall, the findings suggest there is untapped market demand for electricity from nonconventional sources, and willingness to pay a premium for the “right” combination of attributes.

— LOOKING BACK —

Chapter 3. A Meta-analysis of WTP for Green Electricity

The values obtained in the preceding chapter are but one data point in a vast literature of studies that explore the WTP of people from different countries to pay for different attributes of electricity at different points in time. *How to make sense of the disparate values they find? What explains the observed differences in their stated WTP?* These questions motivate the current chapter, which reviews a large number of primary studies and previous meta-analyses to identify the main (non-psychological) factors behind the observed results. Emphasis is placed on within-study variation due to measurement error (fixed effects), as well as between-study variation due to the different methods used by researchers (random effects). A flexible methodological framework succeeds at ‘salvaging’ (accommodating) many of the studies that were discarded by previous meta-analyses, while providing a consolidated view of studies carried out in different locations, dates and using different methods to decision makers interested in ‘translating’ their findings to specific settings.

— LOOKING FORWARD —

Chapter 4. Estimating the Value Produced and Captured by Energy Communities

If a meta-analysis provides a theoretical means of aggregating the values and preferences of individuals, an energy community provides a practical way to do so. An energy community (EC) is in essence an arrangement that allows households to pool, share and trade electricity with one another, and has been recognized at the European and French levels. It provides an ideal setting to capture the value of the hedonic attributes of electricity given its characteristics and mode of operation, though the author could not identify any previous effort to do so. The question of this chapter is therefore *What is the hedonic value produced and captured by energy communities?* Our point of departure is the hypothesis that ECs can capture more value than the equivalent number of dispersed households, partly by virtue of their access to a dual EC/spot market structure. To test this hypothesis a theoretical energy community is set

up to reflect the ratio of households (and their consumption patterns) to that of small solar producers (and their production patterns) in the ARA region. Six scenarios are then introduced to successively incorporate DERs, a local peer-to-peer (P2P) market and access to French spot market. The findings, which include both conventional (financial) and hedonic surplus estimates, suggest that an EC as specified here can provide tangible benefits in terms of lower costs for its members, while boosting the value of hedonic attributes.

CHAPTER I

Theories of Behavior and the Value of Hedonic Attributes

Abstract

In most countries survey respondents often state their willingness to pay a premium for renewable energy sources, yet statistics show that actual adoption of renewables remains low by comparison. Several explanations have been advanced to explain this gap, which draw on many of the theories and frameworks developed since the mid XX century. Nevertheless, the results of field experiments continue to confound researchers and provide decision makers with no clear direction. In an attempt to shed light on the processes behind consumers' valuation of electricity and its attributes, this chapter reviews some of the most well-established theories of behavior, highlighting their main similarities and differences, and providing a synthesis of their main elements. The chapter also aims to provide the reader with a basic understanding of how individual decisions are formulated as a preamble to subsequent chapters in the thesis, and to motivate researchers to broaden the conceptual frameworks they use to collect data and interpret their findings.

Keywords: theories of behavior, behavioral economics, social psychology, renewable energy.

1. INTRODUCTION

The energy sector lies at the crux of the transition toward a more environmentally and socially sound society, and individuals play an essential role in that transition through their consumption patterns and purchase decisions (Goulden et al., 2014; Sintov and Schultz, 2015; Verbong et al., 2013; Wolsink, 2012). That a meaningful proportion of the general population, sometimes as high as 80% or more in the case of wind power (Ek, 2005; Krohn and Damborg, 1999) appears willing to pay a premium for green electricity has been widely documented (Aldy et al., 2012; Aravena et al., 2012a; Beenstock et al., 1998; de Nooij et al., 2007; Kosenius and Ollikainen, 2013a; Longo et al., 2008; Shin et al., 2014a; Yang et al., 2015a). The fact that actual adoption of renewables remains in the single digits in most countries is also a reality (Andrea Bollino, 2009a; Bird et al., 2002; Streimikiene et al., 2019). This discrepancy has been variously attributed to incomplete information from potential consumers, limited access to capital, divergent incentives, imperfect markets and organizational barriers, among others (Brown, 2001; Levine et al., 1994). The fact that these market failures have a strong behavioral component has also been documented (Stern, 1992). Given that the “soft costs” of new customer acquisition range between 10 and 17% of overall costs according to a recent report (Fu et al., 2018), any effort to increase solar photovoltaic (PV) uptake should start by lowering the barriers to their adoption. Self-reported motivations such as expected financial returns, biospheric altruism (Ateş, 2020; Wolske et al., 2017) or enhanced social standing from showcasing green credentials can provide a starting point for the research, but hardly amount to a coherent explanation (Archer et al., 1987; Dastrup et al., 2012a; Stern et al., 2018). Stated preference studies also provide only part of the answer when limited to describing the statistical significance of proxy factors and variables in the absence of a formal theoretical framework (Noll et al., 2014). In this respect researching the stated (hypothetical) choices of consumers

is important since limiting the analysis to revealed (i.e. *post-hoc*) behavior that treats decision making as a black box may overlook relevant information about their motivations and the underlying decision making processes (Wolske et al., 2018). It is therefore clear that despite the growing market for green power, the motivations and preferences behind a household's decision to switch their energy provider or pay a premium for a different energy source are still not well understood. At the same time, it is clear that policymakers and business would benefit from an improved understanding of consumers' decision-making processes to inform cost-benefit analyses, identify market niches or evaluate the impact of policy interventions, e.g. targeted energy subsidies. Ultimately, it could also serve to signal the disposition of consumers to establish or join an energy community, as will be discussed in subsequent chapters of this thesis.

The aim of this chapter is to better understand individual preference and choice, and what motivates them to choose one option over another. Since individuals are assumed to have the same mental structures in place at all times (i.e., preferences are assumed to be stable) and energy consumption is only a very narrow activity within peoples' lives, our objective must be broader than just understanding how individuals make decisions regarding their energy choices – and besides, no theories of behavior have been specifically developed to explain how people value electricity. Instead the general question this chapter aims to address is ***how do individuals formulate their decisions?*** This question has captivated thinkers since antiquity, and in recent times disciplines from economics to psychology, and to a lesser extent sociology, have developed frameworks, models and theories to provide plausible explanations and even predict future behavior. Studies based on them have also attempted to quantify individuals' preferences for the hedonic attributes of electric power, i.e. those intangible qualities conveyed by virtue of the location, ownership or the technology with which it was produced, and which often influence the preferences and decisions of consumers. Most previous studies of this kind have relied on either stated or revealed preference methods, often producing inconsistent results (Sims, 2013a). One of their main drawbacks is that by treating the source of individuals' diversity of preferences as exogenous (i.e. as black boxes) these methods leave researchers with no means to gain deeper insights into their subjects. Being descriptive in nature and based on theoretical axioms (Hauser, 1977; Hausman, 2011), conventional econometric methods have also failed to predict the emergence of altruistic behavior or take into account the fact that much behavior is irrational, detrimental to the individual or simply driven by emotion or habit, all of which limits their applicability and usefulness. Other studies have made a special effort to reconcile the insights from stated preference methods and various theories of behavior, e.g., (Akitsu and Ishihara, 2018; Ateş, 2020; Hansla et al., 2008a; Klöckner, 2013a; Wolske et al., 2017) also with mixed results.

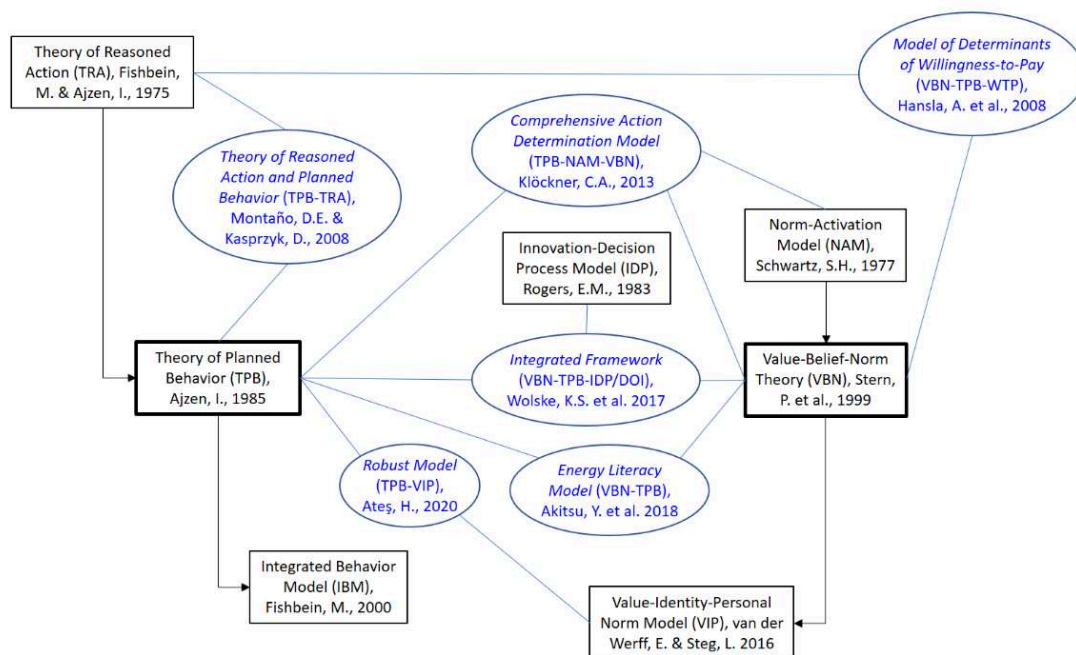
Rather than proposing a new approach, this chapter reviews the main theories and constructs used to explain how individuals make decisions. To fill the explanatory gaps and shortcomings left by individual approaches and lend coherence to their findings, a consolidated scheme is also presented, which constitutes the main contribution of this chapter. From an academic perspective unifying various theoretical approaches into a single framework is also a valuable exercise. More generally, this review aims to provide the reader with a conceptual framework to better understand consumer decisions in general and how values, beliefs, information and other elements interact and come together to produce specific behaviors. It is also hoped that this exercise will nudge researchers to think in more interdisciplinary terms about the methods they use to elicit preferences and the explanations they draw on to interpret their findings, which include insights from other fields that have not been included here for brevity such as neuroscience, artificial intelligence and neuro-linguistic programming (NLP). As noted by

Norwegian researcher Christian A. Klöckner, integrating variables from the most successful theories of behavior change may yield both theoretical and practical benefits (Klöckner, 2013a).

2. LITERATURE REVIEW

This review is limited to the most well-established and widely known theories of behavior. Most of them are the result of efforts from a large number of specialists, and have had the chance to be formalized and tested over years or decades. These are the Theory of Reasoned Action (TRA) (Fishbein and Ajzen, 2010), the Norm-Activation Model (NAM) (Schwartz, 1977), the Innovation-Decision Process Model (IDP)¹ (Rogers, 1983), the Theory of Planned Behavior (TPB) (Ajzen, 1991), the Value-Belief-Norm theory (VBN) (Stern et al., 1999), the Integrated Behavior Model (IBM) (Fishbein, 2000) and the Value-Identity-Personal Norm Model (VIP) (van der Werff and Steg, 2016).

Figure 1. Behavior theories and constructs analyzed in this study.



An additional model from the field of behavioral change known as Diffusion of Innovations (DOI) (Rogers, 1983) is also included given its frequent use to explain technology adoption (Wilson and Dowlatabadi, 2007; Wolske et al., 2017). In addition, six hybrid constructs that attempt to bridge the preceding theories (in ovals) are also included in Annex II. Using the names given to them by their original proponents, these constructs include the Model of Determinants of Willingness-to-Pay (VBN-TPB-WTP) (Hansla et al., 2008a), the Theory of Reasoned Action and Planned Behavior (TPB-TRA) (Montaño and Kasprzyk, 2008), the Comprehensive Action Determination Model (TPB-NAM-VBN) (Klöckner, 2013a), the Integrated Framework (VBN-TPB-IDP/DOI) (Wolske et al., 2017), the Energy Literacy Model (VBN-TPB) (Akitsu and Ishihara, 2018), and the Robust Model (TPB-VIP) (Ateş, 2020).

¹ Also referred to as the *Diffusion of Innovations Theory* (DOI) by (Wolske et al., 2017).

Figure 2. Behavioral theory timeline

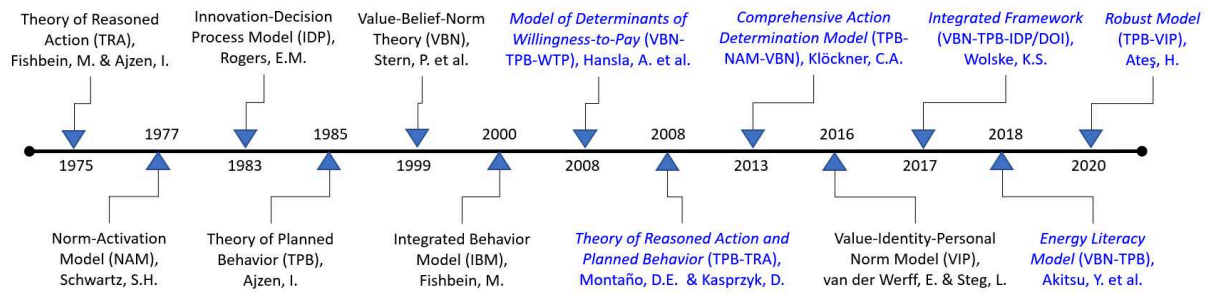


Figure 1 presents the relationship between the various behavior theories and constructs being considered, while An additional model from the field of behavioral change known as Diffusion of Innovations (DOI) (Rogers, 1983) is also included given its frequent use to explain technology adoption (Wilson and Dowlatabadi, 2007; Wolske et al., 2017). In addition, six hybrid constructs that attempt to bridge the preceding theories (in ovals) are also included in Annex II. Using the names given to them by their original proponents, these constructs include the Model of Determinants of Willingness-to-Pay (VBN-TPB-WTP) (Hansla et al., 2008a), the Theory of Reasoned Action and Planned Behavior (TPB-TRA) (Montaño and Kasprzyk, 2008), the Comprehensive Action Determination Model (TPB-NAM-VBN) (Klößner, 2013a), the Integrated Framework (VBN-TPB-IDP/DOI) (Wolske et al., 2017), the Energy Literacy Model (VBN-TPB) (Akitsu and Ishihara, 2018), and the Robust Model (TPB-VIP) (Ateş, 2020).

Figure 2 indicates their timeline. In both cases black squares represent traditional behavior theories and blue ovals the hybrid constructs they spawned. Except for the sociological framework, all others take the individual as the basic unit of analysis. The sociological approach will be useful when analyzing decisions at the household level and above. Special emphasis was placed on the preferences for electric power attributes and distributed energy resources (DERs), such as the motivations of early adopters (Schelly, 2014; Wolske et al., 2017). As will become evident, most of the theories and constructs reviewed share a common set of elements, which is not surprising given that several among them are expanded versions of earlier theories and have often been formulated by the same authors. Although their basic building blocks are often similar they differ in the definitions they use, the assumptions they make and the chain of causality that bind them.

2.1 The Standard Economic Model

Being the first model of human behavior to be formulated (Loewenstein et al., 2001), the **Rational Choice Theory**, also known as the **Expected Utility Theory (EUT)**, represents the benchmark and starting point for several other theories and models of human behavior. The EUT was developed mainly to explain and predict the behavior of rational agents choosing between options with clearly perceived costs and benefits, making economic models especially tractable over a wide range of situations. In traditional economic theory individuals are assumed to make decisions based on expected cost-benefit calculations using well-ordered, complete and stable sets of preferences, providing the basis for **consumer preference theory**. In particular, an individual's demand for a product or service is framed as a utility maximization problem (*Marshallian* approach) or an expenditure minimization problem (*Hicksian* approach), together making up the duality of consumer theory (Nejad Moosavian, 2016). Hence individuals are assumed to be constantly trying to satisfy their various needs in ways that maximize their utility or minimize their cost, given the available information, the price of the goods and services, and their budget constraints. From this perspective an outcome that produces higher utility will be preferred over an alternative with lower utility. Utility (see below) is thus a construct used to

rank preferences for different outcomes. Utility theory is derived from the axioms of preference that set the criteria for rationality of choice (Tversky and Kahneman, 1981), and stated preference methods are a specific application of this theory.

Despite the impossibility of establishing objective measure of value, the preferences of individuals are assumed to follow the following basic axioms, which also ensure they can be represented by utility functions (Autor, 2010; Hauser, 1977). For a given basket of goods (attributes) $k \in \mathcal{K}$ we will assume:

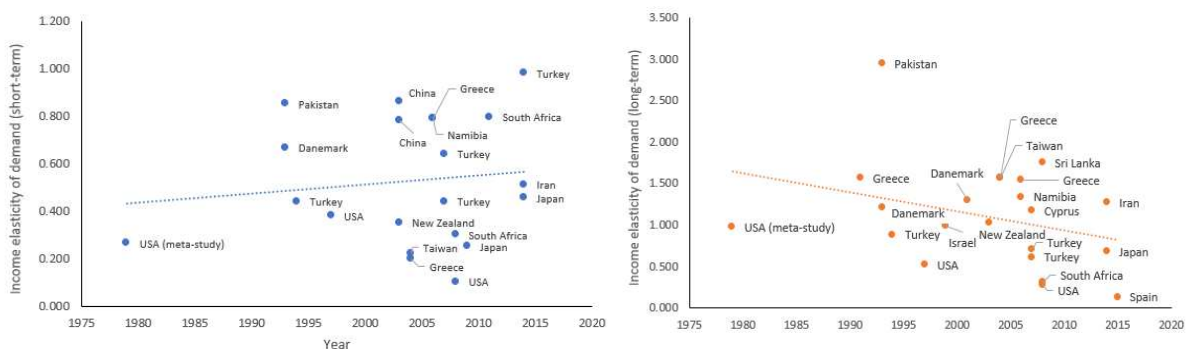
- i. Preference completeness, such that for $ki, kj \in \mathcal{K}$ either $ki \succcurlyeq kj$ or $kj \succcurlyeq ki$ or both.
- ii. Preference transitivity, such that for every $kh, ki, kj \in \mathcal{K}$ if $kh \succcurlyeq ki$ and $ki \succcurlyeq kj$, then by necessity $kh \succcurlyeq kj$.
- iii. Context independence, so that preferences remain stable across contexts and prices, i.e. if an agent prefers $ki \succcurlyeq kj$ within the EC, then he or she will also prefer it when interacting with the main grid.
- iv. Choice determination, in which agents are expected to choose the alternative at the top of their preference ranking, from those they believe to be available.
- v. Partial substitutability between energy attributes.
- vi. Continuity and concavity, to facilitate modeling and analysis.

2.1.1 Elasticity

For simplicity in the remainder of this document we will assume that electricity prices, individual (household) income and demand for electricity remain constant in the short term, even if this is only an approximation. To verify how valid this assumption is we will briefly review the evidence on the elasticity of demand for electric power.

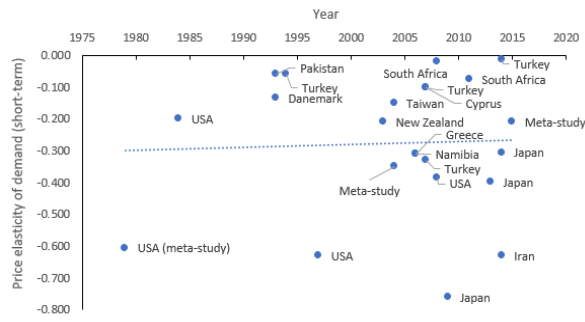
Electric power is considered a normal good, i.e., one whose demand increases with income, yet being a staple good its elasticity of demand is also very low in the short-term. A first distinction to be made is between **income elasticity of demand (IED)** and **price elasticity of demand (PED)**, since they affect relative prices differently. In the case of electric power IED refers to the (positive) difference that an extra unit of income has in terms of an increased expenditure on electric power. PED, on the other hand, refers to the (negative) effect that an increase in the cost of electric power produces on consumption.

Figure 3. Short and long-term income and price elasticities for electric power. Elaborated by the author.

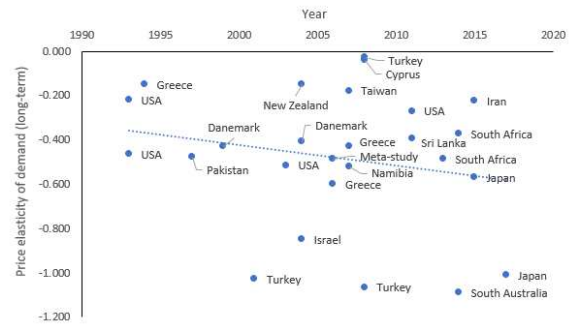


(a) Short-term income elasticity of demand

(b) Long-term income elasticity of demand



(c) Short-term price elasticity of demand



(d) Long-term price elasticity of demand

A second distinction is to be made between **short-term** (under 1 year) and **long-term** elasticity of demand. The conventional view is that individuals and households are not efficient at adapting to short-term price shocks so if, for example, the price of electric power were to double suddenly, consumers would more likely adapt by adjusting their consumption rather than by increasing their energy efficiency or income. In contrast, it is more likely that over several years consumers will be able to better adapt to price changes by replacing appliances, moving or isolating homes or finding additional sources of revenue.

A review conducted by the author of residential electricity demand from 20 countries between 1970 and 2017, including three meta-studies by (Bohi, 2011; Espey and Espey, 2004; Labandeira et al., n.d.) show that (as expected) IED for electric power is always positive and PED is always negative. Interestingly both short-term elasticities display upward trends while both long-term elasticities display downward trends, perhaps reflecting the influence of low-cost energy efficiency improvements over those associated to large investments, although this hypothesis needs further research (See Figure 3). Overall, then, the assumption that short-term elasticity of demand is close to constant (flat) appears reasonable.

2.1.2 Utility

Utility is often interpreted as a subjective level of satisfaction, happiness or personal benefit, which can include the well-being of third parties (i.e. the environment) (Darnton, 2008). Being a psychological construct, it does not need to be measured or observed in order to be perceived to have value. Neoclassical economics considers individual utilities ordinal and interpersonal comparisons impossible (Freeman III et al., 2014), with individual utilities often assumed to be non-negative, non-decreasing, differentiable and concave, i.e. displaying diminishing returns to scale.

Utility functions are mathematical expressions commonly used in microeconomics to describe human behavior, especially regarding preferences and choices. They specify precisely how different factors and variables interact to produce an overall level of utility that directly mirrors the choices made and how options are ranked. Attributes can enter utility functions in a variety of ways, and properly identifying how they interact with other factors of production is key to any modeling effort.

2.1.3 Attributes

Kelvin J. Lancaster suggested in 1966 that individuals' demand for goods and services is in reality a demand for their *use* and *non-use* characteristics or attributes (Lancaster, 1966). Any good or service could therefore be decomposed into its constituent attributes or 'qualities' that provided utility to the individual. Thinking about utility this way made it possible to compare choices where only one attribute (or different levels of the same attribute) varied (McFadden, 1986a).

The **use attributes** of electric power are the measurable physical magnitudes commonly associated to the services it provides, including light, heat, sound and the operation of various electronic devices. Use attributes are considered an *experience good*, as its qualities can be ascertained upon consumption. In contrast, the **non-use attributes** of electric power are the non-measurable qualities associated to it by virtue of its source (e.g. local), ownership (e.g. self-produced), technology (e.g. renewable) or other characteristics. They are considered *credence goods*, as their qualities cannot be known precisely even after consumption.

2.1.4 Electric Power Valuation

Electricity, whether self-produced or purchased from third parties, meets the criteria of the **household production framework** in which utility is a function of the level of final service flows or “commodities” consumed by households:

$$u = u(\mathbf{Z}) \quad (1)$$

These utility-yielding service flows, denoted by $\mathbf{Z} = (z_1, \dots, z_s)$, are implicitly produced by households by combining market goods with the household’s own time and labor, according to a technology common to all households and assumed to be known (Freeman III et al., 2014). Specifically, the attributes of renewable energy become valuable when they produce private ‘use’ goods, private ‘non-use’ goods, and public goods.

Conventional valuation methods for electric power are based on the private use goods only. Regardless of their source, all electric power sources produce the same private goods, which include the various services and amenities that electric power makes possible. In this case individual utility they simplify to

$$u = u(\mathbf{X}) \quad (2)$$

where \mathbf{X} is the vector of consumed power flows.

2.1.5 Valuation with Hedonic Attributes

Hedonic attributes are not intrinsically valuable in themselves, but become so to the extent that they produce utility to individuals. According to (Freeman III et al., 2014) exogenous factors, including non-use attributes, can affect an individual’s utility in three ways: directly by being an argument in an individual’s utility function, indirectly as a factor input in the production of a market good that yields utility, or as an input in the household production of utility-yielding commodities. The ways in which public goods or bads (i.e. pollution) enter households’ production processes has also been explored by (Bockstael and McConnell, 2007). As a general rule while an increase in the services rendered by electric power can be expected to increase demand, an increase in hedonic attributes will not translate into increased demand. If electric power is considered a differentiated good by virtue of its non-use attributes it will give rise to private non-use goods, public goods or both. **Private non-use goods**, also known as *credence goods* (Roe and Sheldon, 2007), possess intangible qualities or characteristics deemed valuable by certain individuals but which cannot be ascertained by consumers even after purchase, such as the consumption of local or renewable energy sources. They are private because they can be appropriated and enjoyed by the energy consumer alone while excluding third parties. One example is energy autarky, an umbrella term that captures certain consumers’ desire for greater control, self-reliance, self-sufficiency or even complete independence from the grid. Notice that private non-use goods are often associated to self-produced energy only (not necessarily renewable), and not to that purchased from third parties. This explains why self-consumption of renewable energy is often valued

more highly by households than its equivalent purchased in the market (Ecker et al., 2018a). In general, any psychological reward resulting from the consumption of renewable energy, such as enhanced self-esteem and status, fall in this category. Even if they are intangible and cannot be measured objectively, private non-use goods *feel* real to certain consumers and increase their utility as well. The relevant utility function in the presence of private non-use goods is:

$$u = u [\mathbf{X}, \mathbf{Z}(\mathbf{X})] \quad (3)$$

The market good \mathbf{X} now enters the utility function twice since there are now two sources of utility: the private use goods that produce utility directly and the private non-use goods that do so indirectly, represented by the term $\mathbf{Z}(\mathbf{X})$. This is a standard approach that has also been used by authors like (Andreoni, 1989; Hanemann, 1993; Herriges et al., 2000) to characterize non-use values. Note that all the terms in equation (3) are *weakly complementary*, meaning that the marginal utility or marginal demand price of \mathbf{Z} will be zero when the quantity demanded of the complementary private good \mathbf{X} is zero. This is an important property when estimating social welfare analytically, as it establishes an initial position for the individual that can be used to determine the constants of integration. As a general rule we will assume that consumers derive no residual utility from not consuming electric power, even if in practice authors like (Dastrup et al., 2012a) have argued that merely installing a conspicuous PV system on a rooftop can enhance the owner's social standing.

Public goods, such as an improvement in air quality or a reduction in greenhouse gas emissions, can also be linked to the consumption of a higher share of clean energy. Public goods are different from private goods in that third parties cannot be excluded from their consumption. The question then arises as to why an individual or household would invest private resources to enhance a public good for which he is only a marginal beneficiary and cannot possibly perceive a tangible short-term improvement. At first glance an expenditure in a public good would only be made by purely altruistic consumers demanding more of a public good, even if their contribution would in all likelihood be marginal and entirely crowded out by large generators, i.e. the state (Menges et al., 2005a). In fact, pure altruists would still be pursuing the maximization of their individual utility, only doing so by enhancing a public good rather than by consuming private goods. An alternative and more plausible explanation is provided by the *impure public good model* (Andreoni, 1989, 1990; Cornes and Sandler, 1994; Menges et al., 2005a), according to which the act of contributing to the common good has the effect of simultaneously producing two goods, one public and one private, hence its '*impure*' nature. The public good is produced from the private good by a simple linear technology (from the household perspective), and likewise spending on a private activity jointly produces a private and a public good (from the consumer perspective). The public goods in question can be environmental, as when purchasing green energy, or social as when buying energy from local producers to conserve local jobs or subsidize the poor. In addition, there is a private benefit to these contributions that authors like (Groh and Möllendorff, 2019; Menges et al., 2005a) have referred to as the '*warm glow*' of giving, and which can be thought of as the feeling of satisfaction about oneself that results from the act of giving to others. In this respect warm glow is no different from any other private non-use good that conveys utility to the individual. A household utility function that captures this duality is

$$u = \mathbf{Z}(\mathbf{X}, \mathbf{Q}) \quad (4)$$

where \mathbf{Q} represents the (exogenous) quality or quantity of the public good. Since the motivations that individuals have for purchasing renewable energy are not comparable in kind or intensity across individuals, it is not possible to determine *a priori* where a given consumer will be located in the

altruism—warm glow continuum, i.e. which factor will have more weight in his or her decision to consume. Nevertheless, both extremes are captured in equation (4). Combining the previous sub-functions produces an overall utility function for all attribute types of the form

$$U = u[\mathbf{X}, \mathbf{Z}(\mathbf{X}, \mathbf{Q})] \text{ s.t. } \mathbf{P}\mathbf{X} + \mathbf{Q} \leq \mathbf{M} \quad (5)$$

We assume this direct utility function to be strictly increasing and concave in \mathbf{X} , \mathbf{Q} and \mathbf{Z} , implying that households have convex preferences. This also ensures that increases in any term increase utility, and maximization produces smooth Marshallian demand curves. This utility function is subject to the exogenous and linear budget constraint $\mathbf{P}\mathbf{X} + \mathbf{Q} \leq \mathbf{M}$ in which \mathbf{P} is the vector of prices for \mathbf{X} , and \mathbf{M} is the available income (budget). The household will also be assumed to spend its entire budget on the two goods in question, as any unspent remainder would lead to a suboptimal allocation of resources, hence the new budget constraint $\mathbf{P}\mathbf{X} + \mathbf{Q} = \mathbf{M}$. For analysis purposes only changes in the price of the market good \mathbf{X} are considered, while the price of the composite good \mathbf{Q} is left unchanged and set to unity.

In this model we assume the direct utility function to be additive, to allow individual parameters to be valued separately. An additive function also ensures the value of \mathbf{X} (the numeraire) is conserved even in the absence of \mathbf{Z} (the composite), while the presence of \mathbf{Z} enhances its value.² The resulting affine function can be represented in extended form as:

$$u(x, z, q) = \sum_i^n u\{(x_i + z_i), \dots, (x_n + z_n)\} \quad (6)$$

and in vector form as:

$$u(\mathbf{X}, \mathbf{Z}, \mathbf{Q}) = u\{\mathbf{X} + \mathbf{Z}(\mathbf{X}, \mathbf{Q})\} \quad (7)$$

This formulation also allows for wide variations between the elasticities of use and non-use attributes, with that of electric power typically being low, and that of non-use attributes contingent on individual preferences. In the next section we will make some strong assumptions regarding the functional form of this utility function to produce an expression more conducive to practical applications.

Among the main strengths of the EUT model are its simplicity and tractability, which allows it to be adapted to many different contexts. This includes its ability to 'translate' individual preferences and valuations into utility, and between the utility experienced by individuals in '*preference space*' (measured in *utils*) and that observed in monetary transactions, i.e. in '*willingness-to-pay (WTP) space*'. Moreover, it offers tools to analyze the trade-offs people make when increasing one attribute (or more) at the expense of another, and does so quantitatively.

2.2 Behavioral Economics

A wealth of experimental and field evidence has shown that individuals do not make consistently rational decisions (Camerer et al., 2011). Preference and time inconsistency, framing effects, anchoring, bounded rationality and various heuristics are only a few of the types of biases studied by behavioral economists, which evidence that decisions often deviate from the axioms of rational choice, casting doubt on the soundness of classic economic theory.

Behavioral economics (BE) seeks to integrate insights from psychology into microeconomics to explain the observed limitations that people display when making decisions in real life, and qualify rather than

² An additive relationship between terms is also accompanied by strong separability, implying that the marginal rate of substitution (MRS) between X and Z is independent of the quantity of any other good in any other subset.

disprove the axioms of preference and choice (Darnton, 2008). Behavioral economics therefore constitutes the closest we have to a *bridge* between economic theory and the theories of other disciplines in the humanities, including psychology and sociology.

Although no general framework or theory exists to provide a coherent explanation of all the empirical evidence gathered by behavioral economics, the following issues have been highlighted by (Laibson and List, 2015) and (Darnton, 2008) to summarize the ways in which this field qualifies traditional economics. They include:

- i. People try to choose the best feasible option, but often do not or cannot, for a variety of reasons.
- ii. People care (in part) about how their circumstances compare to reference points. **Framing** illustrates how presenting the same choice as a gain or a loss, or simply changing the order of choices, affects decisions. **Anchoring** decisions to reference points or values is another example. **Part-whole bias**, which in simple terms characterizes situations in which the valuation of an item differs from the separate valuations of the 'parts' that compose it, has also been found to affect contingent valuation and stated preference methods differently (Foster and Mourato, 1998).
- iii. People have self-control problems. **Inertia** often prevails when people choose the easiest or best known option (i.e. the path of least resistance), preferring to stay with their current energy supplier rather than switch to a better one.
- iv. Although we mostly care about our own material payoffs, we also care about the actions, intentions, and payoffs of others, even people outside our family. Beliefs about fairness, equality and democracy often overwhelm strict cost-benefit calculations.
- v. Markets often do not compensate or 'even out' individual biases to produce more balanced outcomes. Rather, they often amplify and self-reinforce psychological biases to produce more extreme outcomes.
- vi. In theory, limiting people's choices could partially protect them from their behavioral biases, but in practice limiting choices has a mixed track record and is often unpopular. **Bounded rationality** explains how decision processes are 'bounded' by psychological and environmental constraints, such as the effort involved in gathering and processing vast amounts of information (Wilson and Dowlatabadi, 2007). This leads people to use simple decision rules (**heuristics**) rather than reflect on choices in detail.

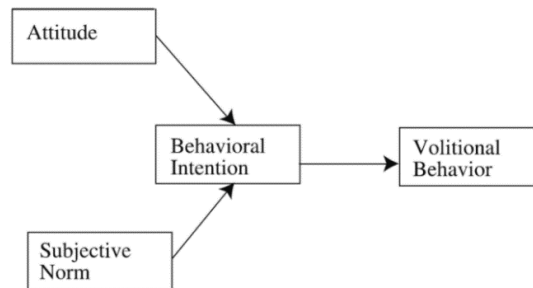
In view of the inconsistencies that have been (and continue to be) documented for the EUT model, the field of BE has provided a framework to salvage the strengths of classic economic theory and identify the situations where it applies and where it does not - it complements the EUT rather than undermining it. On the other hand, the lack of a theory to bind together and give coherence to the multiple instances where the EUT fails is one of the main drawbacks of BE. That is where the psychological and sociological models described in the rest of this document become relevant.

2.3 Theory of Reasoned Action

The Theory of Reasoned Action (TRA) can be traced back to a 1975 book by Martin Fishbein and Icek Ajzen (Fishbein and Ajzen, 1975) and crystallizes the findings and conjectures of academic research carried out in the prior decade. It is also the precursor to various other theories, including the Theory of Planned Behavior (TPB) and the Integrated Behavior Model (IBM). The TRA explains behavior

deterministically as a function of the *intention* that precedes it, and which is in turn influenced by *attitude* and *subjective norm*. Attitude captures the behavioral beliefs held by the individual, as well as the evaluation of the likely outcome of that behavior. In contrast, subjective norm refers to the perceived social pressure that demands a certain behavior from the individual (Korcaj et al., 2015a). A representation is shown in Figure 4.

Figure 4. Basic structure of the TRA model. Adapted from (Madden et al., 1992).

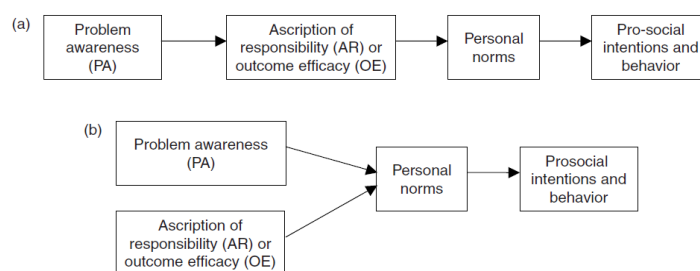


Given its simplicity the TRA model inevitably fails to explain much of the phenomena observed in real life. It nevertheless is valuable as a first attempt to systematize the internal processes that lead to specific behaviors and served as the basis for more complex models, e.g., the TPB (see below).

2.4 Norm-Activation Model

A contemporary of the TRA, the Norm-Activation Model (NAM) was first proposed by Shalom H. Schwartz in 1975 (Schwartz, 1977) to explain prosocial (altruistic) behaviors. According to the NAM prosocial behavior results from the activation of personal norms (PN) that reflect '*feelings of moral obligation to perform or refrain from specific actions*' (Steg and Groot, 2010), collectively termed the ascription of responsibility (AR).

Figure 5. Two variants of the NAM model. Adapted from (Onwezen et al., 2013).



The AR was in turn influenced by the individual's problem awareness (PA), an umbrella term that includes awareness of others' needs, the actions that would need to be taken to assist them, and a recognition of our own ability to carry out those actions, among others. The most common interpretation of the NAM is shown in Figure 5.

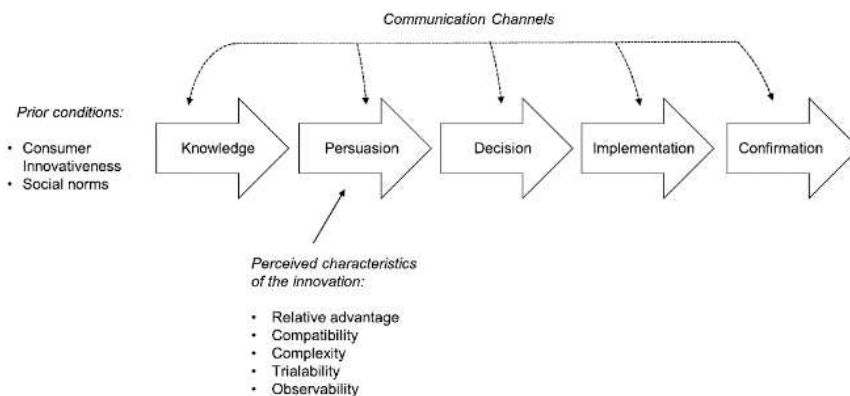
This simple linear process is nuanced by the author's inclusion of various *defense steps*, or coping mechanisms found to be used by individuals to deny or bypass their AR. Among others, they include biased cost-benefit assessments, denial of need, denial of ability to provide relief (also termed *outcome efficacy* by (Steg and Groot, 2010), and denial of a connection or relatedness with the person in need. The fact that the formal structure of the NAM was not explicitly laid out in the original paper has resulted in numerous variations and reinterpretations of its elements by subsequent authors, as documented by (Klößner, 2013b).

The NAM was probably the first model capable of providing a basis for altruistic behavior toward others, which the EUT failed to explain. It also highlighted the role of individual identity in driving behavior, and the role of internal consistency in decision making.

2.5 Innovation-Decision Process Model

The Innovation-Decision Process Model³ (IDP) proposed by Everett M. Rogers (Rogers, 1983) explains the temporal and spatial adoption (i.e. diffusion) of technology through a series of stages that unfold successively:

Figure 6. Basic structure of the IDP model. Taken from (Wolske et al., 2017)



As shown in Figure 6 individuals become aware of an innovation (knowledge), develop attitudes toward it (persuasion), decide whether to adopt the innovation (decision), implement it (implementation), and then decide whether to continue using it (confirmation).

The diffusion process takes place in a specific context and requires certain prerequisites from the individual and the technology. The context needs to include the innovation itself, a social system, communication channels between individuals, including the media and interpersonal communication, and time to allow uptake. Individuals in the social system also need a certain degree of curiosity and low aversion to risk if they are to try new products and services, and the innovation itself should display desirable attributes, such as conveying some advantage to the user, manageable complexity, observability, etc. Using this framework the author assigns the consumer population to one of five categories according to their speed of adoption: innovators, early adopters, early majority, late majority and laggards.

Among other applications, the IDP model has been used to explain early adopters' decision to install solar PV systems given their image as being a novel and modern technology (Wolske et al., 2017). It must be noted that the elements used by the IDP to explain behavior stand in stark contrast to all other theories presented in this study. It is not concerned with values, beliefs, attitudes or intentions, but rather treats individual attitudes toward technology as given and categorizes individuals into neat boxes that follow an orderly and methodical adoption process. Nevertheless, for these very reasons it also provides a distinct perspective and has been able to accurately predict the diffusion path of specific technologies throughout decades. Rather than providing a theoretical framework to be tested in the field, the IDP provides an explanation of what is already observed in practice.

³ Also referred to as the *Diffusion of Innovations Theory* (DOI) by (Wolske et al., 2017).

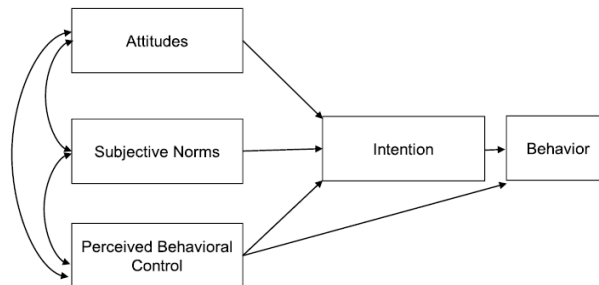
2.6 Theory of Planned Behavior

The Theory of Planned Behavior (TPB) (Ajzen, 1991) is one of the most widely known and cited theories to explain behavior, and one that has been used extensively in the environmental literature. See for example (Akitsu and Ishihara, 2018; Ateş, 2020; Brosch et al., 2014a; Hansla et al., 2008b; Wolske et al., 2017).

Taking the TRA as its point of departure, the TPB incorporated two relevant findings that departed from the linear cause-effect mechanisms of the TRA. First, it recognized the importance of an agency element, also named *volitional control* or *perceived behavioral control* (Ajzen, 1991) in carrying out a behavior, an item that moderated the individual's capacity to act upon an intention. This resulted from individual differences in information, skills and abilities, as well as power of will, emotions and compulsions.

Second, the TPB also recognized the existence of more nuanced interactions between the precursors of intention, i.e. attitudes, subjective norms, and agency, which influenced one another, and between agency, intention and behavior. This last point is important: agency (perceived behavioral control) is recognized to act simultaneously on intention *and* behavior according to the individual's perceived – or believed – odds of success. This expectancy-value calculation (Ajzen, 1991; Fishbein and Ajzen, 1975), which involves assigning probabilities or weights to different options, in effect introduced a random element to an otherwise mostly deterministic calculation. See Figure 7.

Figure 7. Basic structure of the TPB model. Taken from (Ajzen, 1991).



In the case of solar PV several authors have uncovered statistically significant correlations between specific attitudes and purchase intentions using the TPB, ranging from a desire for independence (Claudy et al., 2011a), social status aspirations (Korcaj et al., 2015a), social acceptance and environmental altruism (Wolske et al., 2018, 2017).

For the purposes of this study the value of the TPB resides partly on the introduction of more complex dynamics to decision making - in contrast to its linear predecessors - and especially in providing a testable theory to explore the gap between stated preferences (intention) and revealed preferences (behavior).

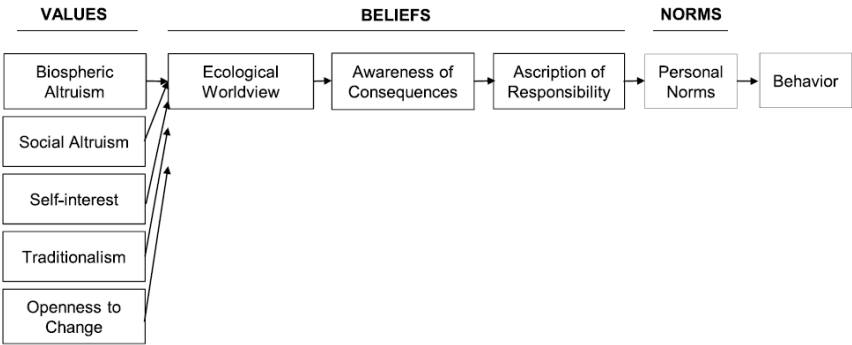
2.7 Value-Belief-Norm Theory

The Value-Belief-Norm theory (VBN) (Stern et al., 1999), together with the TPB, constitute the two most frequently cited frameworks to explain behavior, influencing the creation of four hybrid constructs in the case of the former, and five in the latter, as shown in Figure 1 and Annex II.

The VBN can be traced back to the work of Paul C. Stern (Stern et al., 1999), who tried to provide a theory to underpin social movements in general and environmentalism in particular. The VBN expands the NAM framework to include personal values and create a distinct worldview that he called *new*

ecological paradigm (NEP). The VBN as originally formulated traced the roots of pro-environmental behavior to altruistic values towards humans and other species, while relegating self-interest to a secondary position.

Figure 8. Basic structure of the VBN model. Taken from (Wolske et al., 2017).

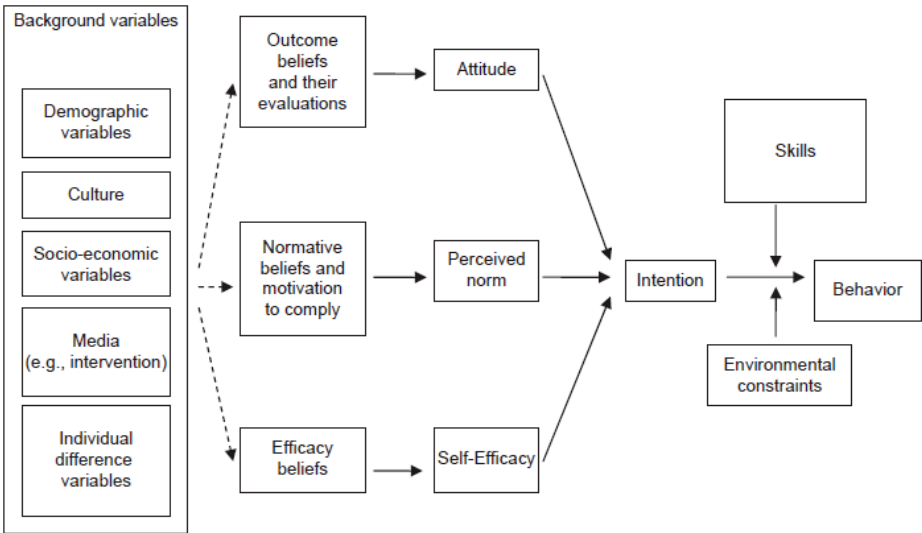


Its main contribution lies in its recognition of values as precursors of beliefs and filters of perception. See Figure 8. Subsequent authors have used the VBN to explore such things as the role of emotions, values and beliefs in guiding energy-saving behavior (Brosch et al., 2014b); values or altruism, self-interest and openness to change in explaining households’ willingness to install PV systems (Wolske et al., 2017); the correlation between energy literacy, worldview and awareness of consequences to explain energy-saving behavior (Akitsu and Ishihara, 2018); and social norms to explore six types of pro-environmental behavior among different ethnic groups (Ghazali et al., 2019). The VBN provides a more comprehensive explanation of altruism than its predecessors but fails to identify selfish motives behind altruistic behavior, as more recent research has uncovered (see section 2.1.5 above).

2.8 Integrated Behavior Model

The Integrated Behavior Model (IBM) (Fishbein, 2000), also known as the Integrative Model of Behavioral Prediction (Yzer, 2012) represents the most recent reformulation of the reasoned action approach (Fishbein and Ajzen, 2010), which had previously informed the TRA and TPB. The IBM is a more general framework intended to be applicable to any behavior.

Figure 9. Basic structure of the IBM model. Taken from (Yzer, 2012).



It connects the elements of the attitude - norm - agency triad from the TPB to its corresponding prior beliefs, and these in turn to a number of explanatory demographic, cultural and socio-economic variables rather than alluding to values.

Depending on the author, it also introduces between two and five additional moderating elements between intention and behavior, such as skills, knowledge, environmental constraints (Fishbein, 2000; Yzer, 2012), salience of the behavior and habit (Glanz et al., 2008). The IBM framework was originally devised to advance health prevention campaigns in the United States, and continues to be most actively used to inform health interventions. Nevertheless, its insights can easily be transferred to other domains. See Figure 9.

The contribution of the IBM model lies in broadening the set of factors taken into consideration to understand behavior. Its 'background variables' also include many of the control variables routinely used in discrete choice experiments. To its credit, it is also specific in proposing *skills* and *environmental constraints* as mediators to explain the intention-behavior gap, even if they are not always credible explanations.

2.9 Value-Identity-Personal Norm Model

The final theory in this section is the relatively recent Value-Identity-Personal Norm Model (VIP), which dates back to 2016 (van der Werff and Steg, 2016). Similarly to the VBN, it appeals to values as the foundation from which problem awareness, outcome efficacy and personal norms derive. Like most other theories, it also assumes a linear cause-effect relationship between its various elements. See Figure 10.

Figure 10. Basic structure of the VIP model. Taken from (van der Werff and Steg, 2016).



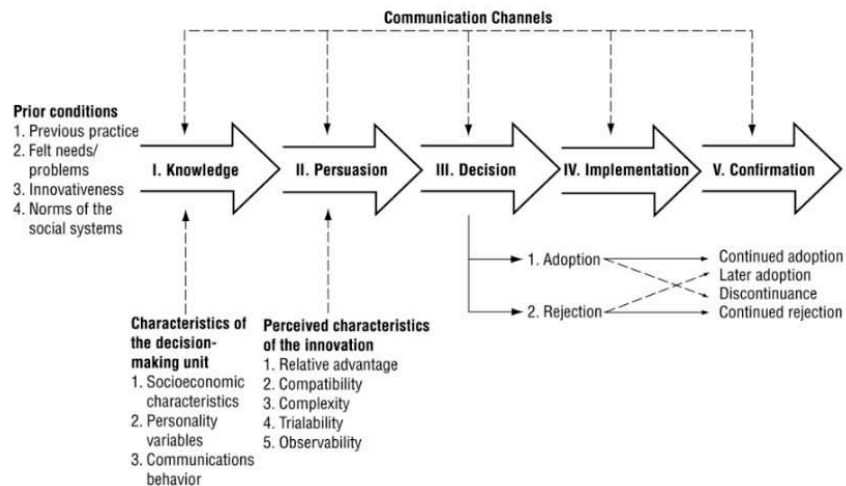
The novelty of the VIP lies in its recognition of *self-identity* as a precursor to personal norm and a result of the values held by the individual. It is also more parsimonious than the VBN and NAM (Ruepert et al., 2016) and has successfully been used to conduct mediation analyses to uncover indirect effects between constructs (van der Werff et al., 2013). When employed in combination with other models it has also increased their explanatory power (Ateş, 2020).

2.10 Diffusion of Innovations Theory

The DoI theory proposes that the process for adopting an innovation occurs in five stages: individuals become aware of an innovation (knowledge), form attitudes about it (persuasion), decide whether to adopt it (decision), implement the innovation (implementation), and then decide whether to continue using it (confirmation).

The speed at which this process occurs is thought to be influenced by several factors, including specific beliefs and attitudes about the technology. The process involves profiling individual characteristics and motivations. The DoI is an explanation to an empirical finding rather than a theoretical proposition. It takes market data as its starting point to map out the paths followed by different technologies, and has produced more accurate predictions than many of its counterparts.

Figure 11. Basic structure of the DoI theory. Taken from (Farhar and Coburn, 2000).



2.11 Social Psychology Models

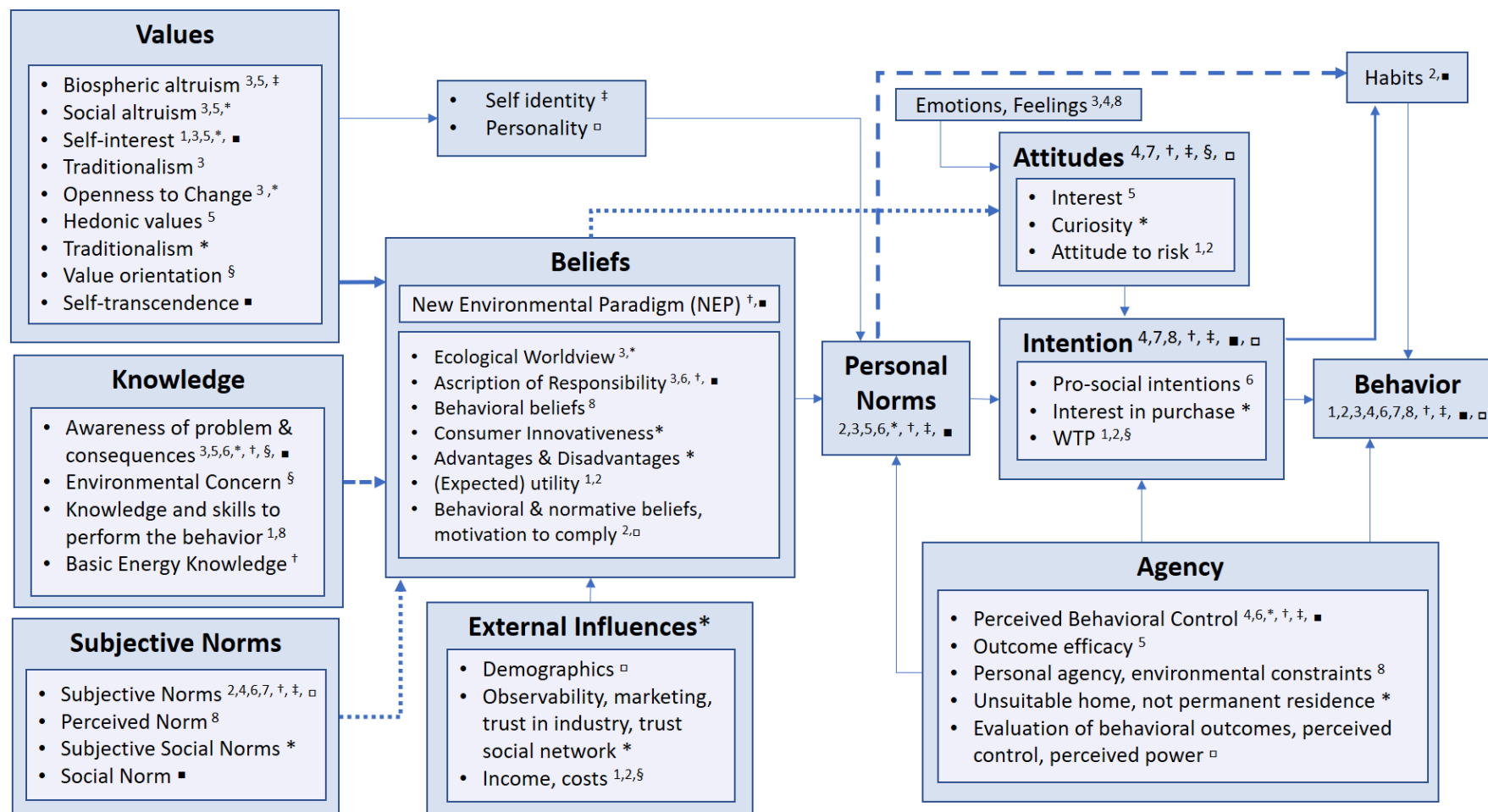
This section provides a brief overview of a selection of social psychology models. In contrast to the theories and models described up to this point social psychology models explain individual behavior in the context of social networks and the relationships between groups. Of the vast number of theories and models in the literature only three will be included here to provide a general overview of their characteristics. They are the Expectancy Value Theory (EVT), the Identity-centered models, and the Systems-centered models.

Figure 12 is an attempt to map out the relationships among the various elements that constitute the theories and models reviewed so far. Different authors (Ateş, 2020; Wolske et al., 2017) have assessed the strength of the links between them, reaching disparate conclusions.

The **expectancy value** (EV) theory is considered the simplest social-psychological model (Darnton, 2008). It is very similar to rational choice theory where individuals are assumed to make rational decisions that maximize their utility based on the value they attach to different outcomes, but approached from a psychological perspective, with special attention given to the '*attitudes*' that influence behavior.

Another useful framework to explain the variable effectiveness of information and incentives to change consumption habits is the **Attitude-Behavior-External Conditions (ABC) model**, in which the importance of attitudes to predict behavior are mediated by external physical, financial, legal and/or social factors that restrain an individual's actions (Stern et al., 1986; Wilson and Dowlatabadi, 2007).

Figure 12. Relationships between the main theories and constructs reviewed in this study.



Main Theories: ¹ EUT, ² BE, ³ VBN, ⁴ TPB, ⁵ VIP, ⁶ NAM, ⁷ TRA, ⁸ IBM

Hybrid Constructs: * IF (Wolske), † ELM (Akitsu), ‡ RB (Ateş), § MD (Hansla), ■ CADM (Klöckner), □ TRAPB (Ajzen)

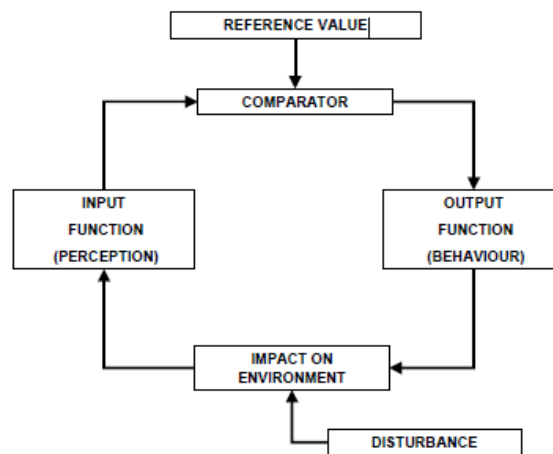
2.11.1 Identity-centered models

Social Identity Theory (Tajfel and Turner, 1979) explains the processes by which individuals tend to form groups following their affinities and similarities to differentiate themselves from outsiders ('*categorization*'), and then promote their group as superior to others ('*self enhancement*'). The **Self Categorization Theory** by the same author (Turner et al., 1987) further elaborated on the process of categorization by exploring the blending of individual and group identities through norms and standards that embody shared values, beliefs, actions and feelings. A central proposition of these theories is that identity and behavior are mutually self-reinforcing, and include the choice of goods and services consumed.

2.11.2 Systems-centered models

Systems thinking has also inspired the development of behavioral models that present an alternative to the linear cause-effect assumptions of the EV theory. Charles Carver and Michael Scheier rely on a self-steered negative feedback loop (see Figure 13) as the fundamental process in their **Control Theory** of behavior (Carver and Scheier, 1982).

Figure 13. The Negative feedback loop in Control Theory. Taken from (Darnton, 2008)



The feedback loop also contains an element to compare the input-output discrepancy to a reference value and decide whether the action should be continued or abandoned.

A similar construct is Bandura's **Social Cognitive Theory of Self Regulation** (Bandura, 1991, 1977), in which the decision of whether to engage in a certain behavior depends on a calculation of its likely success.

2.12 Social Construction Models

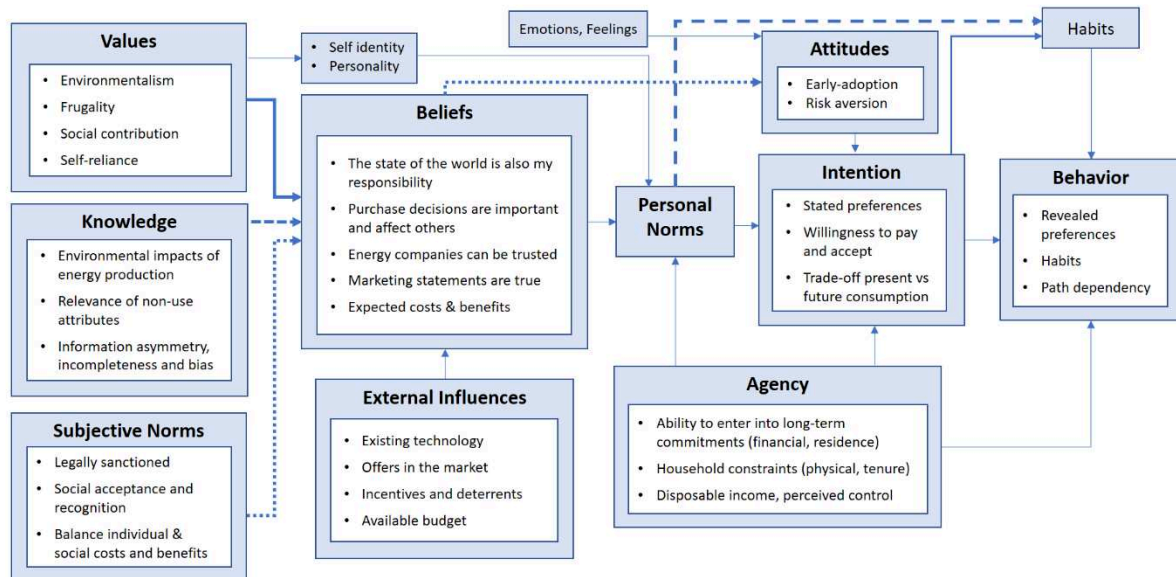
The last models to be explored here are those based on social constructs (Wilson and Dowlatabadi, 2007). They differ from previous approaches in that instead of taking the individual as the basic unit of analysis and then extrapolating or aggregating individual decisions to explain larger-scale phenomena, social construction models start from the premise that it is societies that establish individual aspirations and boundaries. In their view individuals are not independent to choose whatever goods and services they desire, but instead their needs, attitudes and expectations are

shaped by a complex web of norms, institutions, technologies and infrastructures, which some authors have called the **Sociotechnical construction of demand** (Summerton, 1992). This approach recognizes that the demand for energy is indirect and reflects what people really desire, i.e. to consume the goods and services energy makes possible. The drivers for that demand – a desired for a certain standard of living, comfort, cleanliness, etc. are "systematically configured" over long periods of time (Shove et al., 2005). It is therefore unsurprising that models centered on the individual often provide weak evidence to support their claims (Lutzenhiser, 2012). The alternative explanation proposed by sociological models is that households consume electricity as an adaptive response to their specific local conditions, which are highly heterogeneous (Shove, 2003; Shove et al., 1998).

According to (Wilson and Dowlatabadi, 2007) in order to understand residential energy use they rely heavily on '*embeddedness*', understood as the fact that energy is tightly blended into many household activities; '*constraints on choice*', which reflect the fact that households must choose only from the goods and services in the market; '*counter marketing*', in which the dominant social message is to motivate consumption rather than conservation; and '*impetus*', whereby energy does not play a prominent role in peoples' lives or finances.⁴

Figure 14 provides an example of how the items described in the previous sections could be adapted to the specific context of electricity production and consumption, which is the focus of this thesis.

Figure 14. Examples relevant to renewable electricity and its attributes.



3. CONCLUSIONS

The transition toward a sustainable society, of which the energy transition is part, depends on the choices made by all agents in society, of which end consumers constitute an essential part.

⁴ This has recently changed since early 2022 due to armed conflict in Europe and supply chain disruptions across the globe.

Recognizing the role of government policies and the dynamics of the market at large, it is individual choices that ultimately shape how electricity is produced and consumed, both directly and indirectly. In countries with elected governments individuals can influence the choices of governments, and in countries with relatively free markets they can decide which products and services prosper through their consumption decisions. How those decisions are formulated was the focus of this chapter.

To answer this question this chapter presented an overview of the main theories and models of behavior produced since the mid XX century. The intention was to go beyond the treatment of individuals as black boxes and attempt to answer the question *what lies behind the observed decisions of individuals?* as only in so doing do we stand a chance at influencing and predicting those decisions.

Many of the theories proposed so far, including the TRA, NAM, TPB, VBN and IBM share the same building blocks and rely on the same intuitions to reach similar conclusions, which is not surprising since several of them were developed by the same individuals. Others like the DoI employ radically different approaches that take empirical evidence as their starting point and develop a theory around it. After noticing their apparent contradictions, or to make them better fit the data, some authors have taken it upon themselves to 'improve' on these base models by merging or modifying them in different ways, with mixed results. However, it is the models stemming from radically different fields that offer the most novel ideas to frame future research and interpret their findings.

In contrast to the exact sciences where multiple theories and approaches compete to explain the same set of objective facts, in the social sciences these facts can only be known indirectly and vary depending on the methods used to uncover them. To explain behavior different theories and models can coexist as long as their intuitions continue to be useful to interpret observations, even if none of them can account for all the facts observed.

In Chapter 2 an understanding of how individuals make decisions will serve to shed light on why they are willing to pay a premium for certain unobserved attributes regardless of their gender, age or country of origin, and have been willing to do so since the first studies were carried out decades ago. In Chapter 3 we will describe a field experiment to estimate French households' willingness to pay for certain attributes of electricity, and in Chapter 4 we will delve into their motivations and the value they derive for joining an energy community.

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CHAPTER II

How French Households Value their Electricity Supply Choices

Abstract

This paper investigates the willingness to pay of French households for electricity from different sources and including different combinations of hedonic attributes. Using a discrete choice experiment of 503 households from the Auvergne-Rhône-Alpes region we assess the preferences of respondents for supplying their electricity (i) from the national grid, (ii) from a solar PV system in their home, or (iii) by joining a nearby energy community. The three hedonic attributes were green, local and autonomy (self-sufficiency). Analysis of the responses suggest positive valuations for all attributes (except local) when assessed independently, and negative valuations for most combinations, though their influence is limited. Overall, these results suggest there is untapped market demand for electricity from nonconventional sources, and willingness to pay a premium for the “right” combination of attributes.

Keywords: discrete choice, hedonic attributes, willingness-to-pay, renewable energy.

1. INTRODUCTION

The energy sector is central in the transition toward a model of development that balances economic growth with environmental and social imperatives. Despite a global 5.8% decline in CO₂ emissions in 2020 due to the Covid-19 pandemic, energy-related emissions rebounded by 6% in 2021 to reach a new record high of 36.3 gigatons because of the post-pandemic economic recovery. Of these, the largest increase took place in electricity and heat production, which accounted for 46% of the global increase in emissions, of which 36% from coal (IEA, 2022). The same source estimates that the expected rise in coal use will dwarf that of renewables by almost 60% this year. At the European level households accounted for 26% of final energy consumption in 2019, of which electricity represented 25%, a figure that is expected to double by 2030 (Eurostat, 2021). In addition to the long-term trend toward the electrification of transport and other domains (Wappelhorst, 2021) security and inflation concerns have recently gained prominence in Europe. As a result intermittent renewables have been losing priority relative to nuclear plants and fossil fuels, which can still deliver energy more predictably and sometimes also more cheaply. At least in the short-term European policy is shifting toward securing more reliable and diversified energy supplies rather than cleaner ones (European Commission, 2022).

Renewable energy sources are widely believed (United Nations, 2021) to be best positioned to fulfill the vision of an environmentally sound future, especially after the steep cost reductions they have experienced in recent years and more favorable laws and financial incentives in numerous countries (Wolske et al., 2017). As the cost of solar photovoltaic (PV) and energy storage systems has declined

in recent years relative to other sources of supply their adoption has become more widespread. In France, for example, solar PV capacity for self-consumption has increased roughly 4-fold since the previous network rates (TURPE 5) were published in 2017, reaching a total capacity of 223 MW (57,000 installations) at the end of 2019 (“Consultation publique n°2020-007 du 19 mars 2020 relative à la composante de soutirage des prochains tarifs d’utilisation des réseaux publics d’électricité « TURPE 6 »,” 2019). Collectively known as Distributed Energy Resources (DERs) when connected at low voltage (LV) or as Distributed Generation (DG) when connected at medium voltage (MV) and high voltage (HV) levels (Schwaegerl and Tao, 2014a), these systems were initially conceived as a backup rather than primary energy source. More recently, however, they have seen wider adoption as part of the primary energy supply in many households fueled by economic considerations and mounting concerns over greenhouse gas emissions (Soshinskaya et al., 2014). Ultimately it is individual consumers and households who spur the energy transition through their procurement choices. The energy that is not directly used by households in the form of heat, light, transport and other amenities does so indirectly, as households are also the ultimate consumers of most products and services produced by industry and government. Hence the importance of eliciting and understanding their consumption preferences when drafting public policies or tailoring new business offerings (Goulden et al., 2014; Sintov and Schultz, 2015; Verbong et al., 2013; Wolsink, 2012).

This paper aims to elicit the energy preferences of French households towards different *types* of electricity, and assess the strength of their preferences by revealing their willingness to pay (WTP) for them. Although electricity from all sources is the same at the point of consumption, it can be considered a differentiated product if its *hedonic attributes* are taken into account. Hedonic attributes refer to those unobservable characteristics of a product or service which, when subject to an individual’s values and preferences, modify their valuation of those products or services. The hedonic attributes in question are associated to its mode of production (green/renewable or conventional), the location of its production (local or national) and its contribution to energy autonomy (self-sufficiency) when combined with energy storage systems. Likewise, these attributes were matched to three possible supply sources: the national grid, a residential solar PV system, and a nearby energy community.

A first motivation for this study was the limited literature available on green electricity valuation in France. An extensive literature review of stated preference studies on green electricity uncovered only two examples for France. The first, by (Litvine, 2013) focuses only on small and medium enterprises, while the second by (Shi et al., 2013) provides only broad general estimates for different regions. Moreover, both studies report their findings in terms of percentages rather than absolute or marginal amounts. A second source of data are studies commissioned by national and international bodies such as the Organization for Economic Co-operation and Development (OECD, 2014), which by their nature are extensive but not exhaustive. In the absence of detailed information green suppliers in the French market have often commissioned their own market studies to assess opportunities and tailor their offers. Although some of these market studies have been made public (Corso, 2008; EnerCoop, 2021), most are never published lest they erode their owner’s competitive advantage. On the side of policy makers lack of precise information on consumer priorities often leads to blanket policies that easily lose momentum and are easy to abandon when budgets are curtailed.

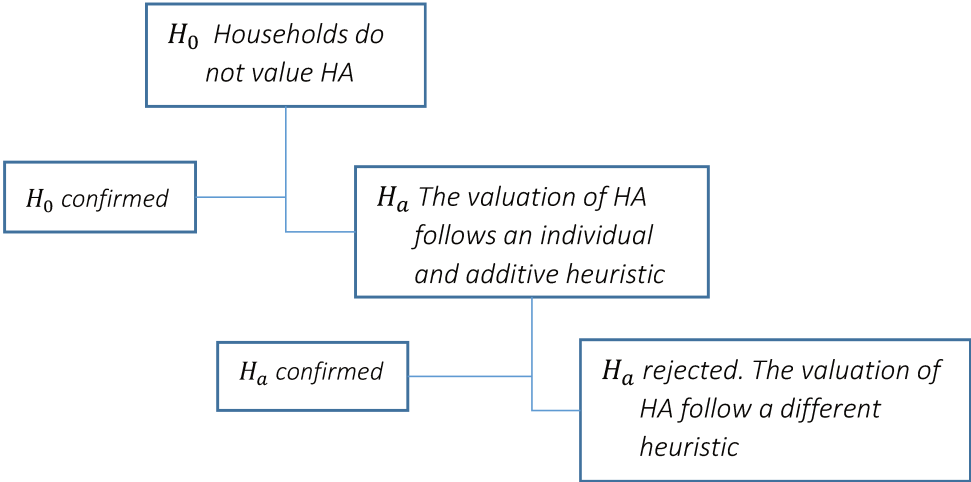
On the side of businesses lack of clear market opportunities (niches) make it more difficult to allocate scarce resources toward expanding their *green offerings*.

A second motivation is that most of the studies conducted to date ignore the interactions between attributes. In the case of electricity consumption all green power is equivalent as long as it complies with the applicable laws.⁵ Few studies have sought to explore the WTP for electricity produced from different technologies like wind, solar or hydro, and even fewer consider the effect that local job creation or self-reliance have on those valuations. It is not even clear if their effects are consistently synergistic or antagonistic, as responses sometimes suggest a willingness to pay for certain types of electricity, while in other cases respondents demand compensation. The influence of psychological effects such as the *part-whole bias* (Foster and Mourato, 1998) and especially the *composition rules* that people apply when combining attributes (Krantz and Tversky, 1971) are not yet well understood.

A third motivation for this study was the need to provide more fine-grained advice to decision makers in the public and private sectors to accelerate the deployment of clean energy sources, as well as raising awareness among the public regarding the choices at their disposal. So far limited research has led to a scant understanding of the preferences of French households vis-à-vis differentiated electricity products. This is especially notorious in the apparent inability to explain the recent surge in energy communities around the country⁶, which defy explanation if only conventional valuation methods are used.

It is a basic premise of this study that the value of electric power lies in its combination of use and non-use (hedonic) attributes. The hypothesis to be tested was whether (and by how much) certain hedonic attributes of electricity are valued by French households, or whether only the use attributes (e.g., heat and light) are taken into consideration when choosing their supply.

Figure 1. Hypotheses of the study



⁵ Specifically, as long as suppliers have the equivalent number of green certificates to back up their offerings.

⁶ The group *Energie Partagée* has documented 274 citizen energy communities (CECs) in France (Énergie Partagée, 2022)

The null hypothesis (H_0) is that only use attributes that produce tangible services are valued by households, and these can adequately explain their preferences and decisions. This is a conventional cost-based *status quo* scenario which implies that in the absence of observable differences a rational consumer would always choose the lowest price. If H_0 is rejected and hedonic attributes have value, the alternative hypothesis H_a explores whether the heuristic being used values attributes individually or whether the valuation process involves synergies between attributes.

In order to test these hypotheses a Discrete Choice Experiment (DCE) was designed and applied to 482 heads of household⁷ in early 2022, and the data processed using different regression models including a generalized linear model (GLM) and a multinomial logit model (MNL).

Section 2 of this paper provides a literature review of electric power valuation, energy communities, discrete choice literature and hedonic attributes. Section 3 introduces the methodology followed, from the experimental design to the implementation of the DCE. Section 4 presents the econometric model and analysis of the data, while Section 5 discusses the findings and concludes.

2. LITERATURE REVIEW

The subject of our research is the valuation of the hedonic attributes of electricity. Having touched on the why of this study in the introduction, we now turn to the what and the how. In the first case providing the reader with a general understanding of what hedonic attributes are therefore seems to be in order. In the second case the most common methods used by researchers to assign a value to these attributes was also deemed useful to understand the rest of the study.

2.1 Hedonic Attributes

Energy from distributed energy resources (DERs) like small-scale solar panels, wind turbines or heat pumps produce electricity as well as a bundle of heterogeneous products over which agents have different piecewise-constant valuations (Chen et al., 2013). While the underlying valuations do not affect its physical distribution, they govern the financial settlements between agents, which is a central tenet of electricity markets. Ample evidence (Contu and Mourato, 2020a; Dastrup et al., 2012b; Ecker et al., 2017, 2018b; Longo et al., 2006; Menges et al., 2005b; Mozumder et al., 2011; Sundt and Rehdanz, 2014; Yang et al., 2015b; Yevdokimov et al., 2019) suggests that when purchasing electric power some households are willing to pay a premium for hedonic (non-use) attributes that cannot be observed, measured nor explicitly verified at the point of consumption⁸ (Yang et al., 2015a). In practice an agent's WTP often serves as proxy for its measure of value (Yevdokimov et al., 2019), giving rise to disparate valuations of the same attribute. In addition to valuations for green energy WTP estimates can be found for such attributes as autarky (Ecker et al., 2018b; Hahnel et al., 2020; Hansla et al., 2008b), job creation (Bergmann et al., 2006a; Ecker et al., 2018b; Goett et al., 2000; Johnson and Desvousges, 1997; Kosenius and Ollikainen, 2013b; Longo et al., 2006; Shin et al., 2014b), improved social status (Dastrup et al., 2012b; Korcaj et al., 2015b) and altruism (Hansla et al., 2008b; Menges et al., 2005b) (See Table 1).

⁷ Defined as those individuals who pay all or part of their electricity bills and/or participate in the choice of supply.

⁸ Also termed "existence", "intrinsic" or "passive use" attributes in the literature. (Freeman III et al., 2014)

Table 1. Examples of hedonic attributes of electricity reported in the literature

Type	Dimension	Attribute	Example	References
Use	Economic	Price	Price, leveled cost Opportunity cost	(Hirsch et al., 2018; Yang et al., 2015a) (Freitas and Silva, 2015; Kirchhoff and Strunz, 2019)
		Quality	Reliability, customer service	(Gerpott and Mahmudova, 2009; Kirchhoff and Strunz, 2019)
Non-Use	Environmental	Green	Air pollution, climate change	(Balcombe et al., 2013; Groh and Möllendorff, 2020; Hirsch et al., 2018; Morstyn and McCulloch, 2019; Yang et al., 2015a)
	Social	Local	Employment, solidarity, local production, identity	(Morstyn and McCulloch, 2019; Palm and Eriksson, 2018; Tröndle et al., 2019)
	Psychological	Autarky, autonomy	Independence, self-sufficiency	(Ecker et al., 2018a; Müller et al., 2011; Pieńkowski and Zbaraszewski, 2019; Rae and Bradley, 2012)
		Control	Security, flexibility, privacy	(Cuijpers and Koops, 2013; Ecker et al., 2018b; Hirsch et al., 2018)
		Altruism	Philanthropy, moral obligation, warm glow	(Groh and Möllendorff, 2020; Ito et al., 2010; Morstyn and McCulloch, 2019; Wolske et al., 2017)
Status	Reputation, conspicuous consumption	(Adomatis et al., 2015; Dastrup et al., 2012a; Krovvidi, n.d.; Menges et al., 2005a; Satsiou et al., 2013)		

However, in contrast to electric power the value of hedonic attributes as approximated by consumers' WTP is not a linear function of the amount of electricity consumed. Psychological phenomena such as the '*warm glow effect*' or the desire for recognition or status can introduce discontinuities. In this study we will define hedonic (non-use) attributes as those characteristics of electricity conferred to it at the point of generation, which cannot be observed, measured nor explicitly verified at the point of consumption. The parameters used as predictors or correlates to explain these findings vary from one study to another. In Canada, for example, (Rowlands et al., 2003a) found that WTP a premium for green electricity was positively correlated with demographic characteristics such as education (0.193) and income (0.136) but negatively correlated to age (-0.163), while attitudinal characteristics varied between 0.187 and 0.246, and social participation at 0.133, all using Spearman's $\rho < 0.01$. Others (Ivanova, n.d.; Susaeta et al., 2011a) have found statistically significant positive correlations with educational attainment (0.289 at $p < 0.01$), a positive correlation to income and negative correlations to gender and age with varying degrees of significance. Yet others (Gracia et al., 2012a; Hammerstrom et al., 2016a; Hansla et al., 2008a; Kosenius and Ollikainen, 2013a; Longo et al., 2008; Oliver et al., 2011a) have explored the relationships between electricity consumption from different sources and the environmental, social

and political attitudes and beliefs of respondents.⁹ In this study the following three hedonic attributes and three supply sources were selected :

- **Green**

“Green” electricity comprises that produced from renewable sources, such as hydraulic, wind, solar or biomass. It is produced with negligible amounts of greenhouse gas emissions, mainly associated to the manufacture and transport of the necessary equipment. Nuclear energy is not considered renewable under this definition because its production depends on uranium (a non-renewable resource) and produces radioactive waste. It is the *technology* used that determines whether the electricity is green or not.

- **Local**

“Local” electricity refers to that produced near its place of consumption with any technology. In this study, we consider local electricity that produced and consumed in the same geographical region¹⁰. It is the *location* that determines whether an electricity is considered as local or not.

- **Autonomy**

Autonomy refers to the level of self-sufficiency or control that the consumer has over his or her consumption. It does not depend on technology or location, but on consuming the electricity produced by our own (PV) system rather than purchasing it from the grid. Levels of autonomy above 20-25% usually require storage.

2.2 *Stated Preference Methods*

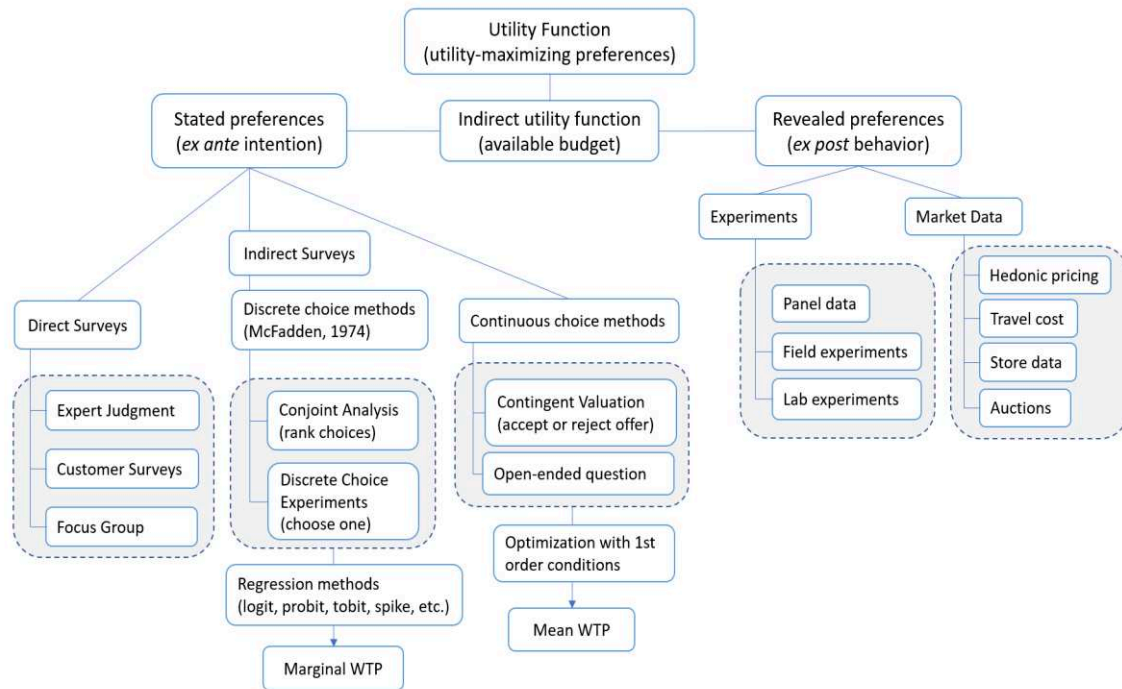
To uncover the motivations of individuals economists have often relied on methods that elicit their stated or revealed preferences. Those based on stated preferences present (non-adopter) respondents with a set of hypothetical choices and explore their responses, while those based on revealed preferences analyze the past decisions made by (adopter) respondents. Stated preference methods can be subdivided into direct surveys, discrete choice methods (DCM) and continuous choice methods. Of these, conjoint analyses (CA), discrete choice experiments (DCE) and contingent valuations (CV) are the most common. Although definitions vary from one author to another, for the purposes of this study a DCE is an exercise where respondents are presented a series of choices that combine different attributes and levels and asked to choose one. If instead respondents are presented the same choices but asked to rank them in order of preference, e.g. most to least, best to worst, it will instead be a CA. In a CV, in contrast, respondents are either asked their maximum willingness to pay (WTP) or willingness to accept (WTA) for an increase or decrease in a given attribute (open-ended version) or asked if they would take or leave an offer at a specific price (bounded version). Although differences in valuations between DCEs and CVs are frequent, authors disagree regarding which one produces higher values (Sundt and Rehdanz, 2015).

⁹ In developing countries motivations often differ, and focus more on power availability and reliability.

¹⁰ In our case the French region of Auvergne-Rhône-Alpes.

In the energy sector, a study of stated preferences could for example survey a sample of the general population to find out their WTP or WTA a financial compensation for specific attributes, such as whether it is produced by renewable sources or whether it is produced locally. In contrast, a study of revealed preferences could focus on those electric power consumers who have already subscribed to a specific energy plan or who have installed a solar photovoltaic system (PV) on their rooftop to uncover their motivations for so doing.

Figure 2. Stated Preference Methods. Adapted from (Breibert et al., 2006a; Carson and Louviere, 2011; Humphrey et al., 2019)



Stated preference studies make up the bulk of the literature. Examples include (Mozumder et al., 2011) who found that a 10% share of renewables in the electricity consumed was worth an additional US 5-14 per month to respondents in New Mexico. Nationwide in the U.S. (Aldy et al., 2012) found the value of the premium to be 13% (US 162 per year) for clean energy. In the Netherlands (van Putten et al., 2014a) found that the value of the average clean energy premium varied depending on whether the implementation was to take place in respondents' houses (€ 9.51 - 14.58/y) or at the neighborhood level (€ 9.97 - 20.41/y). Similar results were found by (Bertsch et al., 2016) in Germany, where it was found that public opinion broadly supported the transition to a clean energy matrix at the national level, while showing strong resistance to large-scale deployment of renewables at the local level. Also in Germany (Hahnel et al., 2020) conducted a stated preference experiment that identified four customer groups that systematically differed in their decision-making strategies while researching the preferences of German households. Although the definitions varied from those employed in the present study, his findings uncovered that virtually all households could reliably be classified as either classic consumers (22.6 %), price-focused prosumers (38.9 %), autarky-focused

prosumers (31.6 %) or heuristic prosumers (7.0%). The same study also found that prosumers were on average more willing to invest in shared infrastructure to enable P2P electricity trading. Finally, a study by a team of researchers from the United States and South Korea (Shin et al., 2014b) found a much lower average premium, with households willing to accept only a 1.39% (US 0.67 monthly) price increase to raise the share of renewables in their energy mix. A table with the main attributes found in the literature is presented below.

Within the DCM framework numerous empirical studies have been carried out that correlate WTP for green electricity to various demographic, social and attitudinal characteristics. Others (Ivanova, n.d.; Susaeta et al., 2011a) found statistically significant positive correlations with educational attainment (0.289 at $p < 0.01$), a positive correlation to income and negative correlations to gender and age with varying degrees of significance. Yet others (Gracia et al., 2012a; Hammerstrom et al., 2016a; Hansla et al., 2008a; Kosenius and Ollikainen, 2013a; Longo et al., 2008; Oliver et al., 2011a) have explored the relationships between electricity produced using different technologies and sourced from different locations and consumers' environmental, social and political attitudes and beliefs.¹¹

In the case of residential PV adoption in various countries, and after controlling for the physical characteristics of the household, logarithmic regressions and other econometric procedures have found that statistically significant predictors of adoption include an array of apparently disparate factors. They comprise the expected energy savings and the combined endorsements from experts and friends (Scarpa and Willis, 2010a), trust in private firms and interest in participating in citizen discussions of proposed DER projects (significant at the 95% level) (Kontogianni et al., 2013a), and a desire for more independence (0.174 at $p < 0.05$) (Claudy et al., 2011a), among others. Often, however, the WTP that resulted from these factors was not sufficiently large to cover the capital costs associated to the installation of (private) solar PV or other micro-generation technologies. This is in stark contrast with the fact that solar PV systems are being purchased and installed by households in many countries.

Part of the explanation lies in econometric models' description of behavior at an aggregate level while downplaying the highly heterogeneous preferences of outliers (Wilson and Dowlatabadi, 2007). Another explanation suggested by (Laitner et al., n.d.) is that the poor characterization of heterogeneous preferences fail to capture the underlying factors guiding behavior, and thus provide only weak and contradictory explanations for the adoption of residential PV systems. The available valuations of energy attributes vary by date, location, sampled population and econometric method, and often provide contradictory guidance to decision makers.

In this study the choice of a residential PV system was made on two grounds, recognizing that energy demand is in essence a derived demand for energy services in the form of *use* and *non-use* characteristics or attributes (Lancaster, 1966). First, it provides a typical example of a System 2 decision process (Kahneman, 2002) that is tractable from a discrete choice perspective, yet where strict cost-benefit calculations often fail to fully explain peoples' behavior and WTP (Whitehead and

¹¹ In developing countries motivations often differ, and focus more on power availability and reliability.

Cherry, 2007a). The system 2 contention is based on the presumption that an investment that typically amounts to tens of thousands of euros and lasts 20 to 30 years is not taken impulsively by individuals or households in real life, though the answers to stated preference surveys that carry no commitment or cost to a respondent might indicate otherwise. Second, it is a situation where the decision process can be swayed by unobserved individual values, norms, beliefs and attitudes to produce an intention (stated preferences) or behavior (revealed preferences), and hence where standard DCM methods are likely to produce inaccurate (false) or unreliable (high variability) estimates.

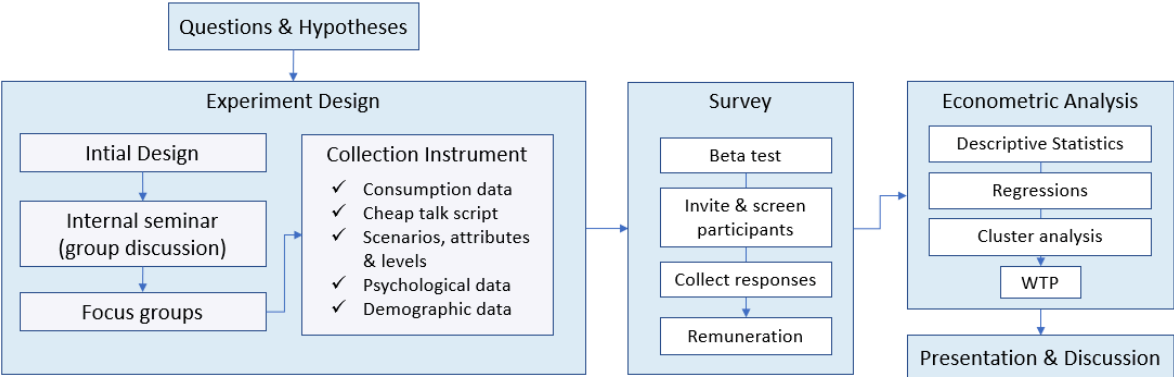
3. METHODOLOGY

For this study we chose stated preference methods as they can be better fine-tuned to maximize the contrast between attributes and capture small differences of degree within the same attribute. In contrast to their revealed preference counterparts, stated preference methods also make it possible to inquire about products and services that do not yet exist in the market, as is the case for many hedonic attributes. Within stated preference methods a DCE was chosen over a CV to obtain marginal WTP (the premium above the regular rate) rather than mean WTP (an estimate of the total payment), since the latter provides an estimate for the combined use and non-use (hedonic) attributes. Finally, regression methods were selected to process the data, as they provide an effective means to disentangle the influence of the different choice attributes and individual characteristics.

3.1 Experiment design

After specifying the initial hypothesis, a DCE was designed by adapting the stages from (Bridges et al., 2011; Reed Johnson et al., 2013) to the objectives of this study. A review of the literature also provided guidance in selecting the relevant sources, attributes, levels and their combinations, as well as econometric methods best suited to process the data obtained. The DCE design included three large blocks of activities that represent the three stages of the study: the experimental design (planning), implementation in the field (survey) and interpretation of the data (econometric analysis). The process is illustrated in Figure 3 below and described in the next pages.

Figure 3. Experiment design



3.1.1 Internal Seminar

A preliminary version of the research protocol was presented internally to other colleagues on January 6th, 2022, to collect feedback on the general methodology and data treatment. This seminar was useful to validate the general methodology and to modify some key aspects of the data collection instrument. Among other things the number of choice situations per scenario was reduced from four (three and a default) to three (two and a default) in order to reduce the mental effort demanded of participants, and an initial design requesting respondents to rank choice situations from most to least preferred (CA) was replaced by one in which only one option was chosen (DCE).

3.1.2 Focus Groups

Two focus groups were conducted with volunteers from the local population to discuss key issues of the questionnaire on the 14th and 17th of March 2002. Each focus group was comprised of nine people recruited from a large database of volunteers that has been compiled by the lab over several decades. Being the person responsible for paying for or deciding on the electricity services in their homes was a requirement to participate. The sessions lasted approximately two hours and participants were remunerated 30 € each for their time. A large screen and two flipcharts were employed as visual aids during the sessions.

The aim of the focus group was to ensure the vocabulary of the instructions and questions in the survey was easily understood by the average layperson unfamiliar with energy attributes and communities.¹² A simple script comprising two large (40 min) sections was followed for both sessions. The first section of the script was designed to gain a general sense of participants' knowledge and attitudes toward the electricity attributes of interest, while the second aimed to elicit individual attitudes toward individual and collective self-consumption.

Upon arrival participants had to sign a statement consenting to the recording of the sessions, and the anonymized use of the information collected for research purposes in line with the EU's General Data Protection Regulation (RGPD). After welcoming participants and providing a brief introduction, including a round of presentations, the first section was opened with an exercise in free associations where participants had to write down the nouns or adjectives that came to mind when hearing about green, local and self-produced electricity, before sharing them with the group. The free association exercise was followed by a set of true/false questions regarding the country's energy mix, the electricity supply choices in France and the implications of switching their supplier. The section concluded with a few questions to stimulate a free discussion among participants.

The same dynamic was followed for the second section on self-consumption, with basic diagrams on solar PV self-consumption with and without storage replacing individual attributes. The free associations exercise was followed by true/false questions on what self-consumption schemes are allowed by current laws and regulations in France and concluded with a discussion on participants'

¹² This was only partially achieved, as two individuals in a group were former employees of the state electricity company and were familiar with most of the content presented.

hypothetical motivations to install solar panels or join an energy community. To close the sessions the recording was halted, and participants were invited to share their general impressions freely with the organizers. Payments were disbursed in cash before their departure.

The focus groups were successful in corroborating the clarity of language and concepts of the Survey. Green (renewable) electricity was by far the most widely known category, followed by local and self-sufficiency. The understanding of “green” varied across participants, with some questioning why nuclear energy was not included since it produced no emissions. A surprisingly high number also mentioned hydro as an important renewable technology. In terms of attitudes toward green electricity the views were mostly positive, with a few having the impression that it was more a marketing gimmick than an actual improvement. Most participants appeared not to have a previous opinion on local electricity and energy self-sufficiency, but nevertheless expressed an overall positive attitude towards those concepts. Cost and housing constraints (e.g., apartments) were often mentioned to explain a low uptake of individual PV systems. The true/false knowledge questions were answered correctly by most participants.

Following these findings, the attribute definitions and other explanations in the questionnaire were modified to dissipate the most common misunderstandings by participants. On a question regarding the familiarity of respondents with the term “green electricity” instead of a yes/no answer more nuanced options were introduced, such as “yes, and I’m interested”, “yes, but I’m not interested” and “yes, but I don’t know what it means”. A former “control/autarky” attribute was replaced by the more familiar “self-sufficiency/autonomy”. Although the terms “self-consumption” and “self-production” were often used interchangeably during the discussions, the term self-consumption was retained in the questionnaire.¹³

3.1.3 Collection Instrument

A web-based questionnaire was prepared using *LimeSurvey* version 3.24.3, an open-source survey platform. A total of 60 questions were split into three sections. An English translation is reproduced in Annex VIII.

The first section of 20 questions included a brief introduction to the survey, the data protection guidelines and an oath to answer honestly and to the best of their ability, which previous research suggests encourages honest responses (Jacquemet et al., 2019, 2013). Participants had to accept both items before proceeding. This was followed by two screening questions inquiring whether the respondent either (i) paid in whole or in part for the electricity bill in their home and/or (ii) would participate in the choice of a new supplier if a switch proved necessary. A negative response to both questions resulted in the immediate exit from the survey without the possibility of rectification. From this point onwards backward navigation was disabled. The remainder of the questions in this section referred to household characteristics that served as consumption proxies, including the type of house, occupancy, area, general heating and water heating, and some additional items such as their

¹³ These terms refer to different concepts. Whereas *self-production* refers to the percentage of a household’s overall consumption that is produced by itself, the term *self-consumption* refers to the percentage of the energy produced by a household (however small) that is also consumed by itself. Complete self-production is thus equivalent to complete self-sufficiency, but complete self-consumption is not.

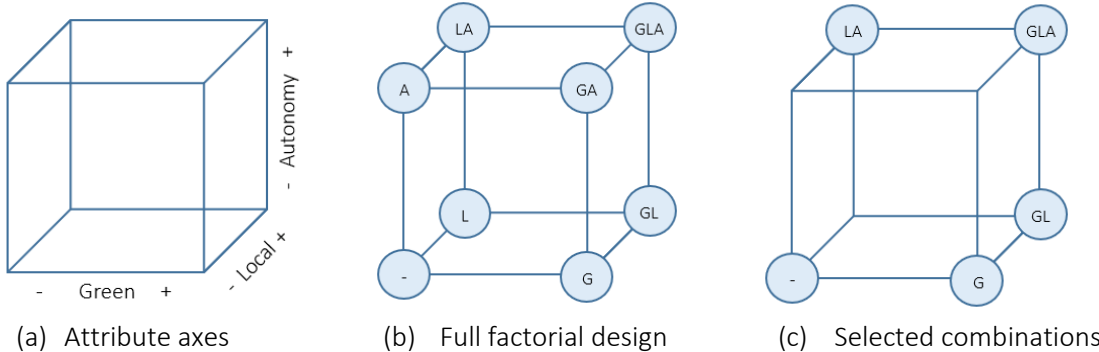
average monthly bill, the ownership status (owned, rented or shared) and the type of supply currently subscribed. These inputs were used to customize subsequent scenarios. Estimating consumption from proxy data was made possible thanks to a spreadsheet shared by colleagues at EdF-R&D¹⁴, which identified the main drivers of residential electricity consumption in France and used them to extrapolate an average monthly consumption for each combination.

The second section focused on consumption preferences. It was here that the different attributes and sources of electricity were introduced. The experiment was limited to three hedonic attributes: green, local and autonomy; and three sources: the national grid, individual self-production/consumption (abbreviated as “self”) and a self-production/consumption community (abbreviated as “P2P”). A cheap talk script also informed participants that the energy mix in France was on average 74% nuclear, 18% renewable or “green” and 8% fossil. These numbers were obtained by averaging the relative abundance of these sources as reported by the national transmission operator RTE over the period 2017-2021. A hypothetical situation was then presented whereby starting from a standard contract with a conventional supplier (< 25% green, 0% local and 0% autonomy) the respondent had to choose between a market supplier (with a conventional or green offer), installing an individual system in their home (e.g., solar PV) or joining a local energy community. Participants were also informed that the quality of supply and customer service was identical for all sources and the transaction costs for switching sources or attributes was negligible. The average monthly consumption was assumed to remain unchanged.

Choice Cards

Scenarios contain two random choice sets (situations) and a default option. Each choice set is made up of a different combination of four attributes: green (G), local (L), autonomy (A) and price (P). This can be represented by a cube plot of hedonic attributes where price is an additional attribute that applies to all corners and corresponds to Figure (a). As can be seen in Table 2 in the actual choices the green attribute contains three levels (G1 – G3), the local attribute three levels (L1 – L3), the autonomy attribute three levels (A1 – A3) and the price attribute five levels (P1 – P5). A full factorial design would thus require every respondent to evaluate $4^1 \cdot 3^1 \cdot 3^1 \cdot 5^1 = 180$ combinations, illustrated by Figure (b), even though many of the combinations are unfeasible or very unlikely in practice.

Figure 4. Attributes selected for the choice cards



¹⁴ We are grateful to our colleagues at EdF for this information and their suggestions to improve the survey.

It was at this point that an existing software package could be leveraged to generate the different combinations. In this experiment we opted for *Ngene* version 1.3.0. *Ngene* is used to compute numerous combinations that maximize the contrast (minimize the correlation) between attributes, i.e., orthogonality. In addition, it is also capable of producing *efficient designs* to minimize standard errors. For the *Ngene* simulations a multinomial logit formulation of type

$$U = \alpha + \beta_2 A + \beta_3 B + \beta_4 C + \beta_5 D \quad (1)$$

and a random parameter (mixed) logit formulation of type

$$U = \alpha + \beta_2 A + \beta_3 B + \beta_4 C + \beta_5 D + \varepsilon_2 + \varepsilon_3 + \varepsilon_4 + \varepsilon_5 \quad (2)$$

were used. A total of 60 scenarios were produced, each with two distinct sets and the default. The code used to generate the *Ngene* cards is reproduced in Annex I. *Ngene* produces efficient designs, but not necessarily designs that are physically or economically realistic.

Including unlikely designs would not only make the scenarios less credible but also produce hypothetical estimates for products unlikely to ever reach the market.

For example, one could theoretically envisage an autonomy-only option (A) if a household installed an energy storage system without an associated generation source and engaged in price arbitrage of conventional grid electricity at different times of the day – however, the autonomy thus achieved would be illusory and hardly cost-effective.

As another example a local-autonomy option (LA) that required households to install non-green microgeneration technologies (e.g., diesel generators) would only shift dependence from the grid to the fuel supplier and (again) hardly be cost-effective. In order to screen physically unfeasible and economically unlikely combinations the following constraints were introduced:

1. The green attribute can be self-produced or purchased from third parties. In this experiment all local is assumed to be green, i.e., no fossil microgeneration technologies. This means the share of *local* in individual and collective self-consumption is never greater than the share of *green*.
2. The local attribute can be self-produced or purchased from energy communities. All self-production is local and supply from the national grid is never local.
3. The autonomy attribute can only be obtained by combining (PV) self-production with storage. Electricity purchased from an energy community is assumed not to provide autonomy, since the (consumer) household is still reliant on an outside third party for its supply. Energy storage without an associated energy source (e.g, arbitrage using the grid) is not considered an economically viable option.
4. The degree (percent) of autonomy cannot exceed the degree (percent) self-produced within a household or an energy community. In practice this also means the share of *autonomy* is never greater than the share of *local*.

Applying these restrictions reduced the viability space to the combinations in Figure (c).

Table 2. Choice cards for the final ten scenarios.

No.	grid.G	grid.L	grid.A	grid.P	p2p.G	p2p.L	p2p.A	p2p.P	pv.G	pv.L	pv.A	pv.P
1	2	1	1	1	2	3	1	4				
2	3	1	1	2	3	2	1	3				
3	1	1	1	1					1	2	2	2
4	2	1	1	2					3	3	3	3
5	3	1	1	3					3	3	3	4
6					1	2	1	2	3	2	1	2
7					3	3	1	3	3	3	3	3
8					2	2	1	1	3	2	2	3
9					3	2	1	2	2	3	1	2
10					2	3	1	3	3	3	3	4

NOTE: *grid.g*, *p2p.g*, *pv.g*: green attribute from grid, community and individual system, respectively. *grid.l*, *p2p.l*, *pv.l*: local attribute from grid, community and individual system, respectively. *grid.a*, *p2p.a*, *pv.a*: autonomy attribute from grid, community and individual system, respectively. *grid.p*, *p2p.p*, *pv.p*: price premium from grid, community and individual system, respectively.

In practice this reduced the initial set of 60 scenarios to 15 and ultimately to 10, which was also done to limit the time and effort required of respondents. The assumption was that three choices (two choice sets and a default) was the maximum number that a respondent could reasonably assess in each scenario. The final selection included two grid vs p2p (community) combinations, three grid vs PV (individual) combinations and five P2P vs PV combinations. This is also shown in Table 2, where each row represents a scenario and the groups of columns named grid, p2p and pv contain the attribute levels of their corresponding choice sets.

Scenarios and Attribute Levels

In defining the value ranges for each attribute steps of 25% were chosen for green, local and autonomy. Although 100% green electricity is possible the green attribute was limited to a range of 25/50/75 with 25% as the attribute floor.¹⁵ The initial 0/25/50/75 range for local and autonomy was revised down to 0/25/50 following a recommendation from colleagues at EdF R&D who reviewed the draft survey for consistency. This seems sensible given that in all cases households maintain a connection to the main grid for back-up. In the case of the price attribute steps of 5% were chosen in the range 0/5/10/15/20.

The price premium was capped at 20% following the findings by (Shi et al., 2013), who observed that a 0 - 15% price premium for green electricity covered 80 - 85% of French households nationwide, while higher premiums of 16 - 30% accounted for barely 5 - 6% of households.¹⁶

¹⁵ The content of renewables in the national grid provides a floor to all electricity sources in the study. To foster symmetry the 18% average green content in the cheap talk script was represented as < 25%.

¹⁶ Between 9% and 17% of respondents in that study could not formulate a response at all.

Table 3. Attribute values and their sources

Attribute	Code	Level	Value	Source		
				Grid	P2P	Self
Green	G1	<i>status quo</i>	<25%	●	-	-
	G2	Low	50%	●	●	●
	G3	Medium	75%	●	●	●
Local	L1	<i>status quo</i>	0%	●	-	-
	L2	Low	25%	-	●	-
	L3	Medium	50%	-	-	●
Autonomy	A1	<i>status quo</i>	0%	●	-	-
	A2	Low	25%	-	●	-
	A3	Medium	50%	-	-	●
Price premium	P1	<i>status quo</i>	+ 0% (€/m)	●	●	●
	P2	Low	+ 5% (€/m)	●	●	●
	P3	Mid-Low	+ 10% (€/m)	●	●	●
	P4	Mid-High	+ 15% (€/m)	●	●	●
	P5	High	+ 20% (€/m)	●	●	●

The price percentages in each scenario were also translated into their euro equivalents using the individual billing information obtained in the first part of the survey. It was also made clear to participants that the prices shown represented supplementary (marginal) premiums over the base contract, and not total cost. Combining the choice cards in Table 2 with the attribute levels in Table 3 produced the final values of the ten scenarios included in the survey, shown in Table 4.

Table 4. Final ten scenarios used in the survey.

No.	grid.G	grid.L	grid.A	grid.P	p2p.G	p2p.L	p2p.A	p2p.P	pv.G	pv.L	pv.A	pv.P
1	50%	0%	0%	0%	50%	50%	0%	15%				
2	75%	0%	0%	5%	75%	25%	0%	10%				
3	25%	0%	0%	0%					25%	25%	25%	5%
4	50%	0%	0%	5%					75%	50%	50%	15%
5	75%	0%	0%	10%					75%	50%	50%	20%
6					25%	25%	0%	5%	75%	25%	0%	10%
7					75%	50%	0%	10%	75%	50%	50%	15%
8					25%	25%	0%	0%	75%	25%	25%	15%
9					75%	25%	0%	5%	50%	50%	0%	10%
10					50%	50%	0%	10%	75%	50%	50%	20%

NOTE: *grid.G*, *p2p.G*, *pv.G*: green attribute from grid, community and individual system, respectively. *grid.L*, *p2p.L*, *pv.L* : local attribute from grid, community and individual system, respectively. *grid.A*, *p2p.A*, *pv.A*: autonomy attribute from grid, community and individual system, respectively. *grid.P*, *p2p.P*, *pv.P*: price premium from grid, community and individual system, respectively.

How the values in this table translate into scenarios can be illustrated as follows. Taking Scenario 1 as an example, the first row in Table 4 contains a *grid* choice card and a *p2p* (community) choice card. The grid choice card in turn contains 50% of green and 0% of local, autonomy and cost, respectively. In contrast, the *p2p* choice card contains 50% of green, 50% of local, 0% of autonomy and a 15% price

premium. These combinations were presented in the survey as shown in Figure 5. The amount in euros at the bottom was tailored to each participant.

Figure 5. Illustration of a scenario produced from the selected choice cards

Offer	Offer A	Offer B	CURRENT
 Source	Supplier (national grid)	Self-consumption community (P2P)	Supplier (national grid)
 Green	75 %	75 %	< 25 %
 Local	0 %	25 %	0 %
 Autonomy	0 %	0 %	0 %
 Additional cost (compared to current bill)	+5 % 2.1 €/month	+10 % 4.2 €/month	0 % 0 €/month
Your choice	<input checked="" type="radio"/>	<input type="radio"/>	<input type="radio"/>

3.2 Survey

3.2.1 Beta Test

The beta test is intended to try out the survey on the “real” subjects targeted by the study but on a limited scale. In the absence of major shortcomings, the data collected can be combined with that of the main survey. Otherwise, it serves to fine-tune the last logistical details before the main experiment.

Invitations to the beta were sent out by email to 215 potential candidates from the lab’s volunteer database, of which 130 responded favorably and subsequently received the link to access the survey. Most records in the database correspond to residents of the Auvergne-Rhône-Alpes (ARA) region in central-eastern France. The invitation specified that since the survey involved electricity preferences only people who paid for or decided on the electricity supply in their household could participate. It also mentioned that it took ca. 30 min to answer and complete responses would be remunerated with 10 euros, to be disbursed using an online platform. Since individual-specific links were sent out, it was possible to track in real time who had already replied and who had not, and reminders sent out accordingly. In the end the beta collected 116 individual responses between March 15th and 17th.

Despite initial hesitation, the beta proved invaluable to uncover that one of the scenarios had mistakenly been hidden from respondents, thus collecting only nine choice combinations instead of ten. After internal discussion it was agreed that the statistical methods available (e.g., extrapolation and bootstrapping) did not entirely compensate for the missing scenario, nor should the main

experiment be devoid of one scenario to force compatibility. The decision was therefore taken to use the results of the beta for data testing purposes, but not to include them in the final analysis.

3.2.2 Main Survey

Following the same dynamic of the beta, the main survey invited 886 different volunteers from the same database, receiving 539 positive responses. After numerous reminders 503 complete responses were collected between March 29th and 31st.

An important drawback to using a web survey was the high number of bounced messages, which were either prevented by firewalls from reaching their destination or were delivered to spam folders. This was particularly notorious for Gmail accounts. Another frequent complaint was that the disbursement process was long and cumbersome. That the disbursement was outsourced to a specialized company and required participants to download an app to their mobile phone may also have contributed to this impression. On the positive side, the comments left by participants at the end of the survey conveyed a positive experience which had in several cases spurred their interest to learn more about the subject.

Since survey links could be used only once, no backward navigation was allowed and unregistered participation was disabled, it proved useful to enable the “token-based response persistence” option in LimeSurvey so incomplete surveys could pick up where they had previously left, e.g., after receiving a reminder. After removing outliers¹⁷ the average time needed to complete the survey was 20:09 min, with a range between 6:25 min and 1 hour 52 min, and a long tail to the right.

4. RESULTS

4.1 Descriptive statistics

The composition of the respondent sample shows a population dominated by middle-aged apartment owners with medium size families. This contrasts with a 2018 regional average that split house and apartment dwellers evenly, and with a 2021 national average¹⁸ that found 55.1% of the population living in houses vs. 44.9% in apartments. The owner vs. tenant ratio is very close to the 2018 regional average, as is the average number of occupants per dwelling. A national survey¹⁹ in 2021 found similar numbers with 57.9% owners vs. 39.8% tenants.

Using the base rate as a default also appears to be a justified, as it accounts for over four-fifths of respondents. Electric heating accounts for roughly a quarter of responses, which is almost identical to the regional average. Electric water heating is present in two-fifths of responses, below the

¹⁷ This included 16 respondents who took more than 3 hours to complete the survey, such as those that completed the exercise over several days.

¹⁸ Répartition de l'habitat individuel et collectif selon la taille de l'unité urbaine au 1^{er} janvier 2021, Insee.fr.
<https://www.insee.fr/fr/statistiques/5761272#graphique-figure3>

¹⁹ Répartition des résidences principales selon le statut d'occupation, Insee.fr
<https://www.insee.fr/fr/statistiques/5761272>

national average of 46.5% for primary residences and 51.9% of houses nationwide in 2016, the most recent year for which official data are available (ADEME Expertises, 2016).

In terms of demographics about half of all individuals living alone in the region are seniors (80 years old and above), while the remaining half is distributed more or less evenly across the remaining age groups. In the sample adults 40-54 years old are therefore overrepresented. Since middle-aged adults tend to consume more energy and spend more on electricity than seniors in absolute terms and as a percentage of their income (Dussud et al., 2017; Merceron and Theulière, 2010) our sample is likely to overstate household energy consumption when extrapolated to the regional population.

The sample is also dominated by educated and affluent female respondents in mid-level jobs earning 43% more than the national average (2,340 €/month) and 77% more than the regional average (1884 €/month). Blue collar workers, retired and unemployed individuals are also underrepresented. To the extent that income is a good predictor of WTP this is also likely to overstate the willingness of the average consumer to pay for specific attributes. More details are provided in Table 5 and Annex III.

The variables *[EST_CONS]* and *[EST_BILL]* refer to the estimated consumption and estimated bill for each respondent, respectively, based on their responses to the proxy variables TYPE, AREA, OCCUP, HEAT and WHEAT. They were included here to corroborate their stated monthly consumption and payment, which are prone to be misread given that different suppliers employ different billing formats and issue statements at different intervals throughout the year.

Table 5. Descriptive statistics of the respondent sample

HOUSEHOLD	Value	No.	%	Reference
Type of dwelling (TYPE)	House	157	31.2%	49.9 %
	Apartment	346	68.8%	49.1 %
	Owner	309	61.4%	58.8 %
Tenure (PROP)	Tenant	185	36.8%	39.1 %
	Shared	9	1.8%	N/A
Occupancy (OCCUP)	Mean no. of residents	503	2.6	2.19
Electricity bill (BILL)	€/month	455	70.5	184 (200) ²⁰
<i>Electricity bill (EST_BILL)</i>	<i>Estimated, €/month</i>	503	82.7	184 (200)
<i>Power consumption (EST_CONS)</i>	<i>Estimated, kWh/month</i>	503	321.8	451.4
Current contract (CONT)	Regular supplier	421	83.7%	N/A
	Green supplier	45	8.9%	N/A
	Self-production	3	0.6%	N/A
	Other	34	6.8%	N/A
Main heating (HEAT)	Percentage electric heating	131	26.0%	26.2 - 32.4 % ²¹
Water heating (WHEAT)	Percentage electric water heating	193	38.4%	46.5 % ²²

²⁰ 184 €/m France, 200 €/m ARA. Source : Baromètre 2021 MonExpert : <https://monexpert-renovation-energie.fr/>

²¹ Insee, *Système d'analyse de la population par l'historique des recensements* (Saphir) de 1968 à 2018.

²² Ademe <https://expertises.ademe.fr/batiment/passer-a-l'action/elements-dequipement/leau-chaude-sanitaire>

DEMOGRAPHIC	Value	No.	%	Reference
Age (AGE)	Mean (2022 – year of birth)	503	43.5	15 % ²³
Gender (GEN) ²⁴	Male	144	29.1%	48.6 %
	Female	351	70.9%	51.4 %
Education (EDU) ²⁵	High school or below	113	22.5%	47.9 %
	Advanced degree	390	77.5%	31.8 %
	Self-employed	29	5.8%	4.7 %
Employment (JOB) ²⁶	Mid-level professionals	173	34.4%	24.6 %
	Employees	175	34.8%	15.6 %
	Blue collar worker	4	0.8%	12.4 %
	Intermediate occupation	63	12.5%	15.2 %
Household income (INC)	Retired	35	7.0%	27 %
	Unemployed	24	4.8%	15.7% (2020)
	Mean (€/m)	503	3,346	1,884 (2019)

Specifically, responses to these five items were matched to the average annual electricity consumption for French households using a table of historical residential consumption provided by EdF and divided by twelve to obtain the average monthly electricity consumption for each respondent. The conversion from kWh/m to €/m was performed assuming the average French household had a contract for 6 kVA²⁷ and purchased electricity at EdF's base rate²⁸, including the applicable fixed and variable taxes.²⁹ This estimate was deemed more accurate than the monthly bill (*BILL*) registered by respondents, which was measured at different intervals by different companies and varied throughout the year.

4.2 Econometric Analysis

The literature on choice experiments to determine WTP for specific attributes spans a wide array of methods and models, which can be broadly classified into five model families: linear, logit, probit, tobit and other. There are abundant examples of studies employing all these methods, and frequently

²³ Within the population living alone in 2018, 7.1% had between 15-19 years; 22.7% had between 20-24 years; 16.0% had between 25-39 years; 15.0% between 40-54 years; 22.6% between 55-64 years; 28.1% between 65-79 years; and 49.2% 80 years or more. All statistics were obtained from Insee.fr for the Auvergne-Rhône-Alpes region in the year 2018 unless otherwise specified.

²⁴ Eight individuals who opted not to indicate their gender were omitted from the calculation.

²⁵ The mean age at completion is based on the French educational system where the *Brevet des collèges* (Junior School Certificate) is obtained at 15; the CAP/BEP (Vocational diploma or equivalent) at 16; *Baccalauréat* (High school or equivalent) at 18; and the *Diplôme du supérieur court* (Advanced Technical Certificate) at 20. Since all subsequent degrees are included in the next category *Diplôme du supérieur long* (Bachelor's degree and higher), a minimum value of 3 years for the bachelor was considered.

²⁶ Self-employed includes *agriculteurs exploitants* and *artisans, commerçants, chefs d'entreprise*; mid-level professionals are *cadres et professions intellectuelles supérieures* and *professions intermédiaires*. The rest are employees (*employés*); Blue collar workers (*ouvriers*); Retired (*retraités*); and Unemployed (*autres personnes sans activité professionnelle*).

²⁷ This corresponded to a monthly fixed fee of 8.175 €/m.

²⁸ Locally known as *tarif bleu, option base*. For the first trimester of 2022 this was equivalent to 0.1740 €/kWh.

²⁹ Fixed taxes include the transmission and distribution fee CTA (21.93% of the fixed fee) while variable taxes include the supply fee CSPE (0.001 €/kWh), the final local consumption fee TCFE (0.00663 €/kWh) and a VAT (TVA in French) that amounted to 5.5% of the fixed fee and CTA, and 20% of the base amount, CSPE and TCFE.

several of them in the same study to compare results. Their main features are presented in the table below.

Table 6. Main models used in DCEs

Model	Characteristics	Examples
Linear	<ul style="list-style-type: none"> ▪ Linear models aim to estimate the mean change in a dependent variable given a unit change in each independent variable. ▪ Explanatory variables are exogenous and linearly related to the dependent variable. They can take any value $(-\infty, \infty)$. ▪ Error terms are i.i.d., normally distributed and homoscedastic. ▪ Linear regressions aim to minimize the sum of the squares of the differences between the observed and predicted values. 	<p>Ordinary least squares (Bärenbold et al., 2020a; Byrnes* et al., 1999; Chan et al., 2011a; Hansla et al., 2008a; Ivanova, n.d.; Kontogianni et al., 2013a; Roe et al., 2001a; Soliño et al., 2009a)</p>
Logit	<ul style="list-style-type: none"> ▪ Explanatory variables are not required to have a linear relationship to the dependent variable but should be linearly related to the log-odds. The probability of an event taking place is estimated by having the log-odds for the event be a linear combination of one or more independent variables. ▪ The probability of an event is assumed to be logistically distributed. ▪ Depending on the data, the explanatory variables in the model can be binary, ordinal or categorical. ▪ Error terms do not need to be normally distributed nor homoscedastic. ▪ Observations should be independent and multicollinearity among independent variables should be minimal. ▪ Logit models do not perform statistical classification. 	<p>Ordered logit (Kowalska-Pyzalska, 2019)</p> <p>Multinomial logit (Bergmann et al., 2006b; Longo et al., 2008; Whitehead and Cherry, 2007a)</p> <p>Random parameter (mixed) logit (Gracia et al., 2012a; van Putten et al., 2014b)</p> <p>Nested logit (Borchers et al., 2007a; Kosenius and Ollikainen, 2013a)</p> <p>Dichotomous choice (binary) logit (Aravena et al., 2012a)</p> <p>Latent class logit (Odam, 2011a; Yang et al., 2015a)</p>
Probit	<ul style="list-style-type: none"> ▪ Dependent variable is binary. ▪ The probability of an event taking place is estimated using the maximum likelihood procedure, with the effect of different independent variables explaining different outcomes. 	<p>Probit (Hanemann et al., 2011; Kontogianni et al., 2013a)</p> <p>Ordered probit (Andrea Bollino, 2009a)</p>

Model	Characteristics	Examples
	<ul style="list-style-type: none"> ▪ The probability of an event is assumed to be normally distributed ▪ Error terms may be arbitrarily correlated. 	<p>Multinomial probit (Ku and Yoo, 2010a)</p> <p>Dichotomous choice (binary) probit (Claudy et al., 2011a)</p>
Tobit	<ul style="list-style-type: none"> ▪ Tobit models censor the range of the dependent variable in some way (e.g., large numbers of zeros). ▪ The tobit likelihood function is a mixture of densities and cumulative distribution functions that reflect the unequal sampling probability for each observation depending on whether the latent dependent variable falls above or below a predetermined threshold. 	<p>Tobit (Grösche and Schroeder, 2010; Kotchen and Moore, 2007; Mozumder et al., 2011; Zorić and Hrovatin, 2012a)</p> <p>Latent class tobit (Ivanova, 2012a)</p>

The standard logit, probit and tobit forms of these models are appropriate when the outcome or dependent variable is binary of the form 0/1. When the outcome or dependent variable is categorical but ordered, e.g., disagree / indifferent / agree, then the *ordered* versions of these models can be used. Lastly, when the outcome or dependent variable is categorical without any particular order, e.g., employment in agriculture / freelance / retired / unemployed, etc. then the *multinomial* versions are appropriate (Torres-Reyna, 2014).

4.2.1 The Random Utility Model

Random Utility Theory (RUT) and its corresponding Random Utility Model (RUM) are among the most widely accepted frameworks to understand and model choices. In the RUM as conceived by (McFadden, 1974a, 1986b, 1997, 2000) the individual must choose one option among J different and mutually exclusive alternatives. A level of utility is associated to each alternative and the individual is supposed to choose the one with the highest level of utility. Only differences in utility are considered rather than absolute levels, which in any case are impossible to compare across individuals.

The utility that individual i derives from choosing option j is denoted U_{ij} and is understood to have a systematic (observable) component V_{ij} and a random (unobservable) component ε_{ij} . This is so because the framework is conceived from the perspective of an external observer (researcher) who only has access to limited data and can only interpret events in terms of probabilities. From the decision maker's point of view the choice may well be deterministic.

$$U_{ij} = V_{ij} + \varepsilon_{ij} \quad (3)$$

The systematic (observable) component V_{ij} is a function of different observed variables or attributes that can in turn be specific to the alternative or to the individual. Three cases are recognized :

- i. Alternative-specific variables x_{ij} with a generic coefficient β ;
- ii. Individual-specific variables z_i with alternative-specific coefficients γ_j ; and
- iii. Alternative-specific variables w_{ij} with an alternative-specific coefficient δ_j .

Hedonic attributes like "green" and "local" are examples of alternative-specific variables that remain unchanged irrespective of the person making the choice. They nevertheless include an i subscript since the choice is derived from a respondent applying his or her personal preferences to the choice set. For modeling purposes, they can be associated to either generic or alternative-specific coefficients. For example, if we deem "green" electricity to be equivalent regardless of the source we would favor a generic β , whereas if the sort produced by one's own PV system is deemed more valuable than that purchased from the grid then perhaps δ_j would be more appropriate. Monetary equivalents are considered generic, since 1 euro is 1 euro regardless of how it is spent. Examples of individual-specific variables include all the psychological and demographic items that vary from one individual to the next. In this case the individual-specific variables are associated to alternative-specific coefficients since they would otherwise disappear in the differentiation when marginal values are estimated. The distinction between x_{ij} and w_{ij} is made to avoid ambiguity and potential confusion between their respective coefficients.

The random (unobserved) component of utility ε_{ij} is an error term that captures the impact of all the unobserved variables which affect the choice of a specific alternative, be they alternative-specific or individual-specific. From the researcher's point of view, it is a random variable. Equation [3] can thus be reformulated as :

$$U_{ij} = \alpha_j + \beta x_{ij} + \gamma_j z_i + \delta_j w_{ij} + \varepsilon_{ij} \quad (4)$$

where :

U_{ij}	utility derived by individual i from choosing option j
α_j	nominal fixed factor (intercept) associated to the base scenario
β	Unobserved generic coefficients associated to x_{ij}
x_{ij}	Observed attributes of choice j evaluated by individual i
γ_j	Unobserved alternative j -specific coefficients associated to z_i
z_i	Observed characteristics of individual i
δ_j	Unobserved alternative j -specific coefficients associated to w_{ij}
w_{ij}	Observed attributes of choice j evaluated by individual i
ε_{ij}	Unobserved i.i.d random error component

The aim of the RUM is to estimate values for the unobserved coefficients, isolate the contribution of each variable-coefficient combination to the overall valuation, and in so doing provide an explanation for the observed choices. Once fitted, the model can be used to make predictions at the individual and population levels. The RUM coefficients are estimated by maximum likelihood using numerical optimization algorithms, the most common being Newton-Raphson, BHHH and BFGS.³⁰ The main difference between these methods lies in the manner in which they estimate the hessian matrix.

³⁰ BHHH stands for the *Berndt-Hall-Hall-Hausman* algorithm; while BFGS stands for the *Broyden-Fletcher-Goldfarb-Shanno* algorithm.

Depending on how the different variables and coefficients are specified equation [4], together with the assumptions in Table 6 above, give rise to different models:

- Suppressing the term $\delta_j w_{ij}$ so independent variables do not vary over alternatives yields the standard logit model.
- Suppressing the terms βx_{ij} and $\delta_j w_{ij}$ to leave only individual-specific variables yields the multinomial logit (MNL) model.
- Suppressing the individual-specific term $\gamma_j z_i$ to leave only alternative-specific variables yields the conditional logit (CL) model.
- Finally, by specifying the alternative-specific coefficients as random probabilities β_{ij} yields the mixed logit (MXL) model.

In this study only four variables are alternative-specific with generic coefficients (PREMIUM, SOURCE_GRID, SOURCE_P2P and SOURCE_PV), three variables are alternative-specific with alternative-specific coefficients (GREEN, LOCAL and AUTONOMY) and all the rest are individual-specific variables with alternative-specific coefficients. All the alternative-specific variables are contained in the ten scenarios that make up the DCE. Regarding their type³¹ GREEN, LOCAL, AUTONOMY and PREMIUM are ordinal while the three sources are nominal. Individual-specific variables are roughly evenly split between dichotomous and ordinal. More details are included in Annex II. Recalling the main hypothesis of the study, the valuation of the hedonic attributes of electricity and their sources can be approximated by a conditional logit model.

4.2.2 Data cleaning

Data cleaning involves, among other things, removing data that is deemed not suited for analysis. A common practice is to identify and remove *protest* answers, which do not add information to the analysis and tend to skew the results. See for example (Contu and Mourato, 2020b; Kjaer, 2005; Mogas et al., 2002). A simple rule is that whenever a respondent consistently chooses the opt-out option, i.e., the default or lowest value - even when the incentives presented are stacked in favor of choosing otherwise - the respondent is assumed to display a protest answer. This is the case if, for example, an individual is willing to forego savings or receive less of a good rather than change his or her answer.

In this survey from the original 503 questionnaires 21 respondents consistently chose the default option, and its removal was justified on several grounds. While it is true that no offer could improve the base scenario on price alone (since its premium was zero) some choices offered additional amounts of green (+25%, scenario 1) and local (+25%, scenario 8) at no additional cost.

A first explanation could be that default respondents were displaying honest disinterest in these attributes, which would not invalidate their answers. However, other items in the survey showed these same respondents to be somewhat (66.7%) or very (9.5%) concerned for the environment,

³¹ For our purposes all variables that are not continuous are considered categorical. Categorical variables can be *dichotomous* (binary) if they take values of [0,1]; *ordinal* if they describe two or more categories that can be ordered or ranked; and *nominal* if they describe categories with no specific order.

while also declaring that their choices had been influenced by considerations such as reducing environmental impact (33.3%), supporting the local community (9.5%), going off-grid (14.3%) or joining a community of like-minded individuals (9.5%). Disinterest therefore does not seem to explain the default choices.

A second explanation could be that although default respondents held some positive beliefs and attitudes toward hedonic attributes, the determining factor in their choices was the price, as was indeed the case for 76.2% of them. Nevertheless, the price awareness of the 482 retained respondents exceeded it with 80.1 % of them stating that price had influenced their choices, thus invalidating the relevance of price awareness to explain default choices. In addition, the belief that renewable energy sources were more costly was more prevalent among the retained group (65.8%) in default respondents (52.4%). That default respondents had on average lower household incomes (76% below 3000 €/month) than retained respondents (55.6% below 3000 €/month) did not alter the fact that acting on their preferences would, at least in some cases, not have entailed any extra cost.

Finally, a third explanation could be that default respondents were simply too impatient to respond thoughtfully and wanted to conclude the survey as soon as possible, which is in itself a problematic justification. Again, data does not support this explanation. The median, mean and standard deviation of the retained sample were 17.2 min, 44.8 min and 166 min, respectively, while for the default sample these same measures were 18.8 min, 151.5 min and 425 min. On average therefore, default respondents took longer to fill out the questionnaire than retained respondents. In summary, the questionnaires of default respondents were removed because they did not seem to conform to the utility maximization premise where $\forall j \neq l U_j > U_l$ and no satisfactory alternative explanation could be found for their choices.

Of the 503 original questionnaires 482 were retained for further analysis.

4.2.3 Linear Models

As indicated in Annex II this study contains variables that are continuous, dichotomous, nominal and ordinal, so the choice of model was not obvious *a priori*. A linear model was used as a first approach, as it can more easily be adjusted to handle all these data types.

The first GLM regression explored the interactions between the 22 source-attribute combinations from the DCE against the 40 household, psychological and demographic regressors from for all 503 questionnaires (which became 108 when their various levels were included). Of the 2376 resulting combinations, 2144 corresponding to 32 regressors could be readily discarded for failing to meet the minimum p-value significance threshold of 0.05. The statistical significance of the remaining 8 regressors varied by level, with 223 combinations statistically significant at the 95% level, 91 significant at the 99% level and 49 significant at the 99.9% level. Overall, this model produced heavily zero-inflated coefficients with values in the 10^{-16} to 10^{-18} range that did not readily fit a binomial (logistic) distribution. Interestingly, many of the regressors frequently used in the literature to characterize respondents appeared to have no meaningful influence on responses. Such was the case for demographic items including age (AGE), gender (GEN) and job status (JOB); the estimated electricity consumption (CONS_EST) and its proxies, such as the number of dwellers (OCCUP), heating

type (HEAT) and floor area (AREA); and even psychological characteristics such as the affinity for solar PV (AFFIN_PV) and storage (AFFIN_ST) technologies. In most cases a good understanding of the sector (K_ and KT_ items) did not influence responses either. The complete list is included as Annex IV. A heat map showing the correlations between individual-specific regressors using Pearson's r is included as Annex V.

A second GLM regression estimated the marginal effect of all the variables (excluding their levels) for the retained questionnaires, considerably improving the results. In this regression the coefficient values were typically in the 10^{-2} to 10^{-4} range and all attributes from the DCE were statistically significant at the 0.001 level except for the green attribute, which at a value of 0.02 was only barely so.

Table 7. GLM regression coefficients and their statistical significance (n=482)

Regressors	Coefficient	Std. Error	t value	Pr(> t)
<i>Intercept</i>	0.2952	0.07872	3.750	0.000177 ***
<i>Source P2P</i>	0.2928	0.01982	14.771	< 2e-16 ***
<i>Source PV</i>	0.09873	0.02084	4.737	2.19e-06 ***
<i>Green</i>	0.05336	0.02298	2.323	0.020215 *
<i>Local</i>	-0.6798	0.04994	-13.613	< 2e-16 ***
<i>Autonomy</i>	0.2476	0.03952	6.265	3.84e-10 ***
<i>Price (BILL)</i>	-0.008832	0.009580	-9.219	< 2e-16 ***

Signif. codes: '***' 0.001 '**' 0.01 '*' 0.05

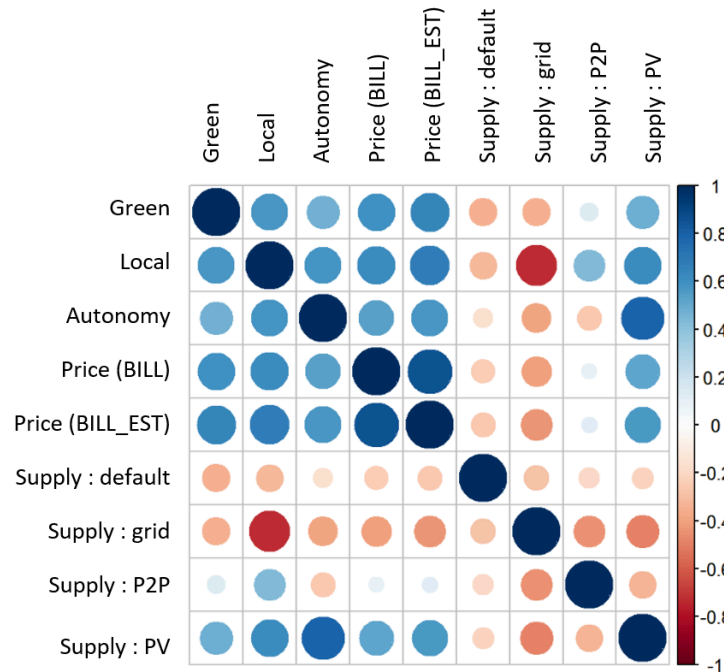
However, in this regression none of the other 40 household, psychological and demographic regressors were found to have any significant effect on the choices of the DCE. In addition, the *local* attribute was found to have a negative value, implying that more of it would correspond to a lower utility (or disutility) for respondents. This was clearly an atypical result that merited additional research. There were three possible explanations: genuine disutility from respondents, attribute non-attendance (i.e., respondents ignoring the attribute when making their decision), or an erroneous regression.

Evidence for the first two explanations was found in the responses to scenario 8, choice set B, where 25% more of the local attribute was offered at no additional cost. The reasoning was that if people still chose the default over this option, they either valued the local attribute at zero (first option) or had just ignored the attribute when making their decision (second option). Of the 482 retained questionnaires 51 had indeed chosen the default option over the one with 25% more local. However, removing these responses and running the same regression on the remaining 431 questionnaires still produced a negative coefficient for the local attribute.

Attention then turned to the third explanation, an erroneous regression. After considerable analysis it was uncovered that the problem resided in the structure of the survey rather than in the data or regression; **the same feasibility criteria that had been used to screen choice sets (see section 3.1.3) had inadvertently created multicollinearities between the choices** so that, if the level of the *local* attribute was zero the source had to be *grid*, and if the value of the attribute was 25% or above then participants selected a non-grid option 100% of the time. From the plot in Figure 6 we can appreciate the high (positive) correlation between hedonic attributes and the bill (both stated and estimated),

as well as the very negative correlation between local and grid. The P2P source was the most weakly correlated of the supply sources, aside from the default (grid).

Figure 6. Correlation plot for sources and attributes



Since the goal of regression analysis is to isolate the effect of each independent variable and the dependent variable, the presence of correlations between variables can cause problems when attempting to fit the model and interpret the results. A Variance Inflation Factor (VIF) test was then performed on the DCE attributes using the entire dataset and the DCE subset. The VIF test serves to determine the strength of correlation between independent variables, where a value of one (lowest possible) indicates no correlation, values between one and five indicate moderate correlation which often does not require corrective measures, and values above five are considered important and will likely produce unreliable results.

Table 8. VIF between DCE attributes, GLM regression and premium as percentage

Dataset	Supply	Green	Local	Autonomy	Price (%)
Complete	13.07	3.47	10.07	3.55	9.92
DCE	13.67	3.53	10.08	3.56	9.92

As can be seen from Table 8 the values for the green and autonomy attributes pose no major concerns, while those for the supply, local and price attributes present severe multicollinearity issues. What this implies in that in its current form the regression does not produce consistent values for the local, source and price coefficients.

Fortunately, in the case of the price premium this could be easily remedied by using premiums calculated after the stated bill (1.9750) or estimated bill (2.3871) instead of the percentage increase.

Since most respondents³² provided information on their bill, which was later used to calculate their individual monetary premiums, it reflects individual trade-offs more accurately than the estimated bill.

In the case of the local and source attributes the multicollinearities are of the structural type. The ideal solution would have involved redesigning the scenarios and conducting the survey again, but since this was not an option the second best solution involved mitigating the effect of the multicollinearities to tolerable levels, i.e. VIF below five. There were several ways of doing this, and three were explored.

- The first and simplest was to standardize the continuous variables by subtracting their means. Yet since none of the variables involved was continuous this method could not be employed.
- The second approach was to combine the highly correlated variables into new variables to be used in the regression. This was attempted as well: the local attribute was combined with the P2P and PV sources to produce two new variables, LxP2P and LxPV, which were then employed instead of the source and local variables, respectively. The new formula was:

$$U_{ij} = \alpha_j + \delta_{1i}GREEN_{ij} + \delta_{2i}L \times P2P_{ij} + \delta_{2i}L \times PV_{ij} + \delta_{3i}AUTONOMY_{ij} + \beta_2BILL_{ij} + \varepsilon_{ij} \quad (5)$$

This resulted in low VIF values for all the main effect terms but extremely high values for the LxP2P (85.1077) and LxPV (175.1386) coefficients, while the value for autonomy turned very negative at -65.0303, which posed new interpretation problems.

- The third solution was to estimate the correlated variables in stages. In a first stage a regression could be conducted with the local attribute and no supply to produce coefficients for the green, local, autonomy and price attributes; while in a second stage the correlated variables were reversed, with supply included and the local attribute removed to produce coefficients for the p2p, pv, green, autonomy and price attributes. The coefficient values thus produced could then be used directly or combined.

As can be seen from Tables 9 and 10 the problem with this approach was that it produced very different coefficients for the attributes that should in principle be unaffected by the regression, all of them statistically significant at the 0.001 level. The largest differences were produced by regressions from different datasets (complete vs DCE). Nevertheless, even within the same dataset differences were considerable.

The green attribute, for example, fluctuated between -0.126 and 0.300 when using the DCE dataset only, a difference of over 30% after conversion into log-odds. Moreover, coefficient values that had previously always been positive (green, autonomy) now also displayed negative variants.

³² This was the case for 455 of the 503 original questionnaires, so estimated bill data was only used on the remaining 48. After removal of the protest responses the number of surveys filled with estimated bills fell to 45.

Table 9. GLM regression omitting the source attribute (n=482)

	Attributes	Coefficient	Std. Error	t value	Pr(> t)	VIF
Complete dataset	Intercept	0.297	0.0795	3.733	1.90E-04 ***	-
	Green	-0.106	0.0266	-3.978	6.99E-05 ***	2.1021
	Local	0.078	0.0230	3.377	7.36E-05 ***	1.8244
	Autonomy	-0.138	0.0286	-4.822	1.44e-06 ***	1.6744
	Price (BILL)	-0.010	9.65E-04	-10.384	< 2e-16 ***	2.4795
DCE dataset	Intercept	0.377	0.0095	39.863	< 2e-16 ***	-
	Green	-0.126	0.0262	-4.789	1.69e-06 ***	2.0495
	Local	0.059	0.0227	2.613	8.97E-04 **	1.7716
	Autonomy	-0.152	0.0284	-5.36	8.43e-08 ***	1.6554
	Price (BILL)	-0.008	0.0009	-9.255	< 2e-16 ***	1.9663

Signif. codes: '***' 0.001 '**' 0.01 '*' 0.05

Table 10. GLM regression omitting the local attribute (n=482)

	Attributes	Coefficient	Std. Error	t value	Pr(> t)	VIF
Complete dataset	Intercept	0.279	0.0792	3.518	4.36E-04 ***	-
	Source P2P	0.066	0.0108	6.099	1.09E-09 ***	3.5109
	Source PV	-0.092	0.0155	-5.946	2.81E-09 ***	
	Green	0.044	0.0231	1.904	0.056888	1.8496
	Autonomy	0.069	0.0375	1.849	0.064445	2.8956
	Price (BILL)	-0.012	0.0938	-12.615	< 2e-16 ***	2.3610
DCE dataset	Intercept	0.925	0.0111	83.1	<2e-16 ***	-
	Source P2P	-0.641	0.0134	-48	<2e-16 ***	3.6124
	Source PV	-0.806	0.0165	-48.95	<2e-16 ***	
	Green	0.300	0.0199	15.1	<2e-16 ***	1.8636
	Autonomy	-0.039	0.0320	-1.22	0.222	2.8729
	Price (BILL)	-0.009	0.0007	-13.24	<2e-16 ***	1.8911

Signif. codes: '***' 0.001 '**' 0.01 '*' 0.05

All told the GLM regressions were not able to produce consistent and coherent values for the attributes of interest despite considerable efforts to fit the data and models.

4.2.4 Zero-Inflated Models

In order to account for the large number of zero responses specific models were also employed. Two subsequent regressions using a zero-inflated Poisson (ZIP) regression and a negative binomial (NB) regression were undertaken using R version 4.1.2 and the *pscl* package. These models are specifically designed to handle zero-inflated and overdispersed data, i.e., data whose variance is much larger than the mean. The ZIP model assumes there are two processes generating zero values: the structural zeros inherent in binary distributions, and sampling zeros due to the Poisson distribution. The first follow a Bernoulli distribution, while the latter follow a Poisson distribution. The NB model, on the other hand, assumes the presence of overdispersion in the dependent variable conditional on the explanatory variables. For a detailed discussion of these and other models see (Fávero et al., 2021).

Zero-inflated models are meant to be used on the entire dataset and not only on that of the DCE. Although the coefficients produced by the ZIP and NB models appear to have high statistical significance this can be deceptive. A closer look reveals their values to be inconsistent, switching between positive and negative and often orders of magnitude apart.

Table 11. Statistical significance of zero-inflated models.

Zero-inflated Poisson regression					
<i>DCE</i>	<i>Dichotomous</i>		<i>Continuous</i>	<i>Ordinal</i>	<i>Nominal</i>
Intercept	TYPE	K_NUC	BILL	OCCUP	PROP **
Supply: P2P	HEAT	K_SUP	AGE **	AREA **	CONT *
Supply: PV	WHEAT	K_AUT *	[EST_CONS]	INF_PRI ***	FAM
GREEN ***	OP_EXP	KT_CEN	[EST_BILL]	INF_ENV **	JOB
LOCAL	OP_ENV *	KT_SYN		INF_LOC **	
AUTO ***	OP_PER	KT_MUN *		INF_IND *	
PRICE (%) ***	OP_MKT	KT_COO *		INF_BEL	
	OP_RICH	KT_NEI		AFFIN_PV *	
	OP_REL	GEN		AFFIN_ST	
				ENV	
				N_KNOW	
				N_RAP	
				EDU	
				INC	
Negative Binomial Regression					
<i>DCE</i>	<i>Dichotomous</i>		<i>Continuous</i>	<i>Ordinal</i>	<i>Nominal</i>
Intercept *	TYPE	K_NUC	BILL	OCCUP	PROP ***
Supply: P2P	HEAT	K_SUP	AGE **	AREA ***	CONT ***
Supply: PV	WHEAT	K_AUT ***	[EST_CONS]	INF_PRI ***	FAM **
GREEN *	OP_EXP ***	KT_CEN	[EST_BILL]	INF_ENV ***	JOB
LOCAL ***	OP_ENV *	KT_SYN		INF_LOC ***	
AUTO ***	OP_PER	KT_MUN		INF_IND ***	
PRICE (%)	OP_MKT *	***		INF_BEL **	
	OP_RICH **	KT_COO ***		AFFIN_PV ***	
	OP_REL *	KT_NEI *		AFFIN_ST *	
		GEN ***		ENV ***	
				N_KNOW	
				N_RAP	
				EDU	
				INC	

^a Including the local attribute in the regression; ^b Including the supply source in the regression.
Significance level codes: '***' 0.001 '**' 0.01 '*' 0.05

Table 12. Results of the ZIP model with no sources and premium as percentage

<i>Attribute</i>	<i>Coef.</i>	<i>s.e.</i>	<i>z</i>	<i>Pr(> z)</i>
<i>Intercept</i>	-1.3556	0.0406	-33.428	< 2e-16 ***
<i>Green</i>	1.6213	0.1177	13.774	< 2e-16 ***
<i>Local</i>	1.1474	0.1369	8.380	< 2e-16 ***
<i>Autonomy</i>	0.9016	0.2309	3.905	9.44e-05 ***
<i>Price (%)</i>	-13.8629	0.7811	-17.749	< 2e-16 ***

Signif. codes : '***' 0.001 '**' 0.01 '*' 0.05

The ZIP and NB models failed to agree on the coefficients that were significant and to what extent. More importantly, when using only the DCE dataset without additional regressors they were unable to estimate coefficients for the sources and attributes simultaneously or handle regressions with premiums expressed in money terms. In the NB model no coefficients were statistically significant. The partial results of the ZIP model are presented in Table 12.

4.2.5 Conditional Logit Model

Conditional logit analysis is attributed to Daniel McFadden, who first proposed it to model population choice behavior from distributions of individual decision rules. (McFadden, 1974b). Conditional logit assumes residuals are independent draws from an identical Type I extreme value distribution, a choice first used by the author for computation convenience since it produces differences in random terms that are logistically distributed and easy to estimate. Given that conditional logit only considers alternative-specific parameters, only the responses to the DCE were coded in binary form for this model, leaving out the psychological and demographic regressors. Since each choice is a combination of one supply source, three hedonic attributes and a premium, a conditional logit model can be represented as:

$$U_{ij} = \alpha_j + \beta_1 SOURCE_{ij} + \beta_2 PREMIUM_{ij} + \delta_{1i} GREEN_{ij} + \delta_{2i} LOCAL_{ij} + \delta_{3i} AUTONOMY_{ij} + \varepsilon_{ij} \quad (6)$$

The dependent variable is the log of the odds ratio and has the form $Log[p/(1-p)]$ where $p = P\{Y = 1\}$ is the probability of choosing the alternative j that produces the greatest utility. It is not a measure but a probability that varies between 0 and 1. The error component reflects the random nature of utility in this expression. The choice was used as the dependent variable and expressed as a dummy that took the values 1 = present or 0 = absent. The intercept α_j corresponds to the *status quo* option in the absence of a premium, i.e., base rate with < 25% green, 0% local and 0% autonomy. It is not reproduced in the results, as it was used as reference to estimate all the other coefficients.

The price premium in the survey was displayed as both a percentage of the monthly bill and its equivalent (individual-specific) amount in euros, and this influenced the results as well. Several R packages³³ that perform logistic regressions encountered drawbacks when the premium was expressed in money terms, given that all other regressors had values between zero and one. More importantly, in conditional logit models with panel data unobserved heterogeneity can quickly spin out of control as the number of observations and random effects grow disproportionately faster than the data available for estimating individual-specific parameters, thus undermining the assumption of conditional serial independence (Kwak et al., 2018; Starkweather and Moske, 2011). As a result, unrealistic coefficients were often estimated, and effect sizes exaggerated by some packages. In the end the *clogit* routine of the survival package using stratified sampling was found to produce the most consistent results, bypassing most (though not all) of the multicollinearity limitations in the data.

The results are presented in Table 13 below. Regardless of their true consumption and monthly bill, the stated bill reflects what respondents *believe* they are currently paying. Since it was also used to calculate the money amounts in the survey it is considered a more accurate reflection of individual preferences. Although the coefficients cannot be interpreted directly, their sign provides an indication of whether the variable in question is positively or negatively correlated to the choice.

³³ As part of this study the *gmnI*, *lme4*, *nnet*, *mlogit*, *logitr* and *survival* packages were explored.

Table 13. Conditional logit results with premium in money and percentage terms

Premium in money terms					
Attribute	Coef.	OR	s.e.	z	Pr(> z)
Source P2P	1.3445	3.8362	0.0931	14.447	< 2e-16 ***
Source PV	0.4297	1.5367	0.0998	4.303	1.68e-05 ***
Green	0.5135	1.6712	0.1100	4.668	3.05e-06 ***
Local	-3.0392	0.0479	0.2539	-11.970	< 2e-16 ***
Autonomy	1.2993	3.6668	0.2229	5.828	5.60e-09 ***
Price (BILL)	-0.0679	0.9343	0.0063	-10.769	< 2e-16 ***
Premium in percentage terms					
Attribute	Coef.	OR	s.e.	z	Pr(> z)
Source P2P	1.100	3.005	9.507e-02	11.574	< 2e-16 ***
Source PV	0.428	1.535	0.1013	4.227	2.37e-05 ***
Green	2.076	7.976	0.1505	13.799	< 2e-16 ***
Local	-0.936	0.392	0.2880	-3.250	0.00116 **
Autonomy	2.144	8.536	0.2247	9.542	< 2e-16 ***
Price (%)	-0.176	2.313e-08	0.9477	-18.552	< 2e-16 ***

Signif. codes : '***' 0.001 '**' 0.01 '*' 0.05

In this sense we can say that more P2P, PV, green and autonomy appear to be unequivocally desirable, while more local and higher premiums appear to be unequivocally undesirable.

To determine by how much each source and attribute influences respondents' choices we must convert coefficients into odds ratios (OR) applying the exponential function. We obtain $OR = p/(1 - p)$ or $p\{Y = 1\}/p\{Y = 0\}$, which is the probability of 'success' $\{Y = 1\}$ over the probability of 'failure' $\{Y = 0\}$. The odds ratios suggest that a unit increase in the P2P source will on average increase the likelihood of choosing an option by $OR - 1 = 2$ to 2.8 times, while a unit increase in the PV source will on average increase this likelihood by $1.53 - 1 = 0.53$ or 53%. In the case of hedonic attributes a unit increase in *green* is expected to raise the likelihood of choosing an option by between 67.12% and 6.97 times, while for *autonomy* the equivalent likelihood is between 2.67 and 7.53 times higher, i.e., between 2.67 and 7.53 persons choosing autonomy for each person that does not, other things being equal. Given the design of our survey a unit increase corresponds to an increment of 25% in the relevant source or attribute, e.g., from G1 to G2 or from G2 to G3. In contrast, the likelihood of choosing an option decreases by between $1 - OR = 60.80\%$ and 95.21% for every additional unit of *local*, which suggests there seems indeed to be a negative perception of the local attribute among respondents.

Table 14. Conditional logit results by attribute level

Premium in money terms					
Attribute	Coef.	OR	s.e.	z	Pr(> z)
Source P2P	-0.3747	0.6875	0.0780	-4.8030	1.57e-06 ***
Source PV	-1.5144	0.2199	0.1154	-13.1250	< 2e-16 ***
Green 50%	0.7111	2.0362	0.0650	10.9370	< 2e-16 ***
Green 75%	0.2749	1.3164	0.0570	4.8200	1.43e-06 ***
Local 25%	1.0106	2.7472	0.0842	11.9980	< 2e-16 ***
Local 50%	NA	NA	0.0000	NA	NA
Autonomy 25%	0.8139	2.2568	0.1154	7.0540	1.74e-12 ***

<i>Autonomy 50%</i>	1.1218	3.0703	0.1256	8.9330	< 2e-16 ***
<i>Price (BILL)</i>	-0.0739	0.9287	0.0064	-11.4610	< 2e-16 ***
Premium in percentage terms					
<i>Attribute</i>	Coef.	OR	s.e.	z	Pr(> z)
<i>Source P2P</i>	0.5850	1.7950	0.0939	6.2290	4.69e-10 ***
<i>Source PV</i>	-0.4238	0.6545	0.1299	-3.2630	1.101e-03 **
<i>Green 50%</i>	1.2490	3.4850	0.0735	16.9840	< 2e-16 ***
<i>Green 75%</i>	1.1860	3.2750	0.0787	15.0810	< 2e-16 ***
<i>Local 25%</i>	0.3369	1.4010	0.0903	3.7300	1.91e-04 ***
<i>Local 50%</i>	NA	NA	0.0000	NA	NA
<i>Autonomy 25%</i>	1.3750	3.9540	0.1207	11.3930	< 2e-16 ***
<i>Autonomy 50%</i>	1.6270	5.0890	0.1277	12.7460	< 2e-16 ***
<i>Price (%)</i>	-19.6600	0.0000	0.9676	-20.3210	< 2e-16 ***

Signif. codes : '***' 0.001 '**' 0.01 '*' 0.05

As was expected, an increase in the price premium is also inversely correlated to the likelihood of choosing an option. In addition to the main effects, appropriate coding also made it possible to run the regression on specific levels of green, local and autonomy while holding the sources and premium level constant. The regressions were again run with the premium in money terms and as percentage. Both sets of results are presented in Table 14.

Despite the limited data points, what these regressions show is even more revealing. This is that the 25% unit increases are not linear but exhibit different slopes at different levels. For example, in the case of green an increase from the base 25% to 50% is accompanied by a larger selection likelihood (1.04 to 2.48 times) than from 50% to 75% (31.64% to 2.27 times), **suggesting decreasing returns to green**. In contrast, the first 25% increase in autonomy raises the choice likelihood 1.25 to 2.95 times, while the second from 25% to 50% does so by 2.07 to 4.09 times, **implying increasing returns to autonomy**. An equivalent comparison could not be made for the local attribute because the 50% local coefficient was singular and was not calculated. The effect of joining an energy community is ambiguous, negative in one case and positive in another.

These results are interesting in themselves and merit further research, ideally testing for additional biases not addressed here (e.g. attribute non-attendance³⁴) which have only become apparent in the form of the seemingly irrational choices made by some respondents (see section 4.2.3 above).

4.2.6 Willingness to Pay

It is important to note that in the retained sample a total of 2,462 choices, or 51.1% of the total, had a premium value of zero. Of those with a positive premium the simple average was 8.9%³⁵. Estimating the marginal WTP implies calculating the marginal rate of substitution (MRS) between the coefficient of interest and the price (cost) coefficient. That is, $MRS_j = -\beta_1/\beta_2$ in the case of alternative supply

³⁴ The tests that were identified to test for attribute non-attendance, namely those proposed by Hess & Hensher (Hess and Hensher, 2010), Lew & Whitehead (Lew and Whitehead, 2020) and Espinosa-Goded et al. (Espinosa-Goded et al., 2021) all apply to random parameter (mixed) logit models only, a treatment not undertaken in this paper.

³⁵ The equivalent amounts of the stated and estimated bills were 6.20 €/month and 7.22 €/month, respectively.

sources and $MRS_j = -\delta_j/\beta_2$ in the case of hedonic attributes, in both cases using the coefficients from Tables 13 and 14.

Table 15. WTP as €/month and its percentage equivalents

WTP as €/month and its percentage equivalents				
Variable	WTP €/month	BILL (70.5 €/m)	EST_BILL (82.7 €/m)	ARA (200 €/m)
Source P2P	19.80	28.09%	23.94%	9.90%
Source PV	6.33	8.98%	7.65%	3.16%
Green	7.56	10.73%	9.14%	3.78%
Local	-44.76	-63.49%	-54.12%	-22.38%
Autonomy	19.14	27.14%	23.14%	9.57%
WTP as percentage and its money equivalents				
Variable	WTP +%/month	BILL (70.5 €/m)	EST_BILL (82.7 €/m)	ARA (200 €/m)
Source P2P	6.25%	4.41	5.17	12.50
Source PV	2.43%	1.71	2.01	4.86
Green	11.80%	8.32	9.75	23.59
Local	-5.32%	-3.75	-4.40	-10.64
Autonomy	12.18%	8.59	10.07	24.36

For the estimates with the price premium expressed in €/m the MRS is the WTP. The comparison is then with the average monthly bill as stated by respondents (BILL), the estimated bill based on proxy questions (EST_BILL) and the mean bill for the ARA region. Where the premium was expressed as a percentage of the bill it is necessary to multiply the MRS by the total bill to obtain its money equivalent, which again produce three estimates depending on the reference bill we employ. Both approaches are included in Table 15.

These results suggest that on average respondents would be willing to pay between 4.41 and 19.80 €/m on top of their current bill for a 25% increase in energy from an energy community; between 1.71 and 6.33 €/m for an additional 25% of energy from PV; between 7.56 and 23.59 €/m for a 25% increase in the green attribute (the only case where the percentage premium was higher); and between 8.59 and 24.36 €/m for a 25% increase in autonomy. In both cases the local attribute appeared to be negatively perceived, requiring a *discount* (compensation) of between 3.75 and 44.76 €/m for a 25% increment. Of course, the same calculations could be performed for different attribute levels specifically, again yielding different estimates

In general the WTP values expressed in money terms are higher than those expressed in terms of percentages. A possible explanation lies in the gap between perceived and actual consumption. It is very likely that on average respondents tended to underestimate their monthly consumption and bill compared to what EdF consumption statistics suggest they should be consuming based on their household characteristics and family size (hence the difference between the stated and estimated bills). Lower perceived bills produced lower premiums in the survey, which could have led to a higher WTP compared to the percentages that applied to all respondents equally regardless of their consumption.

4.2.7 Interactions

Having rejected the null hypothesis H_0 that hedonic attributes have no value, the alternative hypothesis H_a that valuations are independent needs to be tested. Despite the structural local-source multicollinearities in the survey design, the results so far have not provided information on the relationship between hedonic attributes. To estimate these interactions equation (6) was modified so the terms of interest were multiplied instead of added, two at a time.

$$U_{ij} = \beta_1 SOURCE_{ij} (+ \times) \delta_{1i} GREEN_{ij} (+ \times) \delta_{2i} LOCAL_{ij} (+ \times) \delta_{3i} AUTONOMY_{ij} + \beta_2 PRICE_{ij} + \varepsilon_{ij} \quad (7)$$

with the (+ ×) term representing a variant in which two terms were multiplied and all others added. There were nine such combinations in total, as illustrated in Table 16. In this table the premium was expressed in percentage terms, as its equivalent in money terms produced incoherent results. The survey was structured assuming that self-production and storage is a precondition for autonomy; self-production is always local, and it is always associated to a specific source (PV). It is therefore no surprise that the P2P-autonomy and PV-autonomy calculations were singular, and already obviated elsewhere. It is inevitable that interactions between variables produce high VIF values. This is not in itself a problem since the p-values are not affected by the multicollinearity, especially in cases where the indicator variables have three or more levels, as is the case here (Allison, 2012). In this table the WTP was calculated by dividing the interaction coefficient by the coefficient for the price premium from Table 14.³⁶

Table 16. Source-attribute and attribute-attribute interactions and WTP

Interaction		Coef.	OR	s.e.	z value	Pr(> z)	WTP
Source P2P	Green	-2.02	0.13	0.21	-9.59	<2e-16 ***	-10.26%
	Local	1.30	3.66	0.40	3.27	1.09e-03**	6.60%
	Autonomy	NA	NA	0.00	NA	NA	NA
Source PV	Green	-2.17	0.11	0.24	-9.06	< 2e-16 ***	-11.05%
	Local	-5.88	2.80e-03	0.47	-12.38	<2e-16 ***	-29.90%
	Autonomy	NA	NA	0.00	NA	NA	NA
Green	Local	-9.65	6.42e-05	0.60	-16.22	<2e-16 ***	-49.10%
	Autonomy	-7.48	5.62e-04	0.80	-9.35	<2e-16 ***	-38.07%
Local	Autonomy	-10.6	2.62e-05	1.24	-8.523	<2e-16 ***	-53.66%

Signif. codes : '***' 0.001 '**' 0.01 '*' 0.05

Overall source-attribute and attribute-attribute interactions appear to display negative returns to scope, which are not merely below their arithmetic sum but turn deeply negative. Before estimating these interactions, we would have been led to believe that an electricity offer that was, for example, green and sourced from an energy community would correspond to a premium of 11.80% + 6.25% = 18.05%, and indeed so for most respondents. However, the interacted term implies that one in every eight respondents (1/0.13) would instead need to be compensated with a discount of -10.26% to

³⁶ When estimating the interactions between coefficients the non-interacted items should not be considered. That is why the price from Table 13 was used instead.

choose that option. Another example is provided by PV and local, where by simple arithmetic one would suppose a combined value of $2.43\% - 5.32\% = -2.89\%$, with 1.5 respondents choosing that option based on the PV for every one that did not, and only 1 choosing it based on the local attribute for every 2.5 that did not. Including the PV-local attribute suggests that in addition one in every 357 respondents would choose that combination provided they received a -29.90% discount. In other words, the odds ratios of the interacted terms were so unlikely by themselves to result in a respondent choosing a specific option that most of them can safely be ignored.³⁷

Apart from the P2P-local interaction which seems to increase the odds of choosing an option, all other interactions reduced the choice likelihood, with the bottom four log odds being so unlikely as to be irrelevant.³⁸ These results do not support the attribute independence hypothesis, a result that was partly anticipated by the panel format and the fact that the presence of certain hedonic attributes (e.g. autonomy) was contingent on the presence of certain sources (e.g. PV). Annex VI presents residual plots for both models.

5. DISCUSSION AND CONCLUSIONS

This chapter explored the mean preferences of residential consumers in the Auvergne-Rhône-Alpes region for various electricity sources and their attributes, thus contributing to the limited discrete choice literature available for France (Corso, 2008; Litvine, 2013; Shi et al., 2013).

The **null hypothesis** of the study that only the use attributes of electricity were valued by households seems clearly not to be the case. Statistically significant WTP values were estimated for all hedonic attributes considered, with all sources and attributes having positive values except for local power. Regressing over attribute levels separately also uncovered nonlinearities that suggest the green attribute displays decreasing returns to scale while the opposite is true for autonomy. Interestingly, most household and individual-specific control variables found in the literature, including, age, income and education, were not found to exert a statistically significant influence in explaining choices, even after controlling for overdispersion and zero-inflation in the data.

The **alternative hypothesis** which postulated that any two coefficients i and j were orthogonal, and therefore valued independently by households, was only partially rejected. Although the survey contained structural multicollinearities between certain sources and attributes, in four of the seven interactions that were estimated the log odds were so small as to have no perceptible effect in decisions and could be safely discarded. As an example, holding the values of the green and autonomy attributes constant, the influence of the combined green-autonomy term was on average expected to result in one additional respondent choosing that option for every 1,779 respondents that did not. Interestingly, most of the interacted terms had the opposite sign to their main effect attributes.

Overall these results suggest that among hedonic attributes autonomy is the most highly valued, followed by green and local, which has a negative WTP (or WTA). Among the sources joining a P2P

³⁷ These included PV-local, green-local, green-autonomy and local-autonomy.

³⁸ The odds ratios for the interacted terms were 1:357 for PV-local, 1:1,779 for green-autonomy; 1:15,576 for green-local; and 1:38,167 for local-autonomy.

energy community was valued three times more highly than owning an individual PV system, which poses a potential contradiction since autonomy is assumed to be attainable only with PV and storage. Except for the local attribute all others appear to be preferred to conventional grid supply.

Contrary to the commonly held belief that price is the main barrier preventing households from investing in alternative energy sources, these results suggest a sizable population in the ARA region is ready to pay a premium for electricity provided it has the right combination of attributes to fit their preferences. This is good news for suppliers interested in increasing their market share and policy makers aiming to reduce local emissions or polish their green credentials. For energy communities, however, steering their communications strategies away from local energy and toward autonomy appears a more promising approach.

The sample used in this study was small and contained important structural multicollinearities, and its results should be interpreted with caution. Future research in this area would be wise to focus on ensuring a representative sample of the population and adopting more flexibility in the combinations of sources and attributes presented. It should also be careful when introducing restrictions to avoid inadvertently over-specifying the models.

A number of respondents appeared unwilling to switch at any cost and were removed from the final analysis for being ‘protest’ responses. Perhaps future research could explore whether, in addition to the endowment effect and other biases, the realization that switching their supply in real life would carry transaction costs (in time and effort, if nothing else) was transferred to the lab setting and prevented them from making the switch during the choice experiment.

The extent to which other psychological phenomena documented in the literature, such as part-whole bias (Foster and Mourato, 1998) or attribute non-attendance (Espinosa-Goded et al., 2021, p.; Hess and Hensher, 2010) affected these results is also unclear, but remain outside the scope of this work.

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CHAPTER III

A Meta-regression of Willingness-to-Pay for Green Electricity

ABSTRACT

This paper provides an updated meta-analysis of a large number of studies on willingness to pay (WTP) for renewable or 'green' electricity. To identify the factors behind the differences in these studies, it conducted an extensive literature of 96 primary studies from 31 countries and eight previous meta-analyses. The results of various regressions suggest that although not evident at first glance, the source of these differences lies in a combination of within-study (fixed) and between-study (random) error components.

Keywords: meta-regression, renewables, green electricity.

1. INTRODUCTION

Raising the share of green electricity that is produced and consumed worldwide remains an international priority to mitigate the negative effects of climate change as well as avoid the negative effects of air pollution on local populations. From an international policy perspective a more precise diagnosis of the factors that affect willingness to pay (WTP) is critical in order to adapt policies and recommendations to different contexts, rather than proposing a one-size-fits-all approach to pricing green electricity. Within the boundaries set by regulators consumers can decide if an electricity offer counts as 'green' or 'clean' based on the environmental and social impacts of its generation technology, even when these attributes are not observed, measured nor explicitly verified at the point of consumption (Yang et al., 2015a). This has posed problems to neoclassical economics, which have struggled to predict or explain the presence of altruistic behavior or consider the fact that much behavior is irrational, detrimental to the individual or simply driven by emotion or habit.

Numerous empirical studies have sought to remedy this knowledge gap by producing copious studies on willingness to pay (WTP) for different attributes that vary by date, location, population, survey method and econometric model, among many other factors. From a practical standpoint this diversity limits their usefulness by making it difficult to compare their findings, provide a coherent message to decision makers, convey a clear message to businesses interested in entering this space, and in general translating their recommendations to different settings.

In their simplest form meta-regression analyses aggregate large pools of studies to produce average values that broadly fit most previous estimates, while highlighting the most statistically significant moderator variables. In addition some of them also include benefit transfer functions and methods to minimize the inevitable error incurred when applying meta-regression results to specific settings (Pokhrel, 2016). Within-country WTP disparities can be explained away with more ease than

between-country differences. Values from studies carried out in the same country are sometimes difficult for researchers and decision makers to interpret, but their consolidation using fixed-effects models is in general accepted since data are derived from roughly the same population, and deviations from a common 'true' treatment effect are easier to explain away using within-study variances (Veroniki et al., 2015). In contrast, it is more difficult to justify that disparities in WTP values from different countries are caused by methodological differences rather than the true treatment effects (preferences) of different populations. In the absence of systematic means to compare them 'foreign' studies are often regarded by decision makers more as curiosities than as insights to guide policy. In practice this results in a heuristic that assigns more importance to studies with increased geographical and cultural proximity than to distant ones (Hong et al., 2021). Random-effects meta-analyses³⁹ have recently gained acceptance as a means to overcome these limitations (Harrer et al., 2021) including within the green electricity field (Soon and Ahmad, 2015; Sundt and Rehdanz, 2015), as they highlight the extent to which the results of WTP studies carried out in different locations, dates and using different methods can be extrapolated.

In the present study the question we try to answer is: ***what explains differences in WTP for green electricity in the literature?*** To answer this question a comprehensive review of 96 primary studies from 31 countries representing 82,945 individual observations and 8 previous meta-analyses is complemented by a weighted least squares (WLS), fixed effects and random-effects models. We focus exclusively on RE, as it is the attribute that has been most widely documented and has gained global relevance given its role in mitigating climate change. Identifying the sources of heterogeneity could also help to discern whether it is the specific methods used by researchers (fixed effects) or whether it is the true effects that vary between studies (mixed effects). The main contribution of this study is to provide an updated meta-analysis of WTP for green electricity, while introducing a flexible framework to accommodate heterogeneous studies that would otherwise end up discarded. To the author's knowledge this is the most comprehensive meta-analysis of end consumers' WTP for renewable ('green') electricity to date, and the only one that uses framing to sort and integrate otherwise incompatible information sources.

Section 2 provides a comprehensive literature review of primary studies and meta-analyses. Section 3 introduces the proposed regression model and section 4 presents the model results. The discussion and conclusions are presented in sections 5 and 6, respectively.

2. LITERATURE REVIEW

The first section will present information on the primary studies collected, while the second section will compare the approaches followed by the various meta-analyses conducted to date. Further details can be found in the Annexes.

³⁹ Referred to as *mixed effects models* by (Ma et al., 2015a).

2.1 *Individual studies*

2.1.1 Data collection and selection criteria

The starting point for the literature search was the combination of terms ‘renewable energy’, ‘green electricity’ and ‘clean energy’ with ‘willingness to pay’, ‘WTP’, ‘conjoint analysis’, ‘contingent valuation’ and ‘discrete choice’, in both Google Scholar and BibCnrs, the French National Scientific Research Database. The references included in pertinent matches, and especially in meta-analyses, were then used to identify additional studies that had been missed in the first search. In some cases where the original publications or their annexes were not available online, e.g., [Ivanova 2005] [Shi, 2013] the co-authors or their institutions were contacted to request copies. The cross-screening and collection of reference literature began in early 2020 and ended in June 2022.

- Only studies that directly valued RE or used RE as a vehicle to attain other benefits (e.g., reliability against black-outs) were considered. It was deemed acceptable if the studies in question aimed to value an individual characteristic (e.g., pro-environmental behavior) by means of their propensity to purchase RE.
- The exception to the previous criterion is rural electrification. Studies on the average WTP for rural electrification with RE such as (Abdullah and Markandya, 2012; Alam and Bhattacharyya, 2017; Entele, 2020) assess not the value of RE but the use attributes of electrification (as opposed to being off-grid), and therefore were not considered comparable.
- Studies had to include WTP in monetary terms. Percentages as in (Dastrup et al., 2012b) and (Faber et al., 2014) and likelihood ratios that could not be converted into their money equivalents were discarded.
- Both time-specific WTP (e.g., WTP/m or WTP/y) and unit-specific (e.g., WTP/kWh) results were included. Only external data from national statistics offices and international organizations (World Bank, OECD, Eurostat) was used to convert unit-specific values into their time-specific counterparts.
- Whenever more than one WTP was provided by a study, for example when the results of different regression models were included, an effort was made to retain only one value. When various models were involved the WTP of the regression with the best fit (r-squared) was used. When differences referred to different sub-populations or different dates, the values were averaged after adjusting for inflation and purchasing power. When payment card methods were used and WTP results were published for all levels the values were pondered by the appropriate percentages.
- Only studies that obtained data through stated preference methods were included. Revealed preference results, e.g. (Yevdokimov et al., 2019) were excluded. Studies that relied exclusively on secondary sources like national census, e.g. (Knapp et al., 2020) were excluded.
- Accepted studies had to be based, at least partly, on stated preference methods such as contingent valuations (CV), bounded contingent valuations (CVB), discrete choice experiments (DCE), conjoint analyses (CA), open-ended inquiries (OE) or other methods published in the

relevant literature (O) such as payment cards and referendums. Traditional CV experiments present a dichotomous choice to respondents, who must then choose whether to accept or reject the offer. In CVB the process is repeated several times to identify price floors and ceilings. DCE and CA present respondents a series of hypothetical scenarios that combine different attributes (or attribute levels) and ask them to either choose their preferred option (DCE) or rank them in order of preference (CA). Open-ended (OE) methods simply ask respondents for the maximum amount they would be WTP (or WTA) for an increase or decrease in a given attribute. See (Braidert et al., 2006b; Humphrey et al., 2019) for more details.

- Negative WTP values were included if the original question was framed in terms of WTP, e.g., “How much would you pay...” and not in terms of a willingness-to accept (WTA) compensation, e.g., “How much would you need to receive to accept...”. Although the Coase theorem establishes that compensation can take place in both directions, it has also been shown (Freeman III et al., 2014; Tversky and Kahneman, 1981) that WTA tends to systematically exceed WTP valuations due to the endowment and other psychological framing effects. Overall, only three WTA values were collected, accounting for only 3.2% of the total.
- Some studies with multiple co-authors can be considered reinterpretations of the same data published under different names. The most extreme case is that of a 1997 study by Robert Ethier (Ethier et al., 1997) from the United States who analyzed the same 1996 survey data as five other authors (Cameron et al., 2002; Ethier et al., 2001; Poe et al., 2002; Rose et al., 1999; Vossler et al., 2003). A manuscript by a team from Auburn University in Alabama, United States (Duffy et al., 2007) is also available under a slightly different name with the authors appearing in a different order (Hite et al., 2008).
- Most of the collected sources are peer-reviewed articles but working papers and manuscripts (gray literature) were also included. Also included are three thesis: a doctoral thesis by N.J. Odam (Odam, 2011b) and two masters theses by N. Liu (Liu, 2014) and K.R. Pokhrel (Pokhrel, 2016), the last being a meta-analysis.

The search, collection and coding of the relevant literature resulted in 90 primary studies and 8 meta-analyses of WTP for RE from 28 countries representing 81,796 individual observations.

2.1.2 Dataset coding

When a single study included results from surveys conducted in different countries (Merk et al., 2019), different locations (Byrnes et al., 1999), different sub-populations (Botelho et al., 2017, 2013) or different years (Andor et al., 2016; Kotchen and Moore, 2004) they were treated as separate entries in the database. When the same sample population was used to produce two different studies with different WTP estimates, perhaps employing different econometric techniques, as in (Batley et al., 2001, 2000), (Ivanova, 2012b, 2005) or (Yang et al., 2016, 2015a) the studies were counted separately but the number of observations counted only once.

WTP. For each primary study information was recorded regarding the effect size in the original currency and format (per time or unit). It was then adjusted for inflation using OECD CPI data from

the year after the survey until 2020, and finally converted into its USD PPP equivalent using OECD PPP conversion factors. Final WTP values were expressed in US dollars per month (USD/m) in 2020 prices.

Survey year. In most cases the survey year was provided in the study. When this was not the case, and no date could be inferred from the article, the year of publication of the first manuscript or the year of submission to a journal was used.

Country. No distinction was made between national and subnational surveys. Only country names and not subnational states or regions were recorded, the only exception being Scotland. Countries were later assigned to specific macro regions.

Sample size. When provided, information on the number of the initial collection attempts (persons approached, letters sent, phone calls made), completed surveys, usable surveys and number of data points used to obtain WTP values (after discounting outliers and protest responses) were recorded. The sample sizes served to compute a proxy of the standard errors, which was not available in many cases.

Technology. Eight categories were included: generic green, wind, solar, biomass, hydro, geothermal, fossil and nuclear. Fossil and nuclear were only included when they appeared in the choices presented to survey respondents alongside renewables. In some cases, though not all, the reference or default means of production was made explicit to respondents as benchmark, while in others it was left implicit. Data on this difference was not collected during the literature review.

In five cases (Claudy et al., 2011b; Dagher and Harajli, 2015; Heng et al., 2020; Scarpa and Willis, 2010b; van Putten et al., 2014a) WTP values refer not to electricity purchased from the grid but to domestic microgeneration technologies, such as solar PV panels or biomass boilers. These are typically valued as average WTP for an initial investment plus a recurring maintenance fee. These values were also included if an appropriate unit conversion was available. If only the initial investments were provided their monthly equivalent was calculated assuming a useful life of 20 years. (Sundt and Rehdanz, 2014) found that WTP/m tended to yield higher values than WTP/kWh.

Format. The survey format could be face-to-face, mail, web (online) or telephone. Some studies used more than one format, and many outsourced the actual data collection to a third party, usually a polling firm.

Elicitation. Five elicitation methods were included:

- Discrete choice experiments (DCE), where respondents had to choose one among several scenarios or 'choice cards', each of which contained a different combination of attributes.
- Contingent valuations (CV) where only one decision needed to be made, and which included dichotomous choice CV, payment cards, stochastic payment cards and traditional referendum model.
- Bounded CV, where values were capped, or more than one decision needed to be made. This category included single-bounded, double-bounded and multiple-bounded CV.

- Open-ended, where the respondent was free to state any value.
- Unspecified, where none of the above was indicated.

Though at first glance these approaches may appear very similar, the format has repeatedly been shown to influence the valuations obtained. CV methods tend to reflect mean values, whereas DCE methods typically estimate marginal values.

In previous meta-regressions DCE methods have been found to produce higher valuations than CV methods by a factor of two to three, other things being equal (Ma et al., 2015b). In a similar vein (Sundt and Rehdanz, 2014) compared 6 models and found that CV studies were penalized in their valuations by a lack of specific technologies. The findings by (Soon and Ahmad, 2015) are more nuanced, with single-bounded CV, double-bounded CV and DCE producing lower valuations compared to other methods including open-ended questions, payment cards and traditional referendum. (Grilli, 2017) added a twist by combining elicitation methods and modes (e.g. phone, mail, web) and finding that online CV surveys have a statistically significant and negative contribution to overall WTP beyond that of CV, CE and web taken separately.

Model. The econometric model used to obtain the WTP estimate was also recorded. Six categories were included:

- Linear. The most frequent linear models were simple linear regression (SLR) and ordinary least squares (OLS).
- Logit. This covers many different methods in the logistic family, including binary (dichotomous choice) logit, conditional logit, multinomial logit, nested logit, latent class logit, random effects logit and random parameter (mixed) logit.
- Probit. The probit family includes binary probit, random effects probit and multinomial probit.
- Tobit. In addition to explicit mention of a Tobit model, truncated regressions were also included in this category.
- Other. This category includes Weibull, spike and studies that used only statistical tests and metrics without a proper regression.
- Unspecified. This category includes generic binomial, parametric and non-parametric regressions.

Frame. This category was introduced to discern what is being valued, and thus be able to include many disparate valuations without sacrificing consistency.

During the literature screening process studies were clustered according to the motivations that they provided respondents for purchasing RE. It must be stressed that not all of these categories were used in the final meta-analysis. They included:

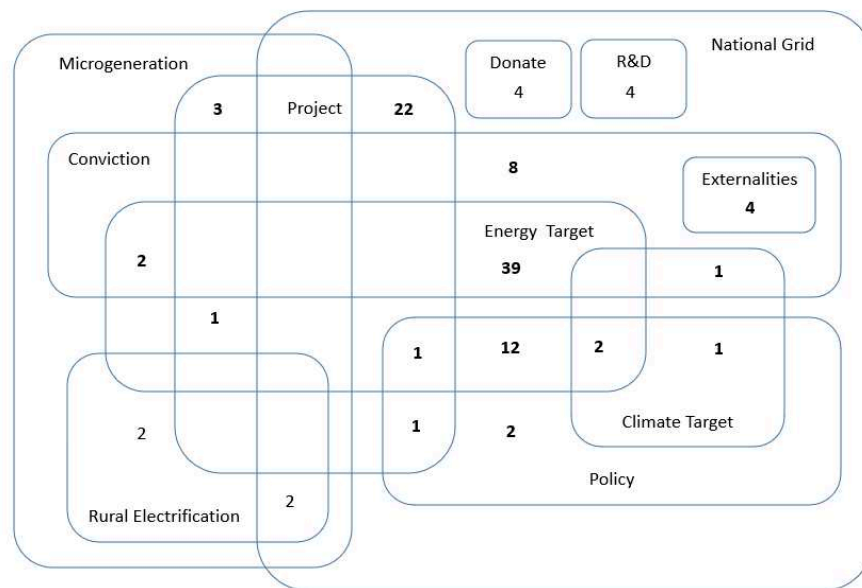
- **Rural electrification (FRAME.RURAL).** In this case respondents are typically isolated communities in developing countries that lack electricity. Their WTP reflects their motivation to have electricity, whether provided by the grid or a microgeneration technology. These studies are always accounted for in the average WTP estimates.

- **Conviction (FRAME.CONV).** This is the most common case and applies when surveys mention only diffuse public goods benefits or none, for example when they ask respondents how much they would pay for a given % of RE without explicitly stating *why* they would do so. They appeal to altruistic motives and tap into warm glow motivations. In total 54 studies fell in this category. This category also includes studies that aim to assess the value of the positive (WTP) and/or negative (WTA) externalities resulting from various renewable energy sources. These studies may use hypothetical projects to make scenarios easier to understand, but do not refer to any specific project. RE leasing arrangements with no specific location are also included in this category (Kotchen and Moore, 2004). In other cases no project is specified, and benefits accrue elsewhere, e.g., in improved air quality (Whitehead and Cherry, 2007b), improved forest habitat (Susaeta et al., 2011b) or improved supply reliability (Bakkensen and Schuler, 2020).
- **Policy (FRAME.POL).** This applies when a specific national or international policy or target is invoked to justify expenditures in RE. Policy-oriented studies are closely related to specific RE and GHG targets but deserve to be treated separately given the authority and institutional support lent to them by the policy. Examples include renewable portfolio standards in the USA and South Korea; clean energy standards in the USA; the 20-20-20 target in the EU; and the Green Electricity Fund in China. In climate policy the framing involves decarbonizing the energy or electricity sectors, as in the EU's -20% and -40% GHG for energy and electricity by 2020, respectively (Hanemann et al., 2010; Martínez-Paz et al., 2011) or the -60% GHG by 2050 in the UK (Longo et al., 2006).
- **Project (FRAME.PROY).** These studies emphasize positive and/or negative externalities resulting from specific infrastructure projects. Valuations range widely depending on whether WTP is aimed at obtaining a benefit or avoiding harm (Aravena et al., 2012b; Garcés-Voisinat and Mukherjee, 2016), especially when sub-populations at opposing sides of a project are sampled, as in (Botelho et al., 2017, 2013). Contrasting different RE projects to supply a site or region to test for social acceptability (e.g. wind vs solar) also falls in this category (Navrud and Grønvik Bråten, 2007). A total of 28 studies are project-related.
- **Renewables Target (FRAME.TARGET).** In many stated preference studies a specific percentage or share of RE is presented to prompt or anchor choices, or simply to distinguish levels in an attribute. In general, a specific percentage of RE is valued based on either personal conviction or to comply with a national policy. The RE target level is also useful to tease out 'warm glow effects' associated to minimum commitments to a given amount of RE, with higher shares offering diminishing marginal returns to respondents (Ma et al., 2015b). In total 57 articles provide specific RE targets. The average RE percentage was 52.8% (s.d. 42.5). Climate and GHG mitigation targets were sometimes also included if they were associated to the deployment of renewables and helped to justify paying a premium. In some cases benefits are typically framed in terms of a percentage of GHG reductions to be attained while in others no specific percentage is provided (Markantonis and Bithas, 2010). Some

authors have also obtained specific values for the effect of climate policies from regression coefficients (Roe et al., 2001b).

- **Microgeneration (FRAME.MICRO)**. This is a small-scale version of the externalities category, in which residential consumers assess the possibility of owning the generation technology outright. They differ by requiring a substantial down payment and a commitment spanning years or decades. Six studies fall in this category, although two of them also satisfy the *conviction* category and one (Su et al., 2018) was removed since it required too many assumptions to arrive at a WTP in USD/m.

Figure 1. Frames used to sort the collected literature.



Studies that were not included in the final analysis include those addressing respondents' willingness to donate to green electricity projects to assess altruism and the 'warm glow of giving' (Champ and Bishop, 2001; Ito et al., 2010; Menges et al., 2005b) and WTP for energy research and development (Han et al., 2020; Jin et al., 2019; Li et al., 2009). Figure 1 provides an illustration of the relationship between the frames used in this study. For convenience these categories were placed inside the national grid category. Numbers in bold refer to the number of studies used in the meta-regression. Except for RE targets which include specific percentages all other frames are dummy variables. To the author's knowledge no previous RE meta-analysis has employed an equivalent framing approach to avoid excluding a large portion of the identified studies.

Additional frames were employed during the literature review and classification process, though they were not used in the final meta-regressions. These include studies that formulate choice questions in terms of willingness to donate (**FRAME.WTD**) i.e., make voluntary donations to fund green energy projects (Champ and Bishop, 2001; Ito et al., 2010; Menges et al., 2005b), as investments in research and development (**FRAME.RD**) to improve the performance or reduce the impact of renewable energy sources (Li et al., 2009; Mueller,

2013), and in terms of other positive or negative externalities (**FRAME.EXT**) not associated to specific technologies or projects, such as air pollution (Bergmann et al., 2006a; Whitehead and Cherry, 2007a); landscape attributes (Ladenburg and Dubgaard, 2007), landscape and employment (Ku and Yoo, 2010a), positive effects on the environment (Susaeta et al., 2011a) and environmental, health and employment combinations (Johnson and Desvousges, 1997).

An additional category not considered during the review was that of the *status* attribute, or the improvement to one's reputation or social standing that comes from conspicuous consumption (Adomatis et al., 2015; Dastrup et al., 2012a; Krovvidi, n.d.; Menges et al., 2005a; Satsiou et al., 2013).

Consent rate. It is very misleading to assume that the WTP reported in a study applies to the entire sample interviewed or to the average respondent in that sample. Very often only a small fraction of respondents have a WTP > 0, with the rest declaring their WTP to be zero. That is why many studies employ models capable of handling zero-inflated data, such as the tobit or spike. This information was collected for 52 studies, with the average number of respondents with a positive WTP being 68%. The remaining 32% of respondents provided various reasons for their refusal to pay or were simply treated as protest zeros.

2.1.3 Descriptive Statistics

Nine data categories were collected in addition to WTP. These include the geographic distribution of the studies by country and region (no distinction was made between national and sub-national samples), the format used to interact with participants, whether specific technologies were specified, the stated preference method employed to elicit preferences, the econometric model used to conduct a analysis, the type of WTP value reported (average or marginal), the frame or situational context used to design the survey, the survey year and the sample size. Table 1 presents the list of items collected for every individual study, their code and description.

Table 1. Metadata collected from primary studies

Variable	Code	Description
Nominal		
COUNTRY	Country	
CODE	Country code	
REGION	Geographical region	
Continuous		
YEAR	Year of survey	
SAMPLE	Sample size, number of individual respondents	
SE	Standard error, estimated as $1/\sqrt{n}$	
WTP <i>Willingness to pay</i>	WTP	Willingness to pay
	WTP.0	Response rate (WTP > 0) as percentage
	WTP.MIN	Lower value of WTP range
	WTP.MAX	Higher value of WTP range
Dichotomous		
FORM <i>Format</i>	FORM.F	Dummy: face-to-face = 1
	FORM.M	Dummy: mail = 1
	FORM.W	Dummy: web = 1
	FORM.T	Dummy: telephone = 1

Variable	Code	Description
TECH <i>Generation technology</i>	TECH.G	Dummy: generic 'green' = 1
	TECH.S	Dummy: solar = 1
	TECH.W	Dummy: wind = 1
	TECH.B	Dummy: biomass = 1
	TECH.H	Dummy: hydro = 1
	TECH.N	Dummy: nuclear = 1
	TECH.T	Dummy: geothermal = 1
	TECH.F	Dummy: fossil = 1
ELI <i>Elicitation method</i>	ELI.DCE	Dummy: discrete choice experiment = 1
	ELI.CV	Dummy: contingent valuation = 1
	ELI.CVB	Dummy: contingent valuation, bounded = 1
	ELI.OE	Dummy: open-ended = 1
	ELI.U	Dummy: unspecified = 1
MOD <i>Econometric model</i>	MOD.LIN	Dummy: linear model = 1
	MOD.LOG	Dummy: logit model = 1
	MOD.PRO	Dummy: probit model = 1
	MOD.TOB	Dummy: tobit model = 1
	MOD.O	Dummy: other model, tests = 1
	MOD.U	Dummy: unspecified = 1
TYPE	TYPE.MARG	Dummy: marginal WTP = 1
	TYPE.AVG	Dummy: average WTP = 1
FRAME <i>Framing of WTP in survey</i>	FRAME.RURAL	Dummy: rural electrification = 1
	FRAME.CONV	Dummy: conviction = 1
	FRAME.POL	Dummy: national policy = 1
	FRAME.PROY	Dummy: specific project = 1
	FRAME.TARGET	Dummy: renewable energy target = 1
	FRAME.MICRO	Dummy: microgeneration = 1
	FRAME.GHG†	Dummy: climate mitigation target = 1
	FRAME.WTD†	Dummy: willingness to donate = 1
	FRAME.RD†	Dummy: research & development = 1
FRAME.EXT†	Dummy: externality (without project) = 1	

† Coded during literature review but not used in meta-analysis.

The findings of the literature review are shown in Table 2. Specific categories are described below.

Table 2. Descriptive statistics (n=100)

Code	Description	No.	Freq %	Code	Description	No.	Freq %
Country	United States	23	22.8%	Elicitation	DCE	41	44.1%
	Germany	7	6.9%		CV	37	39.4%
	Greece	6	5.9%		CV bounded	13	14.0%
	Spain	6	5.9%		Open-ended	13	14.1%
	United Kingdom	6	5.9%		Unspecified	1	2.2%
	Italy	5	5.0%	Model	Linear	13	14.3%
	Portugal	5	5.0%		Logit	44	47.8%
	Republic of Korea	5	5.0%		Probit	13	14.3%
	China	4	4.0%		Tobit	12	13.2%
	UK (Scotland)	4	4.0%		Other	23	25.3%
	(20 others)	30	29.7%		Unspecified	7	7.7%
	Region	Europe	54		54.0%	Type	Marginal
North America		25	25.0%	Average	16		17.4%
Asia		14	14.0%	Frame	Conviction	85	90.4%†
Africa		2	2.0%		Externality	11	11.7%†

Format	South America	2	2.0%	Policy	16	17.0%†		
	Oceania	2	2.0%		Project	16	17.0%†	
	MENA	1	1.0%		Target	56	59.6%†	
	Face-to-face	39	42.9%		Microgeneration	7	7.4%†	
	Mail	24	26.1%		Rural	4	4.3%†	
	Web	24	26.4%		Willing to donate	4	4.3%‡	
	Telephone	17	18.7%		R&D	2	2.1%‡	
Tech	Green	50	53.2%	Survey year	2008.1	6.0	1992	2020
	Wind	34	36.6%					
	Solar	29	31.2%					
	Biomass	21	22.6%					
	Hydro	16	17.4%					
	Nuclear	4	4.3%					
	Geothermal	2	2.2%					
Fossil	6	6.5%	Sample size	893.8	1597.4	30	14,304	
								WTP (USD/m PPP)

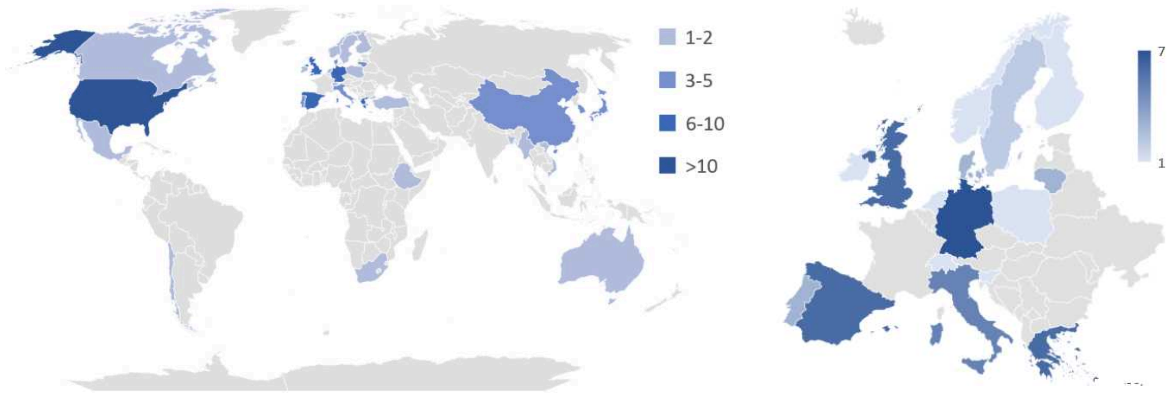
† Percentages overlap. ‡ Collected and reviewed but not included in the analysis.

Geographic distribution. A total of 114 studies were collected and screened. After removing nonconforming studies and duplicates 94 were selected for the meta regression. Studies that aim to contrast the WTP of two populations, or to compare the results of different econometric models often report different WTP values for different sub-samples. In these cases the characteristics, treatments and results obtained for different sub-samples were treated as separate entries in the dataset yet counted as a single study. This was the case of (Byrnes et al., 1999) who reported on respondents in Colorado and Wyoming; (Kotchen and Moore, 2004) who compared the responses from clients of different utilities in the United States; (Menges et al., 2005b) who compared preferences in different German cities; (Andor et al., 2016) who sampled preferences in the same population at different dates with partial replacement (i.e. with some respondent overlaps); and (Merk et al., 2019) who compared preferences in Germany and the U.K. These instances increased the total number of entries in the dataset, which is detailed in Annex I.

In terms the geographical distribution the United States and Europe accounted for the vast majority, though this is partly a result of the inflated number of earlier studies from the United States pointed out earlier. In terms of number of observations Asia ranked third after North America and Europe by virtue of a single large study from Viet Nam which accounted for 14,304 observations. Most studies from Africa are framed in terms of rural electrification and were thus excluded from the analysis, save for two from South Africa. The Middle East counted only one study from Lebanon, Oceania two from the same author in Australia and. Latin America four from Chile and Mexico, of which one was omitted.

The use of continents or regions was not included in the meta-analysis but is presented here for information purposes. Previous meta-analyses by G. Grilli (Grilli, 2017) and a team of researchers from the Kiel Institute for the World Economy (Sundt and Rehdanz, 2014) have found significant differences in regional mean WTP using the Kruskal Wallis non-parametric test. Europe and North America account for 79% of the studies conducted to date, which explain why most of them have explored WTP for intangible attributes rather than electricity provision or reliability, which are often the priorities of developing nations.

Figure 2. Geographical distribution of collected studies



Moreover, only four studies were identified for China and none for India, which between them account for roughly 2.8 billion people or about one third of the world population. Expanding renewables in the energy mix of developing nations is essential if international clean energy and GHG targets are to be achieved. More resources should therefore be allocated to learn about the potential demand for clean energy in developing nations, so policy makers and the private sector can take the necessary steps to incentivize their adoption. South America, Oceania and the Middle East and North Africa (MENA) region are also very underrepresented, not to mention the rest of Africa.

Figure 3. Studies by region and sample size

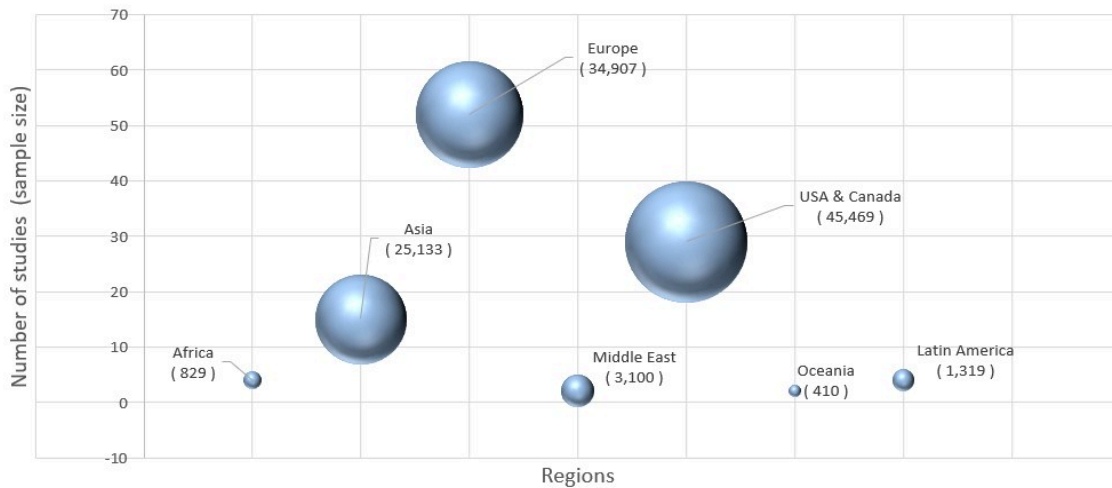
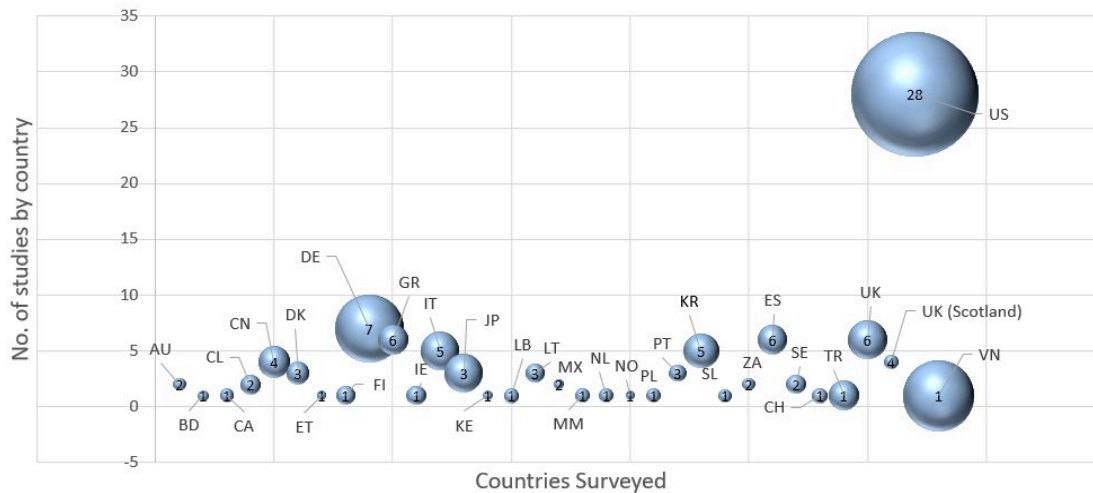
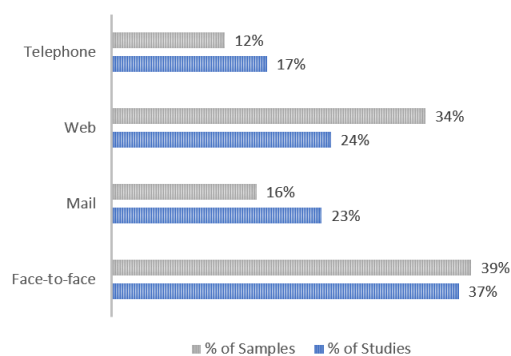


Figure 4. Studies by country



Format. The survey format also varied significantly. Four options served to sort all studies: face-to-face, telephone, web (online) and mail, with some studies using more than one format. Noteworthy are the discrepancies between studies and samples in online surveys, which suggest ease of recruitment, while mail surveys suffered from a notoriously low response rate given the additional effort required to send back replies. When older studies were conducted in the 1990s web technology was not as prevalent as it is today, limiting their use. Most studies conducted before the mid-2010s did not remunerate participants, assuming they were content to lend their time to share their opinion. Confidentiality of personal details was only an afterthought. Face-to-face surveys continue to be prevalent today, as they enable the swift collection of data from more or less captive respondents and facilitate the payment of remunerations. They are also favored over telephone and web surveys when sampling is targeted to specific cohorts or household types.

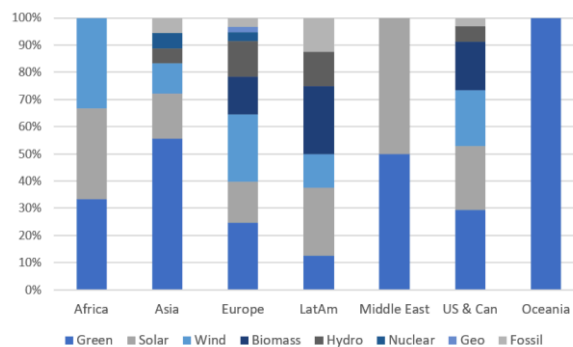
Figure 5. Survey Format



Technology. Given that electricity gains its 'green' credential by virtue of the technology used to produce it, this item is particularly relevant. When a specific technology is included in addition or instead of a generic 'green' electricity it may reflect the energy mix of the country or a specific project under consideration, though this does not hold when the number of studies is small. Nuclear and fossil fuels are included as part of diverse choice sets that also contain renewables, generally in DCEs

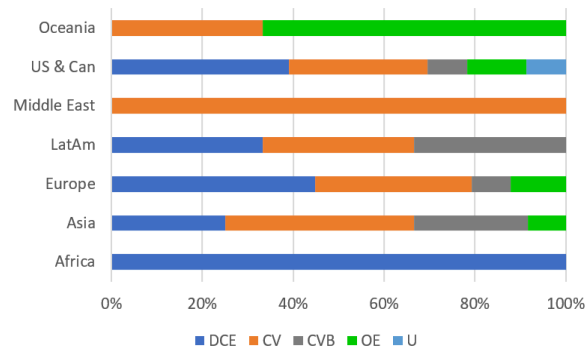
that ask respondents to choose one energy mix among many. In these cases fossil fuels are often included as defaults. In general technological differences are much more prevalent in DCE studies than in their CV counterparts, where generic attributes tend to dominate. In general regions where the public awareness of renewables is more advanced, or where green electricity has been on offer for longer, tend to draw finer distinctions regarding technology. This probably reflects previous exposure to information on the positive and negative externalities of certain technologies, which have in turn produced more discerning consumers. In the case of Africa, Oceania and the Middle East the number of studies is so limited as to be unrepresentative with respect to technology. As will be shown below, certain patterns do emerge when valuing green electricity by technology. Where the value of solar (Botelho et al., 2017) and wind (Botelho et al., 2013) was studied in the context of a specific project valuations were lower and sometimes even negative. Consistently lower values were found for hydro and biomass, which often have even higher externalities.

Figure 6. Technologies



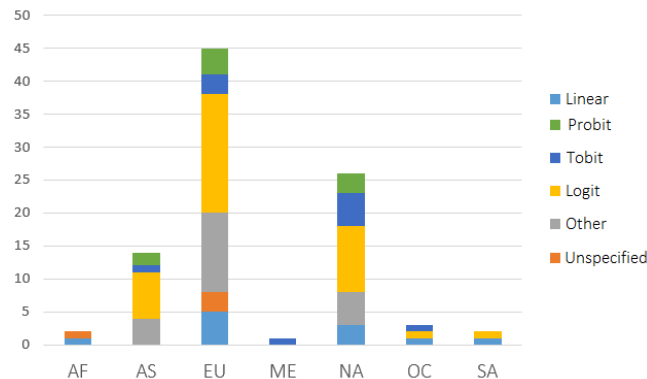
Elicitation. The stated preference method used also varies by country and region. As mentioned before, the classifications used in this study are discrete choice experiment (DCE), contingent valuation (CV), bounded contingent valuation (CVB), open-ended (OE) and unspecified (U). In general DCEs are more complex than CV and OE surveys to design and require more effort from respondents, requiring them to make more explicit trade-offs between attributes. In fact before web surveys were available telephone surveys were often limited to CV formats given the impracticality of describing scenarios with different attribute levels over the phone (Byrnes et al., 1999; Hanley and Nevin, 1999). The vast majority of DCE surveys (24 out of 39) were later processed with logistic regressions, roughly six times more than using other methods. Simple CV surveys, in contrast, were most often processed with 'other' methods (17 out of 37). DCE methods have been widely documented to produce different (usually higher) estimates than CV and CVB methods when applied to the same underlying choices and individuals (Danyliv et al., 2012; Mogas et al., 2002; Ryan and Watson, 2009; Sundt and Rehdanz, 2015). Countries and regions where DCEs have been more widely used could therefore be expected to have produced higher WTP estimates than their otherwise similar counterparts, after controlling for relevant variables.

Figure 7. Elicitation methods



Model. The regression models used to obtain WTP estimates also vary widely. Of the 125 models identified in the papers the logit family is by far the most popular with 48 instances (34.4%), followed by 18 probit models (14.4%), 13 linear models (10.4%) and 12 tobit models (9.6%).

Figure 8. Econometric models by region



AF: Africa, AS: Asia, EU: Europe, ME: Middle East, NA: North America (including Mexico), OC: Oceania, SA: South America.

A full 27 (21.6%) belonged to the category 'other', which included less frequent models as well as isolated statistical tests favored in studies from the 1990s. Seven studies (5.6%) did not explicitly indicate the model used. From Figure 88 it is clear that stated choice experiments involving regressions of some kind comprise the overwhelming majority, with logit models the most popular. Europe produced the largest number of studies that failed to specify the models they used to arrive at their estimates.

Figure 9. Econometric models by marginal WTP

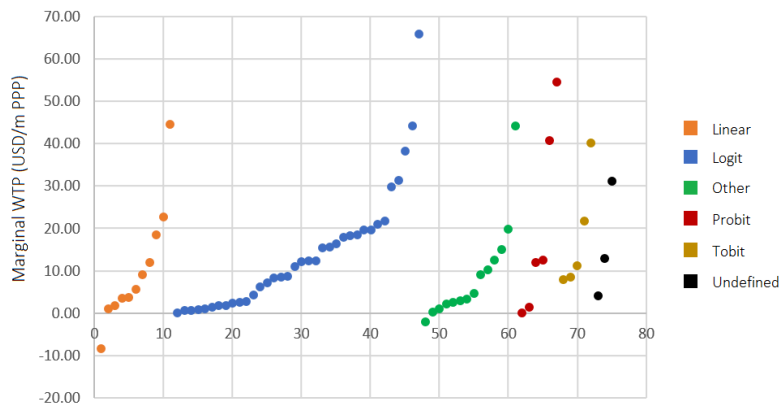
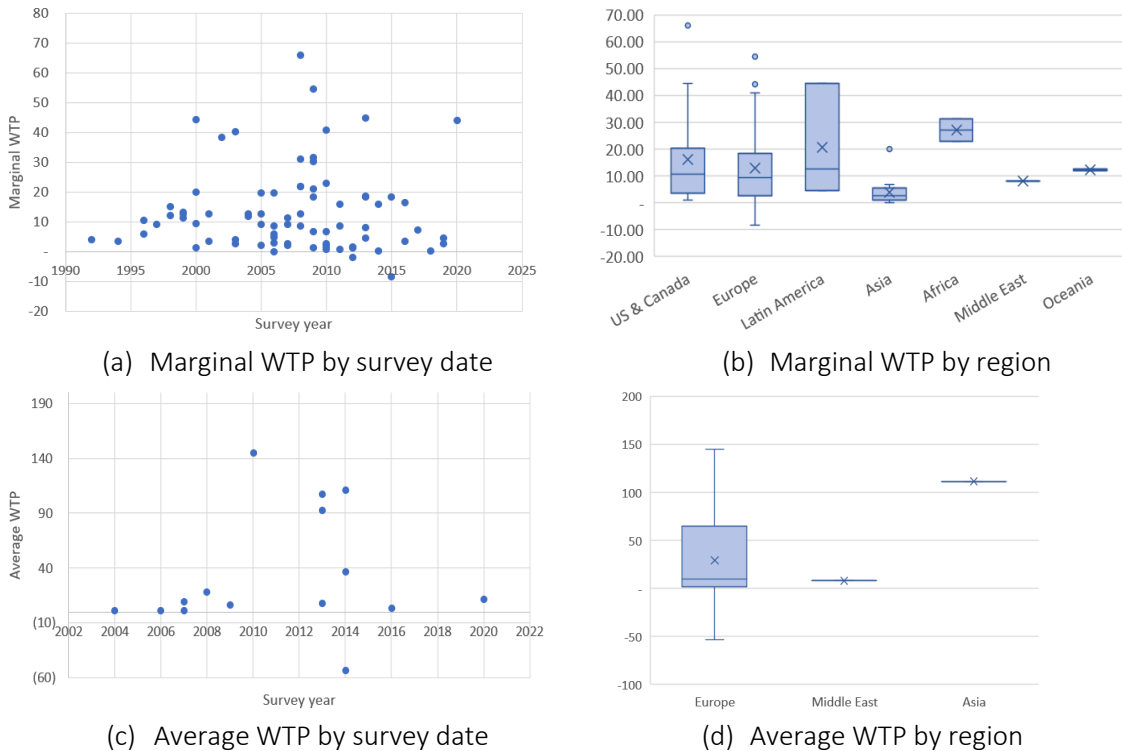


Figure 9 shows the same WTP values sorted by model type. It suggests only the values of linear and logit models are robust enough to produce reliable results, given that the 'other' (green) category is a diverse mix that cannot be properly characterized. As we will see in the section on regression analysis, part of the difficulty in analyzing this data lies in the large number of variables with respect to the relatively few data points for many study types.

WTP values. The values for marginal WTP display a clear funnel shape, with values peaking for surveys conducted around 2010. By region Latin America displays the widest interquartile range, though this reflects the values of only three studies.

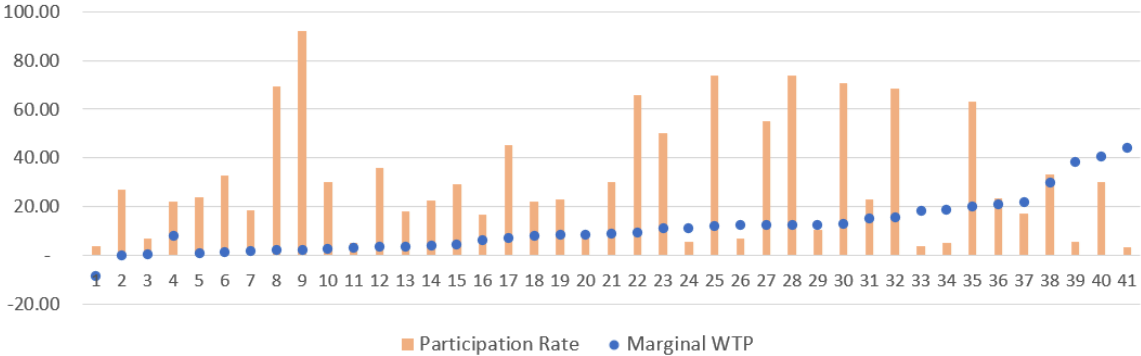
Figure 10. Marginal and average WTP by survey date and region



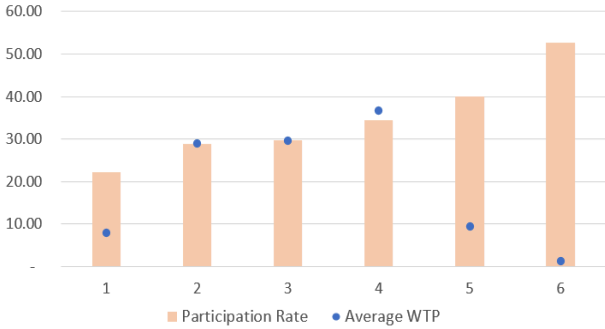
Europe and USA & Canada have similar median and range, but the European minimum is dragged down by a higher number of studies with negative valuations and WTA. Asia is notorious for its narrow range despite a high number of studies, while Africa, the Middle East and Oceania are skewed by limited publications.

Of the 96 studies reviewed only 47 provided information on participation rates, i.e., the percentage of individuals surveyed who had a WTP > 0 or had a WTP of zero that did not count as a protest response. The two outermost values (largest positive and negative, both for average WTP) were removed, and the rest were split into marginal and average WTP. No trend is evident between WTP and participation rate, which suggests that attrition and protest responses reflect the attitude of people toward surveys in general rather than the content of this particular survey. Average WTP valuations paint a similar picture albeit with less data points; of the 15 studies included 13 came from Europe.

Figure 11. Participation rate vs WTP



(a) Marginal WTP



(b) Average WTP

Finally, the **sample size** is also important in meta-regressions, as it provides a means to compare different studies in the absence of their covariance and standard errors, which many studies do not report. Employing the square root of the sample size *in lieu* of the standard errors to estimate covariance is an approach championed by some researchers from the United States (Stanley and Rosenberger, 2009) and adopted in Australia (Ma et al., 2015a). The meta-coefficients can then be interpreted as elasticities, as was done by J.J. Soon and others (Soon and Ahmad, 2015). Alternatively,

the minimum and maximum WTP values reported in each study could be used to estimate the corresponding variance and standard deviation.

2.2 *Meta Regression Studies (MRS)*

Eight meta-regression studies for WTP for green electricity were identified in the literature. Although they each pursue a slightly different objective their common characteristic is an interest in identifying the sources of WTP heterogeneity by using different combinations of individual-specific, country-specific and survey-specific explanatory variables. Apart from tapping into slightly different pools of studies during the literature review, their specific objectives influence their choice of econometric model, which in turn defines their screening criteria for including or excluding sources.

The first meta-regression of WTP for green electricity was published by (Sundt and Rehdanz, 2014) and aimed to research the survey-specific factors affecting WTP as well as testing the quality of results for benefit transfer applications. It processed 85 individual observations from 18 studies and 10 countries using a weighted linear regression with robust standard errors and obtained an estimate of 13.13 USD/m (3.17 USD/kWh). Among its main qualitative findings was the gradual decrease of WTP values over time, the usefulness of converting values into WTP/kWh to control for household-specific regressors, and the finding that hydro is the least desirable RE source.

Two subsequent studies by (Soon and Ahmad, 2015) and (Ma et al., 2015a) the following year employed similar size pools to arrive at similar conclusions using different methods. These studies analyzed 29-30 papers from 13-14 countries representing 137-142 individual observations from surveys conducted between 1996-2013.

The paper by (Soon and Ahmad, 2015) aimed to improve upon previous meta-regressions by using more recent literature and controlling for publication bias, while (Ma et al., 2015a) sought to find consensus on the WTP effect size and disentangle fixed effects (survey noise) from random effects (country and individual noise). Since both studies aimed to test for the presence of publication bias⁴⁰, they had to either select studies that included variance estimates (Soon and Ahmad, 2015) or find a proxy such as the inverse square root of the sample size (Ma et al., 2015a). However, the exclusion criteria used by (Soon and Ahmad, 2015) was more rigorous. None of them conclusively identified the presence of publication bias.

In terms of the models (Soon and Ahmad, 2015) employed the weighted random-effects model shown in Annex III, whereas (Ma et al., 2015a) mentions the use of an undisclosed weighted least squares (WLS) regression on the full set to test for fixed effects and a residual maximum likelihood (REML) regression with standard errors on a subsample to test for mixed effects. The final estimates were 7.16 USD/m in the case of (Soon and Ahmad, 2015) and 0.015 USD/kWh for (Ma et al., 2015a). Although they both identify certain statistically significant explanatory variables, their conclusions diverge on their individual influence. An important finding by (Ma et al., 2015a) is that study design explains more variation than the energy type, consumer demographics or consumption patterns.

⁴⁰ Publication bias refers to situations in which researchers publish only (or mostly) results that show a significant finding or effect, while shelving those that do not. This results in published works with more positive results than is actually the case in the original samples.

The study by (Bigerna and Polinori, 2015) published the same year had a different focus. It aimed to better understand the mechanisms determining RE acceptance, from the consumer and local resident perspectives. It employed a hybrid approach that combined results from their meta-analysis with a local survey that included the community's prior experience with similar projects. It used an unweighted and weighted ordinary least squares (OLS) regression to arrive at a WTP of 7.003 EUR/m (euros per month) for project supporters and a WTA of -7.935 EUR/m for detractors.

In chronological order the next meta-analysis to be published was a master's thesis by (Pokhrel, 2016), which simply aimed to identify the factors that affect consumers' WTP for green electricity. It analyzed 21 studies from 18 countries, which included 99 individual observations from surveys between 2000 and 2013 and estimated a mean WTP of 26.69 USD/m.

The meta-regression by (Grilli, 2017) used a WLS model on 34 articles from 16 countries to identify understand the effects of some country-level variables on the stated WTP for RE. It estimated mean WTP to be 13.29 USD/m for generic green electricity and also provided technology-specific meta-estimates for solar (14.40 USD/m), wind (14.66 USD/m), biomass (11.02 USD/m), hydro (9.57 USD/m) and geothermal (36.90 USD/m).

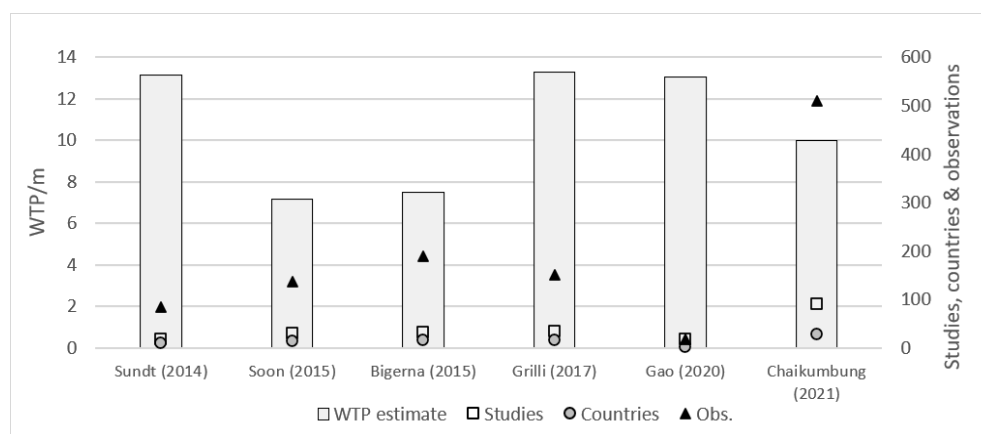
The only country-specific meta-analysis was conducted by (Gao et al., 2020) for Japan. Despite its narrow focus on individual characteristics, it was a valuable contribution to the WTP literature because it summarized the findings of 17 previous studies from in Japanese that had remained inaccessible to many researchers. Its aim was to evaluate the impact of WTP on achieving RE targets in Japan and simulate its expansion between 2015 and 2030. It employed a simple OLS model in combination with an 'acceptability curve' to propose a flexible feed-in tariff tailored to the populations of specific prefectures, potentially lowering the financial burden on their respective public finances. It also found income and gender to be strong predictors of WTP.

The last and most recent meta-analysis by (Chaikumbung, 2021) is also the most comprehensive. It screened 91 published and unpublished documents from 27 countries from the period 1992-2018. In addition to the usual search for explanatory variables, it aimed to determine whether there is a correlation between WTP for RE and national institutions, as measured by internationally published rankings of democracy, free markets, inequality and similar metrics. This study also used a WLS model, and since data on standard errors is frequently missing the author used the square root of the sample size as proxy. The average WTP from the raw data was 13.69 USD/m, while its equivalent from the regression model was 9.97 USD/m. The main contribution of this paper was to establish a correlation between WTP for RE and the effectiveness of national institutions as measured by rankings of economic freedom, inequality, democracy and governance, as well as per capita GDP and GHG emissions, among others. It also found that RE behaves as a luxury good and found no publication bias in the data.

Table 3. RE WTP meta-regression basic statistics

Author	Surveyed period	Studies	Countries	Obs.	WTP
Sundt, S. et al. (2014)	2000-2011	18	10	85	13.13 USD/m ; 3.17 USD/kWh (USD 2010)
Soon, J-J. et al. (2015)	1996-2011	30	13	137	7.16 USD/m (USD 2013)
Ma, C. et al. (2015)	1999-2013	29	14	142	0.015 USD/kWh (USD 2006)
Bigerna, S. et al. (2015)	1999-2014	31	15 ⁴¹	189	7.003 EUR/m (EUR 2013)
Pokhrel, K.R. (2016) ⁴²	2000-2013	21	18	99	26.69 USD/m (USD 2008)
Grilli, G. (2017)	1998 - 2014	34	16	151	13.29 USD/m (USD 2010)
Gao, L. et al. (2020)	1998-2015	17	1	18	13.03 US/m (USD 2020)
Chaikumbung, M. (2021)	1992-2018 ⁴³	91	27	509	9.97 - 13.69 USD/m (USD 2011)

Figure 12. Meta-Regression WTP vs Number of countries, studies and observations.



Most of the studies cited used $\log(\text{WTP})$ instead of WTP as the dependent variable to reduce heteroscedasticity. All meta-regressions measured marginal WTP, six as WTP/m, one as WTP/kWh and one measured both. The authors that included WTP/kWh argued that this measure was better suited for policy recommendations (e.g., taxes) as it was not affected by household-specific effects. Given the diversity of sources, countries and observations these meta-regressions have produced remarkably homogeneous results, as is shown in Table 3 and Figure 12. Additional details are provided in Annexes II and III.

3. ECONOMETRIC MODELS

A meta-analysis is an empirical exercise that attempts to combine the results of multiple individual studies, each of which employed a different set of regressors and contains some degree of error. All the meta-analyses previously described employ regression models that adhere to the Random Utility Model (RUM), which acknowledges the existence of a random error in every measurement and sets confidence intervals to address them. In this study we used a weighted least squares (WLS) regression

⁴¹ Undisclosed in the study, estimated from references.

⁴² This is a non-peer-reviewed master's thesis.

⁴³ 2018 is the most recent publication year, not the year of the most recent survey.

as our first model, following the example of two related meta-analyses (Chaikumbung, 2021; Ma et al., 2015b).

The observed random error may be the result only of within-study sampling (measurement) error from researchers, or also of differences in the way studies are designed and the methods that are used. Sampling error that results in *within-study variance* may be prevalent in studies conducted in the same country, during the same year and for the same technology, while otherwise using identical methods. In contrast, the error introduced by using different formats (*FORM*), elicitation methods (*ELI*) and model types (*MOD*) are examples of *between-study variance* (Veroniki et al., 2015). Depending on our assumptions about the sources of variation that apply in our meta-analysis, we may include one or both sources of error. In this study we employ both approaches, depending on the availability of data. In general the variables collected by the literature review exceed the number of studies by a wide margin, so that for each variable only few data points exist to perform a regression (especially in the case of average WTP). In these cases fixed effects models were favored.

All the meta-regressors used here are country and survey-specific, i.e., no individual-specific regressors such as age, gender, education, income or attitudes were included, as these are assumed to have been controlled for in the original studies. We also introduce framing as an explanatory variable.

3.1 Model I. Weighted Least Squares

Following the example of two related meta-analyses (Chaikumbung, 2021; Ma et al., 2015b) the first model used was a weighted least squares (WLS) regression that included the square root of the sample size as proxy for the standard errors. This is an approach suggested by some authors (Stanley and Rosenberger, 2009) when data on standard errors is missing from the primary studies, as is the case here. Other authors (Begg and Berlin, 1988) also argue that the inverse of the square root sample size is also proportional to the publication bias, although we will not test for publication bias in this study.

The RUM model as applied to WTP meta-regressions has the general form:

$$WTP = \alpha + \beta_i X_i + \varepsilon \quad (1)$$

After adapting to the explanatory variables in Table 1 we obtain the following formulation:

$$WTP = \alpha + \beta_i COUNTRY_i + \beta_i YEAR_i + \beta_i WTP.0_i + \beta_i FORM_i + \beta_i TECH_i + \beta_i ELI_i + \beta_i MOD_i + \beta_i FRAME_i + \varepsilon_i \quad (2)$$

This is a simple linear regression using only marginal values, which reduces the sample size to 77 data points. Several regressors that had too few values were also removed.

3.2 Model II. Fixed Effects Models

Models that include only within-study variance are called fixed effects (FE) models⁴⁴. They assume that all studies in the meta-analysis share an identical true effect size, and that the sole reason the observed estimates vary between studies is because of sampling error. Following the notation

⁴⁴ Or alternatively *common-effects models*.

proposed by (Harrer et al., 2021), the fixed effects models assumes that when the observed effect size $\hat{\theta}_k$ of a study k deviates from the true effect size θ_F , the only reason is the sampling error ϵ_k :

$$\hat{\theta}_k = \theta_F + \epsilon_k \quad (3)$$

Where $\epsilon_k \sim N(0, v_i)$, $Var(\hat{\theta}_k) = v_i$ and $w_{i,FR} = 1/v_i$ is the weight (the inverse of the variance) assigned to each study.

In many instances this assumption is unrealistic and may lead to excessive type I errors (false positives) if there is unexplained heterogeneity (Ma et al., 2015a). Some studies also included negative WTP values, which posed a problem for the regression analysis. Some of these represented respondents' WTP to avoid a specific project from being carried out (Botelho et al., 2017, 2013; Dimitropoulos and Kontoleon, 2009) while others reflected a reduced WTP in comparison to previous years (Andor et al., 2016). To deal with negative values two approaches were used: replacing them by zeroes or removing the observations altogether, and this for both marginal WTP and average WTP.

3.3 Model III. Random Effects Models

On the other hand, random effects (RE) models allow the true effect sizes to vary across studies. The RE model assumes that there is a distribution of true effect sizes μ_{RE} , and that the WTP estimates obtained from the primary studies are a random sample from this distribution. In addition to the within-study error random effects models include an additional term ζ_k to account for between-study variance (the weighted version includes an additional term in the denominator):

$$\begin{aligned} \hat{\theta}_k &= \theta_i + \epsilon_i \\ \theta_i &= \mu_{RE} + \zeta_k \\ \hat{\theta}_k &= \mu_{RE} + \epsilon_i + \zeta_k \end{aligned} \quad (4)$$

Where $\epsilon_k \sim N(0, v_i)$, $\zeta_k \sim N(0, \tau^2)$, $Var(\hat{\theta}_k) = v_i + \tau^2$ and $w_{i,RE} = 1/(v_i + \tau^2)$ is the appropriate tau-adjusted weight for the random effects model. The relationship between the fixed and random effects models is illustrated in *Figure 13* while the relationship between within- and between-study effect sizes is illustrated in *Figure 14*.

Figure 13. Comparison of the fixed and random effects models.
Taken from (Spinelis and Pandis, 2020)

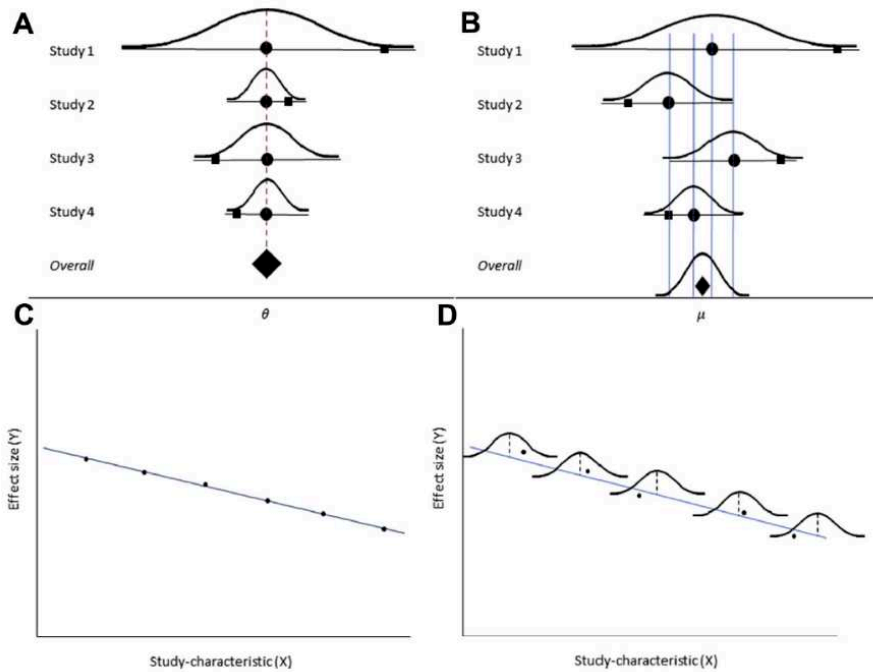
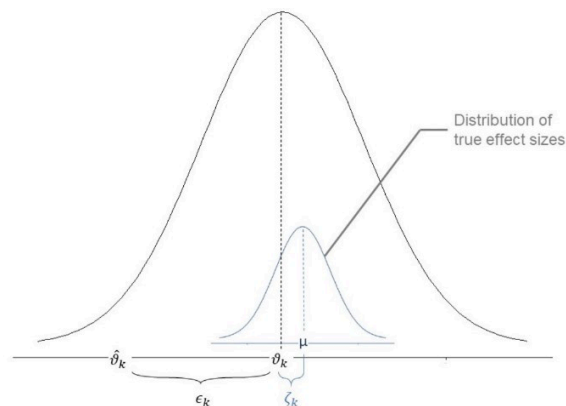


Figure 14. Illustration of the random effects model. Taken from (Harrer et al., 2021)



Several methods have been suggested to quantify the between-study variance in meta-analytic data (Veroniki et al., 2015). In the most popular family of methods this variance is represented by the variance of the distribution of the true study effects, commonly denoted as τ^2 . The Restricted Maximum-Likelihood (REML) estimator was chosen as τ^2 in this study, as some evidence suggests that it performs better for continuous data like WTP (Veroniki et al., 2015). Its downside is that it is restricted to non-negative values only.

4. RESULTS

This section presents the results of three types of models: weighted least squares (WLS), fixed-effect models and random effects models. They constitute the means through which we will try to discern the different factors that affect the observed differences in WTP estimates in the literature.

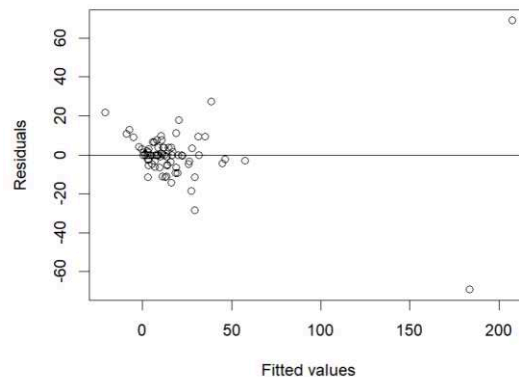
4.1 Least Squares and Weighted Least Squares Models

The first model used was a simple least squares regression that we will call Model 1. The equation for Model 1 can be represented as:

$$WTP = \alpha + \beta_i COUNTRY_i + \beta_i YEAR_i + \beta_i WTP.0_i + \beta_i FORM_i + \beta_i TECH_i + \beta_i ELICIT_i + \beta_i MOD_i + \beta_i FRAME_i + \varepsilon_i \quad (5)$$

In this model virtually none of the coefficients obtained was statistically significant, the standard error was 27.77, R-squared 0.8415, adjusted R-squared 0.3741 and the p-value 0.07866. A simple inspection of the plot below shows that residuals are not evenly distributed. A Breusch-Pagan (BP) test for heteroscedasticity (which adopts as null hypothesis the absence of heteroscedasticity) yields a value of 75.386 and a p-value of 0.04305.

Figure 15. Residual plot for the WLS model

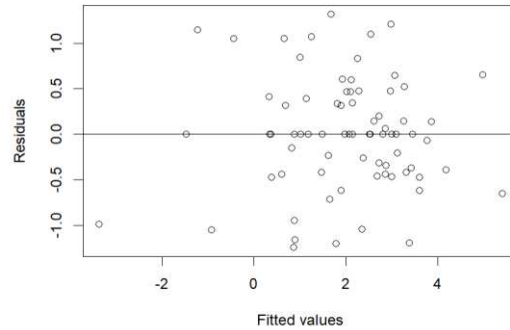


To improve the fit in the next model, which we will call Model 2, we used $\ln(WTP)$ as the dependent variable, thus removing another eleven observations since the natural logarithm of negative values are undefined. The new equation is:

$$\ln(WTP) = \alpha + \beta_i COUNTRY_i + \beta_i YEAR_i + \beta_i WTP.0_i + \beta_i FORM_i + \beta_i TECH_i + \beta_i ELICIT_i + \beta_i MOD_i + \beta_i FRAME_i + \varepsilon_i \quad (6)$$

Model 2 is still a simple least squares regression. The new standard error is 1.282, with an R squared of 0.8468, an adjusted R squared of 0.3423 and a p-value of 0.1191. As can be seen in Figure 16, the residual plot is now more evenly balanced. The BP test yields a value of 56.942 with a p-value of 0.4398. In this case four coefficients are significant at the 0.1 level and one at the 0.05 level. We will call this Model 2.

Figure 16. Residual plot for model 2



For Model 3 we follow the approach by Stanley and Rosenberger (Stanley and Rosenberger, 2009) and introduce standard errors as weights. Since standard errors are missing from many studies, we use the inverse square root of the sample size as proxy:

$$wt_i = SE_i \approx 1/\sqrt{n_i} \quad (7)$$

We now have a weighted least squares (WLS) model. The complete equation has the form:

$$\ln(WTP) = \alpha + \beta_0 SE_i + \beta_i COUNTRY_i + \beta_i YEAR_i + \beta_i WTP.0_i + \beta_i FORM_i + \beta_i TECH_i + \beta_i ELICIT_i + \beta_i MOD_i + \beta_i FRAME_i + \varepsilon_i \quad (8)$$

This version has three coefficients significant at the 0.05 level and three at the 0.1 level. Its standard error is 0.2834, R-squared 0.837, adjusted R-squared 0.3001 and p-value 0.1565. Its plot is presented below.

Figure 17. Residual plot for model 3

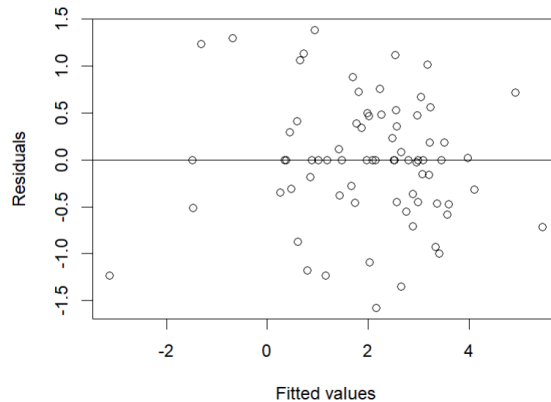


Table 4 summarizes the goodness of fit parameters of the three models described above.

Table 4. Model fit

Model	s.e	R ²	adj R ²	p-value
1	27.77	0.8415	0.3741	0.07866
2	1.2820	0.8468	0.3423	0.1191
3	0.2834	0.8370	0.3001	0.1565

4.2 Fixed Effects Models

Fixed effects models seek to identify the influence that research methods have on the values reported in the literature. In this case they were used to explore the effect of the format, technology, elicitation method and type of regression model, with each level taken as a separate variable since many studies combined several of them. The term 'fixed' refers to the fact that the levels in a given study are either present or absent.

Using marginal WTP only one survey format (telephone) was statistically significant in addition to the intercepts, as can be seen from *Table 5*. In the case of the average WTP none of the regressors was statistically significant.

Table 5. Results of the Fixed Effects Model for Marginal WTP

FORMAT	Coefficient	Std. Error	t value	Pr(> t)
Intercept	13.332	4.788	2.784	0.00685 **
FORM.F	-3.902	4.568	-0.854	0.39586
FORM.M	-5.396	4.370	-1.235	0.22089
FORM.W	5.547	5.195	1.068	0.28916
FORM.T	10.999	4.865	2.261	0.02678 *
TECHNOLOGY	Coefficient	Std. Error	t value	Pr(> t)
Intercept	15.073	4.787	3.148	0.00244 **
TECH.G	-3	4.979	-0.603	0.54882
TECH.W	-3.83	4.954	-0.773	0.44206
TECH.S	1.139	4.549	0.25	0.8031
TECH.B	1.304	5.028	0.259	0.79613
TECH.H	6.862	5.224	1.314	0.19338
TECH.N	17.814	15.373	1.159	0.2506
TECH.T	2.684	15.373	0.175	0.8619
TECH.F	-10.752	8.883	-1.21	0.23029
ELICITATION	Coefficient	Std. Error	t value	Pr(> t)
Intercept	3.834	11.354	0.338	0.737
ELI.DCE	10.876	11.468	0.948	0.346
ELI.CV	10.021	11.173	0.897	0.373
ELI.CVB	1.329	12.122	0.11	0.913
ELI.OE	8.911	5.452	1.635	0.107
ELI.U	8.366	15.103	0.554	0.581
MODEL	Coefficient	Std. Error	t value	Pr(> t)
Intercept	19.34254	5.05577	3.826	0.00028***
MOD.LIN	-8.46713	6.20156	-1.365	0.17652
MOD.LOG	-4.45844	5.06008	-0.881	0.38128
MOD.PRO	-0.6305	5.74652	-0.11	0.91295
MOD.TOB	-0.06749	5.06814	-0.013	0.98941
MOD.O	-6.46506	5.01571	-1.289	0.20165
MOD.U	-5.06877	8.4571	-0.599	0.55087

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05

4.3 Mixed Effects Models

A total of eight mixed effects models were applied to the dataset, four to studies containing marginal WTP estimates (I-IV) and four to those with average WTP estimates (V-VIII). Within each category

there were two additional differences: how to handle negative values and how to estimate the effect size variance. For negative values the options were to either convert them to zeroes or remove them from the dataset. Effect size estimates could be obtained from either the standard deviation (using the minimum and maximum values reported in each study) or as the inverse of the square root of the sample size. The mixed effects models were calculated with the R package *metafor*.

Table 6. Mixed effects models for marginal WTP

I. Negative as zero and effect size from s.d.							
	<i>Estimate</i>	<i>s.e.</i>	<i>t value</i>	<i>d. f.</i>	<i>p value</i>	<i>CI lower</i>	<i>CI upper</i>
<i>Nothing is statistically significant</i>							
II. Negative as zero and effect size from sample size							
	<i>Estimate</i>	<i>s.e.</i>	<i>t value</i>	<i>d. f.</i>	<i>p value</i>	<i>CI lower</i>	<i>CI upper</i>
Intercept	735.442	138.992	5.291	30.000	0.00001***	451.582	1019.301
SURV.Y	-0.364	0.069	-5.275	30.000	0.00001***	-0.505	-0.223
TECH.G	-1.951	0.906	-2.152	30.000	0.040*	-3.802	-0.100
TECH.H	-2.914	1.275	-2.285	30.000	0.030*	-5.517	-0.310
MOD.TOB	2.345	0.922	2.544	30.000	0.016*	0.462	4.228
FRAME.POL	2.521	0.559	4.512	30.000	0.00001***	1.380	3.663
FRAME.TARGET	0.015	0.006	2.699	30.000	0.011*	0.004	0.026
III. Negative dropped and effect size from s.d.							
	<i>Estimate</i>	<i>s.e.</i>	<i>t value</i>	<i>d. f.</i>	<i>p value</i>	<i>CI lower</i>	<i>CI upper</i>
<i>Nothing is statistically significant</i>							
IV. Negative dropped and effect size from sample size							
	<i>Estimate</i>	<i>s.e.</i>	<i>t value</i>	<i>d. f.</i>	<i>p value</i>	<i>CI lower</i>	<i>CI upper</i>
Intercept	403.286	135.966	2.966	44.000	0.005**	129.264	677.309
SURV.Y	-0.197	0.067	-2.934	44.000	0.005**	-0.332	-0.062
FORM.M	-2.857	1.287	-2.220	44.000	0.032*	-5.451	-0.264
TECH.G	-2.072	0.839	-2.469	44.000	0.017*	-3.764	-0.381
TECH.W	1.696	0.576	2.946	44.000	0.005**	0.536	2.857
TECH.H	-1.777	0.824	-2.155	44.000	0.037*	-3.438	-0.115
ELI.DCE	-4.808	1.298	-3.706	44.000	0.001**	-7.424	-2.193
ELI.CVB	-5.189	1.999	-2.595	44.000	0.013*	-9.219	-1.159
ELI.OE	-3.949	0.934	-4.228	44.000	0.0001***	-5.832	-2.067
MOD.O	-4.256	1.528	-2.786	44.000	0.008**	-7.334	-1.177
MOD.U	-8.192	2.010	-4.076	44.000	0.0001***	-12.242	-4.141
FRAME.RURAL	5.071	2.166	2.341	44.000	0.024*	0.705	9.437
FRAME.CONV	2.552	1.246	2.047	44.000	0.047*	0.040	5.064
FRAME.POL	1.194	0.585	2.042	44.000	0.047*	0.016	2.372
FRAME.PROY	-3.301	1.337	-2.469	44.000	0.018*	-5.995	-0.606

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05

As can be seen from Table 6 mixed effects models performed much better than the previous ones when using the sample size to estimate variance (estimates using the s.d. produced no significant results). For marginal WTP the survey year, generic green power, hydro power and the policy frame were statistically significant in both cases. In the first case (top) using the tobit model and having a national target appeared to be good predictors. In the list is more extensive and includes one format, three technologies, three elicitation methods, two model categories ('other' and 'unspecified' do not refer to any particular model), and four frames. Overall the survey year, policy frame, open-ended

format and not specifying the method used were the strongest predictors, with only the policy being positively correlated (positive sign).

For average WTP there were fewer data points, yet one of the models (VI) was able to estimate five statistically significant regressors in addition to two intercepts (in mixed effects models every variable has an intercept). Since average WTP represents a binary choice between all attributes (use and non-use) or none, it is reasonable to suppose that the valuations it uncovers are also more widely spread to the upside and downside. Removing the outliers and truncating the values at zero was less effective at finding significant results than removing the negative values altogether. Nevertheless, given the limited number of studies in this category and the various models that were employed to produce statistically significant coefficients these results should be used with caution.

Table 7. Mixed effects models for average WTP

V. Negative as zero and effect size from s.d.							
	<i>Estimate</i>	<i>s.e.</i>	<i>t value</i>	<i>d. f.</i>	<i>p value</i>	<i>CI lower</i>	<i>CI upper</i>
<i>Nothing is statistically significant</i>							
VI. Negative as zero and effect size from sample size							
	<i>Estimate</i>	<i>s.e.</i>	<i>t value</i>	<i>d. f.</i>	<i>p value</i>	<i>CI lower</i>	<i>CI upper</i>
Intercept	474.025	139.453	3.399	6.000	0.015*	132.795	815.254
SURV.Y	-0.235	0.069	-3.426	6.000	0.014*	-0.403	-0.067
Intercept (ELI)	3.389	0.857	3.956	7.000	0.005**	1.363	5.414
ELI.DCE	-2.213	0.887	-2.495	7.000	0.041*	-4.311	-0.116
FRAME.CONV	4.839	1.228	3.940	5.000	0.011*	1.682	7.996
FRAME.PRO	-2.291	0.717	-3.197	5.000	0.024*	-4.134	-0.449
FRAME.MICRO	-1.651	0.328	-5.032	5.000	0.004**	-2.494	-0.807
VII. Negative dropped and effect size from s.d.							
	<i>Estimate</i>	<i>s.e.</i>	<i>t value</i>	<i>d. f.</i>	<i>p value</i>	<i>CI lower</i>	<i>CI upper</i>
Intercept	3.389	1.193	2.841	7.000	0.025*	0.568	6.209
VIII. Negative dropped and effect size from sample size							
	<i>Estimate</i>	<i>s.e.</i>	<i>t value</i>	<i>d. f.</i>	<i>p value</i>	<i>CI lower</i>	<i>CI upper</i>
<i>Nothing is statistically significant</i>							

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05

5. DISCUSSION

What these results suggest is that between-study variance is significantly more pervasive than the within-study kind, so it is indeed more appropriate to think of differences in WTP as arising from differences in the true preferences of respondents and the methods used by researchers. Differences in research methods manifest themselves in different ways depending on the formats and methods used by researchers to conduct their stated preference experiences and the econometric methods they apply to the data afterwards. In the absence of individual-specific regressors the fact that various technologies were also statistically significant is an indication that respondents' preferences also vary from one sampled population to another, even becoming negative in some instances.

6. CONCLUSIONS

This chapter has shed light the characteristics of a large number of primary studies that explore the WTP for green electricity, as well as the eight meta-analyses that have been conducted to date. If primary studies control for individual-specific characteristics, meta-analyses control for the differences within and between studies.

The main question we tried to answer regarded the factors that explained the observed differences in WTP valuations in the literature. After an extensive literature review and numerous analyses we can conclude that these differences derive from both genuine discrepancies in the preferences of different populations, as well as the methods used to uncover those preferences.

Meta-analyses should be considered an ongoing piece of work, to be updated as more and more data becomes available. The hope is that a deeper understanding of individual preferences and a better characterization of the methods used to unveil them will allow decision makers in government, business and academia to design more effective interventions, and in so doing facilitate the transition toward a more sustainable energy future.

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Estimating the Market Surplus of Energy Communities

Abstract

Energy communities (EC) provide an ideal setting to capture the value of the hedonic (non-use) attributes of electric power given their characteristics and mode of operation. This study presents a simple model to quantify the market surplus that is produced and captured by an EC. By successively introducing and measuring the impact of distributed energy resources (DERs), a local peer-to-peer (P2P) market and access to the French spot market for electricity the individual contribution of these factors can be estimated. To account for the value of hedonic attributes two measures are proposed: the Hedonic Compensating Variation (HCV) and the Hedonic Equivalent Variation (HEV). To the author's knowledge this study constitutes the first attempt to quantify the hedonic value generated and captured by an EC. The results suggest that an EC market allows its members to increase total surplus by around 8-9% over isolated DERs, while access to the spot market would further boost the surplus by 23-24%, even if this remains mostly a theoretical possibility for residential ECs. The inequalities in the distribution of these surpluses is reduced if green power is used to cover deficits.

Keywords: energy community, green electricity, distributed energy resources, hedonic attributes.

1. INTRODUCTION

Distributed energy resources (DERs) such as solar PV systems, fuel cells and small wind turbines, have the potential to lower emissions, increase the security of supply and reduce network losses (Braun and Strauss, 2008). However, their indiscriminate introduction into distribution networks, originally designed for passive operation of unidirectional power flows, can produce unintended network disturbances, including voltage and frequency variations, and pose significant control and communication challenges to network operators (Lasseter, 2007). As the economic consequences of wider DER adoption began to be noticed by utilities and electricity suppliers in the form of diminishing revenues and a shrinking customer base due to grid defections (Zapata Riveros et al., 2019), regulators were forced to intervene. Later, as the planning and regulatory processes became more participatory and open to other stakeholders the initial technical and economic considerations were broadened to include environmental and social objectives as well (Schwaegerl and Tao, 2014a). Recent efforts have focused on making DERs more responsive and supportive of network operations and making distribution networks more flexible and accommodating to DERs.

At the European level energy communities (EC) are being actively promoted by EU Directive 2018/2001 and EU Directive 2019/944, while at the national level countries are encouraging their adoption through national legislation, as France's *Code de l'énergie* illustrates. And yet the households that constitute their main target population remain largely absent from this debate and disengaged from their benefits. Household DER aggregation into energy communities (EC) promises

tangible benefits such as lower load variability (thus reducing the need for backup generation and storage) and potentially lower costs for end-users. When clean microgeneration technologies are used positive externalities may also include improved environmental quality, the sale of green certificates and possibly the creation of local jobs (Kosenius and Ollikainen, 2013b; Longo et al., 2006). From the perspective of the grid operator ECs can be leveraged to relieve congestion at times of peak demand, reduce losses and in general provide more flexibility in everyday operations.

Although many studies have estimated the hedonic prices of individual electric power attributes, e.g., (Grilli, 2017; Soon and Ahmad, 2015; Sundt and Rehdanz, 2014), prior attempts at estimating the value of DER aggregation into energy communities of various sorts (see below) have often relied on traditional Marshallian metrics of producer and consumer surplus for changes in prices rather than hedonic valuations.

The question we aim to address is therefore: ***what is the value produced and captured by energy communities for their members when use and non-use values are taken into account?*** To answer this question, we make the following hypotheses:

Hypothesis I. *Agents in energy communities can capture more value than either strict consumers or independent prosumers.*

Hypothesis II. *The value captured from exposure to a dual market structure, at least one market of which contains hedonic attributes, exceeds that of either market considered separately.*

In this study value is equated with the market surplus (welfare)⁴⁵ produced by an interconnected EC by virtue of its electric power transfers with and without hedonic attributes, compared to an equal number of independent consumers and prosumers with access to a retail supplier.

The study introduces a modified version of the double-sided auction mechanism proposed by (Zou, 2009) to maximize social welfare. Since Marshallian surplus cannot be integrated directly, the original model makes an approximation using a piecewise linear function in which the average prices of bids are represented as linear segments of a supply and demand curve, respectively. It then proceeds to estimate the marginal contribution of every bid to the total surplus and to compensate bidders according to their contribution to that surplus.

The model presented here modifies the original in three important ways. First, instead of estimating the market surplus based on price changes for the use attribute only (electric power) we estimate the supplementary transfer payments using hedonic price methods, i.e. willingness to pay for non-use attributes. Second, since the EC depicted in the study is composed of agents that simultaneously produce and consume electricity, i.e. prosumers, a single equation serves to estimate the surplus of supply and demand bids of individual households. Third, instead of a single market our model considers both the internal EC market and the external (grid) to estimate the total surplus. The proposed model does not consider the potential effects of policy interventions or technical

⁴⁵ Although surplus and welfare are often used interchangeably in the literature, we will favor surplus since we are interested in a single market, even if it is one that presents intrinsic externalities. Likewise, we will use (dual) market surplus rather than social surplus since we are only interested in assessing the value to the members of an EC and not other stakeholders.

constraints and does not claim to be viable within any specific legal or regulatory environment. It also does not provide an optimum solution to the energy management problem as in (Olivares et al., 2011; Park et al., 2019; Polanco Vasquez et al., 2018). Finally, it does not consider the possibility of strategic behavior by EC members and excludes from its estimates the utility variations experienced by other stakeholders outside the EC. This paper makes a contribution to the field of social welfare maximization in a bound environment (Dalkilic et al., 2018; Fang et al., 2019; Faqiry and Das, 2016; Gazijahani and Salehi, 2019; Hoa Nguyen et al., 2020). To the author's knowledge no prior research has attempted to quantify the effect of a boundary (physical or otherwise) on the value that can be appropriated by members of an energy community, including hedonic attributes.

The rest of this paper is organized as follows: after the introduction section 2 provides a literature review of three concepts central to our model: hedonic attributes, aggregation approaches and market surplus. Section 3 introduces the dual market model, while results are presented in Section 4. The discussion and conclusions are presented in Sections 5 and 6, respectively.

2. A REVIEW OF AGGREGATION APPROACHES

This section has been included to introduce the reader to the various ways in which households can be aggregated to share investments, installations and energy. The way participants are aggregated and the technologies they deploy determines the attributes generated are how much of them they can capture, i.e. the economic and hedonic surplus of the EC. The distribution of that surplus is another important element in defining an EC, but one that goes beyond the current paper. Despite the extensive effort made to cover the main typologies, it is impossible to ensure this list is exhaustive. Instead, its objective is to convey a sense of the possibilities that exist for grouping households and other small agents into shared endeavors, many of which will certainly be called by different names in different places.

Given that in most industrialized nations electric power supply is reasonably stable, reliable and affordable, and the costs and efforts involved in setting up an EC can be considerable, private investments would hardly seem justified if their purpose were only to further improve use attributes or guard against the sporadic black-out. Rather, ECs emerge as customers perceive their supply to have superior non-use attributes to those of the national grid, providing an ideal setting to measure those attributes.

Among the prior studies on the valuation of energy systems that have been produced to date a 2016 report by the Pacific Northwest National Laboratory in the U.S. that researched the valuation of *transactive energy systems*⁴⁶ deserves special mention (Hammerstrom et al., 2016b). While this report acknowledged that the exchange of electrical energy represented the principal commodity being traded, it also recognized the existence of non-monetary benefits like environmental quality, health and comfort for which no market is available to discover a monetary equivalent. Like the present study, it resorts to consumers' willingness to pay

⁴⁶ Defined as systems capable of transferring value among its members. Value is embedded into a '*value object*' that can include goods, services and information other than energy and financial instruments, and which is - importantly - "*in the eye of the beholder*".

(WTP) and willingness to accept (WTA) to estimate monetary values where no market exists, and (contrary to this study) drew on Multi-attribute Utility Theory (MUT) to rank or weigh alternatives with different attributes⁴⁷ for the ultimate valuation of unmonetized benefits. Also departing from the present study, it proposed mapping the objectives of all relevant stakeholders and ranking them to produce a ‘hierarchy of objectives’ that included the maximization or minimization of numerous attributes, each of which would then need to be quantified.

Another noteworthy report that explored the social, economic and environmental benefits provided by microgrids was produced as part of the EU project More Microgrids (Schwaegerl et al., 2009). Although its main focus was assessing the benefits to the grid operator, it also identified two types of benefits broadly applicable to all collective DERs, in addition to the individual benefits reaped by individual homeowners. They named them *locality* benefits and *selectivity* benefits. **Locality benefits** are associated to the creation of an internal peer-to-peer (P2P) energy market where DER units can sell energy at a premium while end consumers can purchase energy below the retail price, bypassing intermediaries and avoiding some of the charges of regulated supply. **Selectivity benefits**, on the other hand, are associated with benefits of scale, where the aggregation of supply and demand allows individuals to benefit from (collective) access to wholesale markets and real-time dispatch after exceeding a certain threshold. The authors use this classification to estimate the economic, technical and environmental benefits of microgrids in different countries for every decade between 2010 and 2040. In this study locality benefits are accounted for by including an energy clearinghouse, while selectivity is interpreted as having access to a spot market.

The boundaries of an electric system can be set arbitrarily following such criteria as existing physical, political or administrative borders (Müller et al., 2011). Aggregation is a balancing act between conventional electricity consumers, prosumers, energy suppliers, aggregators and system operators, all of whom are pursuing their own interests and objectives. The diversity of approaches to aggregate local generation and consumption reveals the heterogeneity of objectives that motivate their formation. Although the boundaries of an electric system containing DERs can be set arbitrarily following such criteria as existing physical, political or administrative borders (Müller et al., 2011), a useful classification is provided by (Braun and Strauss, 2008) who identify four broad integration approaches to achieve this, and which can in turn coexist and create the following hybrid structures: i. Autonomous controllable DERs (AC-DER), ii. Active customer networks connected either to the public distribution network (ACN-D) or to the public transmission network (ACN-T), iii. Active distribution networks (ADN), and iv. Commercial aggregation (CA). These categories are in turn special types of **transactive energy systems** (TES), defined by (The GridWise Architecture Council, 2015) as “*system[s] of economic and control mechanisms that allow[s] the dynamic balance of supply and demand across the entire electrical infrastructure using value as a key operational parameter.*”

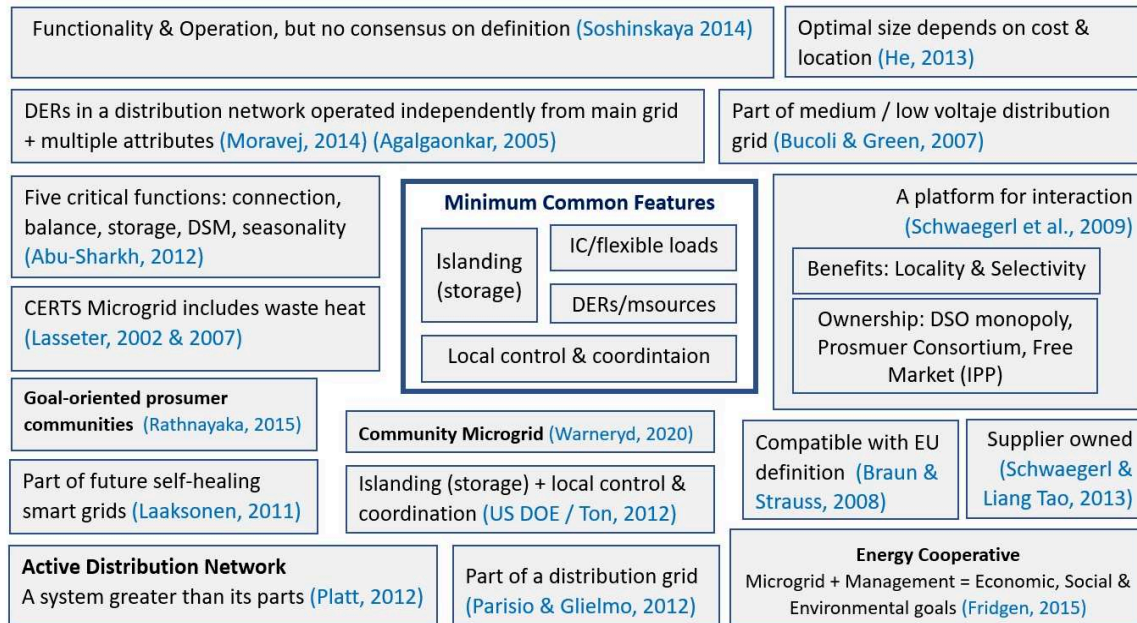
AC-DERs typically denote independent fuel-based generation and storage systems that can provide ancillary services to the distribution grid. When coupled with solar PV or other non-controllable

47 In the MUT overall utility is simply the weighted sum of the utility of all the attributes in an alternative.

technologies they rely on storage systems for control. Although these systems usually operate independently of one another, they can also respond collectively to Distribution System Operator (DSO) price signals to enhance the technical resilience and reliability of the local grid.

ACN-D and **ACN-T** are the result of aggregating controllable DER units in a physically delimited private network that may be operated islanded if necessary. They serve their individual constituents by pooling resources and interacting with public networks at a single point⁴⁸ through which they receive and deliver energy and other services.

Figure 1 Aggregation approaches and criteria



Low voltage residential systems are grouped as ACN-Ds while commercial and industrial medium/high voltage systems are often grouped as ACN-Ts. In contrast to AC-DERs, operation by an ACN ensures that the energy and ancillary services of its constituents are aggregated more coherently in the pursuit of a common objective, such as lowering energy costs or reducing emissions. They also facilitate the deployment of P2P energy exchanges within the private networks, which often require the creation of a legal person.

A type of ACN that has received special attention in the literature is *microgrids*. Although no consensus exists on the definition of a microgrid (Soshinskaya et al., 2014) several authors (Agalgaonkar et al., 2005; Braun and Strauss, 2008; Chenrui Jin and Ghosh, 2011; He Jun et al., 2013; Laaksonen, 2011; Lasseter, 2002, 2007; Moravej and Afshar, 2014; Parisio and Glielmo, 2012; Platt et al., 2012; Schwaegerl, 2009; Schwaegerl and Tao, 2014a; Warneryd et al., 2020) broadly agree on four basic features shared by all microgrids: local generation, interconnected loads, local control & coordination, and importantly the ability to operate islanded if necessary. Of these, local control and coordination is what sets microgrids apart from simple distribution feeders with DERs (Schwaegerl

⁴⁸ In the case of distribution networks the point of connection is known as the Point of Common Coupling (PCC), while in transmission networks it is known as the Grid Supply Point (GSP).

and Tao, 2014a), while islanding is what sets them apart from other ACNs (Platt et al., 2012). Energy storage is facultative in most cases. Microgrids also display a variety of internal structures depending on the nature of their stakeholders, their ownership model and the objectives they set out to achieve. Their microgeneration technologies may be owned by a utility, a DSO, an energy supplier, end users operating as a prosumer consortium or an Independent Power Producer (IPP) (Schwaegerl and Tao, 2014a, 2014b).

The term **energy cooperative** has been used by (Fridgen and Gründler, 2015) to denote a microgrid which incorporates an additional organizational layer under the consumer consortium approach. According to (Yildiz et al., 2015) this ICT-based organizational form facilitates the pursuit of increased profits, the promotion of renewables (Schreuer, n.d.; Viardot, 2013) greater independence from the main grid (Khalilpour and Vassallo, 2015) and such elusive goals as local pride (Borst, 2010) or a combination of these. On the other hand, the term **community microgrid** as defined by (Warneryd et al., 2020) and exemplified by configurations such as those proposed by the California-based Clean Coalition (Clean Coalition, 2020) were not found to contain any meaningful distinction that could not be accommodated by regular microgrids.

A different approach is provided by active distribution networks (**ADNs**) in which the operators of public networks actively control the various DERs in their local control area instead of relying on them to react to voluntary signals and incentives. Critically, ADNs are distinct from ACNs in that they place DSOs at the center and cannot operate islanded (Platt et al., 2012). This makes so-called *Virtual Microgrids* (VMGs) as defined in (NEDO KEEP Project, 2012) more akin to ADNs than ACNs, as they are based on Energy Management Systems (EMS) whose primary objective is to enhance the stability of the local network by continuously balancing supply (of intermittent DERs) and demand without the possibility of islanding. When islanding capability is added to ADNs they become public microgrids or so-called *cells* as described by (ten Donkelaar, 2004).

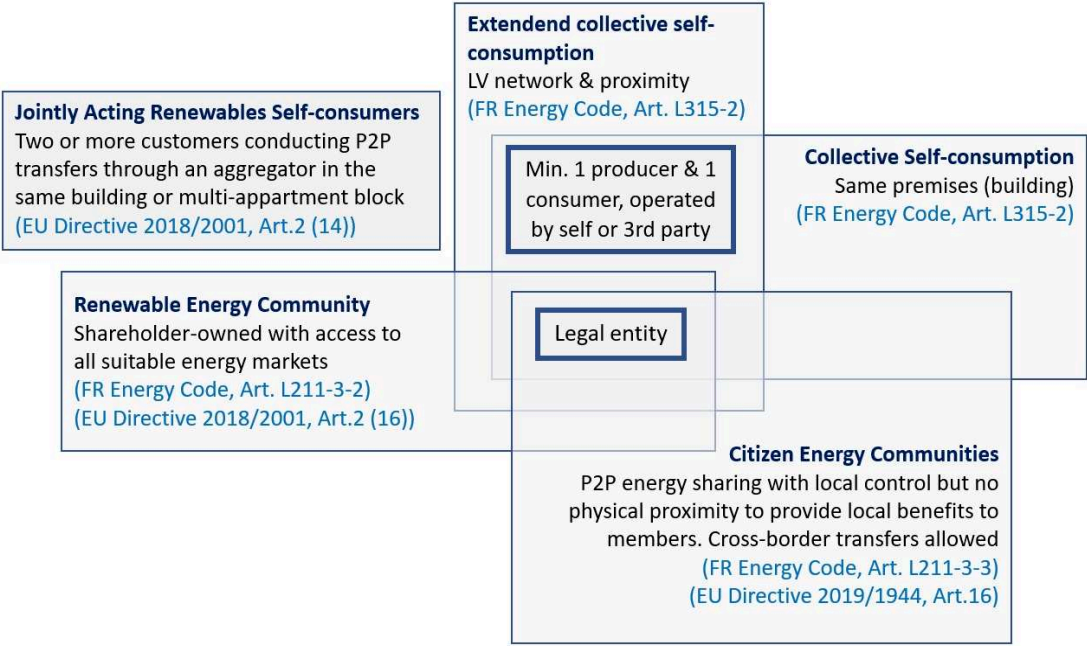
At the EU level the **jointly acting renewables self-consumers**⁴⁹ mentioned in EU Directive 2018/2001, Art.2 (14) aim to promote the widespread adoption of small-scale renewables at the household level by grouping two or more final customers in the same building or multi-apartment block into a legal person to trade energy directly or through an intermediary (EU Directive 2018/2001, 2018; EU Directive 2019/944, 2019). They can be classified as either ACNs or ADNs depending on whether their networks are private or public, respectively, but cannot be considered microgrids given their inability to operate in isolation (Code de l'énergie, 2020). The same applies to the French **collective self-consumers** (CSC) described in the Energy Code, Art. L315-2. However, the same article also introduces a variant named **extended collective self-consumption**⁵⁰ in which the withdrawal and injection points must be located in geographic proximity within the LV network following more flexible criteria. To date there are 28 active CSC operations in France, involving 398 consumers and 57 producers, while 23 additional operations are planned ("Consultation publique n°2020-007 du 19 mars 2020 relative à la composante de soutirage des prochains tarifs d'utilisation des réseaux publics d'électricité « TURPE 6 », 2019).

⁴⁹ In France the equivalent are the *collective self-consumers* cited in the Energy Code, Art. L315-2.

⁵⁰ *Autoconsommation collective étendue*.

Finally, **commercial aggregation (CA)** refers to contractual arrangements between an aggregator and the owners/operators of the individual DERs, on the one hand, and between the aggregator, network operators and wholesale market, on the other. CAs offer the most diversity of all aggregation schemes, yet a characteristic they all share is that they are not location-specific, in contrast to ACNs and ADNs. However, their aptitude to be deployed anywhere also limits the services they can provide to the grid, which are usually limited to power exchange and balancing services. The existence of CAs is justified by the reduction in transaction costs that it offers its members, who would otherwise need to engage in bilateral trades with each other and the network operator.

Figure 2. French and European aggregation criteria



Moreover, a CA enhances the bargaining power of its members and may grant DERs access to wholesale energy markets from which they would otherwise be excluded given their small volumes (Veit et al., 2013). Since CA aggregators have no control over physical infrastructure their role is often limited to being the legal person coordinating ACNs through data exchanges.

According to (Braun and Strauss, 2008) CAs may rely on unidirectional smart metering (DER to CA), unidirectional variable pricing (CA to DER) or a bidirectional energy management interface enabling direct communication between the aggregator and individual household appliances to optimize performance or minimizing cost. Most of these CA architectures are top-down arrangements that exclude the possibility of P2P interactions. The same authors include Virtual Power Plants (VPP) as an exception where an external aggregator in a CA has direct control over scattered DERs.

In Europe examples of bottom-up CA schemes include shareholder-owned and controlled legal entities such as the **renewable energy community (REC)**, known in France as *communautés d'énergie renouvelable*, which have their origin in the EU Parliament's Renewable Energy Directive (EU Directive

2018/2001, 2018), Art.2 (16). Their primary objective is the provision of extended environmental, economic and social benefits to the community rather than financial profits. They are also entitled to share (rather than trade) the energy produced within the community and can benefit from tailored bidding procedures and access to all suitable energy markets (EU Directive 2018/2001, 2018). In France renewable energy communities were introduced by the Energy Code, Art. L211-3-2.

Table 1. Differences between CEC and REC

	Citizen Energy Community (CEC)	Renewable Energy Community (REC)
Membership	Voluntary and open to all entities	Restricted to natural persons, local authorities (including municipalities) and SMEs.
Control	Limited to members or shareholders that are not engaged in large-scale commercial activity and for whom the energy sector does not constitute a primary area of economic activity.	Control is exerted by shareholders or members located in the proximity of the renewable energy projects that are owned and developed by the REC
Operational autonomy	CECs are entitled to own, establish, purchase or lease distribution networks and to autonomously manage them, thus in effect managing electricity transfers between their members.	RECs may not own or operate distribution networks. The relevant distribution system operator must cooperate with the REC to facilitate energy transfers within them.
Energy sources	May include renewable or conventional electricity sources.	Include all renewable energies technologies and applications (electricity, gas, cold and heat)

A hybrid model is provided by the **citizen energy communities (CEC)** introduced by the EU Parliament's Electricity Markets Directive (EU 2019/944), Art.16, and its French equivalent from the Energy Code, Art. L211-3-3. The CEC corresponds to the French *communauté énergétique citoyenne* in which shareholders may be physically distant and even extend across national borders, yet belong to a legal entity that allows them to 'share' their energy for accounting and settlement purposes, resembling a CA. However, they can also operate as DSOs in their own right and provide demand-side management services, thus resembling private ADNs. While both CECs and RECs share the same primary purpose, namely to '*provide environmental, economic or social community benefits for its shareholders or members or for the local areas where it operates, rather than financial profits*' (EU Directive 2019/944, 2019), several differences also exist. See Table 1. The more generic **collective self-consumption** (*autoconsommation collective*) is a legally sanctioned term encoded in the French Energy Code (*Code de l'énergie*), Art. L315-1 to L315-8 and R315-12 to R315-16.

Another term sometimes encountered in the literature is that of **prosumer community** which is used by some authors as a catch-all term to describe any CA community of prosumers that generates and shares energy, including electricity prosumer communities, integrated community energy systems

and clean energy communities (Espe et al., 2018; Rathnayaka et al., 2015). An alternative definition of prosumer community is provided by (Zapata Riveros et al., 2019) who conceive it as *'a group of households that are organized together to consume energy from a common DG system'*. In both cases the term refers to a grassroots scheme where private individuals self-organize to achieve common goals more efficiently. Interestingly, in addition to the usual benefits derived from aggregation (Espe et al., 2018) identifies penalty strategies to be important motivators to spur participation. Overall, however, the term 'prosumer community' does not indicate the presence of any unique characteristic absent from other schemes described above and will not be discussed further.

This study has selected an **energy community** as the unit of analysis, loosely defined as *a collection of energy producers and consumers⁵¹ connected to a LV network that trade energy among themselves and can be treated as a single entity by a supplier or network operator*. This regulatory construct is more akin to a European CEC than to a REC, since members can exchange electricity directly and differences are compensated at the community level by a single back-up supplier. Although there is no preset limit to the number of households that may join, a soft limit is provided by the number of customers served by the same low-voltage feeder, and which can be "seen" as a single consumer by the system operator. The energy community in this study is held together by the appropriate contractual arrangements without incurring any major investments in infrastructure, save for the costs associated with establishing, purchasing or leasing their distribution network. The electricity produced is pooled and trades are cleared using uniform pricing (UP) with differences covered by the main grid (supplier or spot market). Additional compensatory transfers based on hedonic pricing methods are included. A more precise taxonomy is not deemed necessary, as it does not alter the general procedure followed nor the conclusions reached. To illustrate the workings of such an EC we provide a case study at the end which compares the benefits that result from different scenarios.

3. SURPLUS ESTIMATION REVISITED

Whereas welfare denotes the social surplus accrued over all markets (Johansson, 1991), market surplus refers to the increase in utility within a single market (e.g., an electricity market). The focus of this study is the quantification of the costs and benefits that accrue to EC members by virtue of joining an energy community. Specifically we will focus on the costs and benefits that result from interacting with the main grid, with the internal peer-to-peer (P2P) market within an EC, and with a wholesale electricity market. The benefits to non-participating households, the national grid and society will not be considered here and justify using the term market surplus over welfare henceforth.

3.1 Marshallian consumer surplus

In consumer theory Marshallian consumer surplus (CS) is the most basic measure of welfare change and is interpreted as the utility change converted to monetary units by a weighting factor: the marginal utility of income.

Marshallian CS, producer surplus and their sum, total surplus, can usually be estimated from the corresponding (observed) supply and demand curves in a single market, without recourse to the

⁵¹ All producers are also consumers, i.e. prosumers, but not all consumers are producers.

underlying utility function. Marshallian surplus can still be linked to utility by inverting the demand function to obtain the direct utility function, and the direct utility function can be turned into the demand function by constrained maximization through Lagrangian. Likewise, the indirect utility function that measures utility in monetary units is also related to the Marshallian demand function by Roy's identity (Nejad Moosavian, 2016).

Although prosumers are affected by consumer theory (Marshallian utility maximization and Hicksian expenditure minimization) as much as by production theory (cost minimization and profit maximization), our model focuses exclusively on consumers. This is not to say that prosumers do not benefit from selling electricity to third parties, which they do. Instead this means that transactions like these are already accounted for by conventional markets and regulations that measure and compensate parties for every kilowatt-hour that is exchanged. Instead, the *utility* that households gain from consuming that electricity is not fully captured by market prices, and that is because this utility is proportional not only to the electricity itself but also to the hedonic attributes it embodies. The value of these attributes is reflected - albeit imperfectly - in their willingness to pay for them, and determines their consumer surplus to a large extent (see preceding chapters). In this study we will assume it is the consumption of these attributes that produces utility and not its production, which is already captured by conventional measures.

3.2 *The Path Dependency Problem*

While the consumer surplus has the benefit of being based on observable Marshallian demand functions, it has also been recognized to have several important shortcomings as a welfare indicator. To produce a reliable estimate, the consumer surplus requires the marginal utility of income to be constant, so the measured surplus is proportional to a change in utility for any price change. This condition is problematic since it conflicts with the real world observation that utility is concave and displays diminishing returns to scale. Moreover, if nonlinearities or discontinuities in utility cause the marginal utility of income to vary (as is the case with hedonic attributes) integration can produce different outcomes depending on the path followed, i.e. the order in which prices and/or incomes are assumed to change between the initial and final values of the variables of integration. This is known as the path dependency problem (Samuelson, 1947, 1942; Silberberg and Suen, 2000).

To overcome the path-dependency problem the alternative concepts of **compensating variation (CV)** and **equivalent variation (EV)** were proposed by (Hicks, 1943) as the correct theoretical measures of the welfare impact of changes in prices and income on an individual (Willig, 1976). They are also considered superior to CS since they do not rely on any assumption about the immutability of the marginal utility of income, as their integration over multiple price changes is path independent.

Compensating Variation

In simple terms the CV is a measure, usually in money terms, of the exogenous compensation that is required to return an individual who is faced with a new set of prices to a previous level of utility. In terms of the indirect utility function CV can be formulated as

$$v(\mathbf{P}_0, M) = v(\mathbf{P}_1, M - CV) = u_0 \quad (1)$$

Where \mathbf{P}_0 and \mathbf{P}_1 are the initial and final prices, respectively, M is the money income and u_0 is the original level of utility. Importantly, CV equals WTP whenever utility increases (prices decrease), and it equals willingness to accept (WTA) when utility decreases (prices increase) (Bockstael and McConnell, 2007; Freeman III et al., 2014). Alternatively, the CV can also be formulated in terms of the dual of the utility maximization problem, which seeks to minimize the cost (expenditure) of achieving a fixed utility level. In terms of the expenditure function the CV can be represented as

$$\begin{aligned} CV &= m(\mathbf{P}_0, u_0) - m(\mathbf{P}_1, u_0) \\ &= M - m(\mathbf{P}_1, u_0) > 0 \end{aligned} \quad (2)$$

Where m is the expenditure function. Taking electric power as the market good, what the CV tells us is that if the price of the same grid power with utility u_0 is raised from \mathbf{P}_0 to \mathbf{P}_1 a household would need to receive a lump sum payment of CV to prevent its utility from falling below u_0 .

Alternatively, if the choice is between keeping grid power with utility u_0 at price \mathbf{P}_0 or switching to power with higher utility u_1 (e.g. due to hedonic attributes) and higher price \mathbf{P}_1 , theory tells us that the household would be indifferent between switching and making a payment $CV = \mathbf{P}_1 - \mathbf{P}_0$ to offset the increased utility or not making the switch at all.

Equivalent Variation

As a welfare measure EV represents the money equivalent of a price change between two utility levels. Alternatively, the EV can also be used to rank a consumer's level of well-being under various sets of prices. This measure takes the indirect utility function as its point of departure but adopts the final utility u_1 as its reference. It can be formulated as

$$v(\mathbf{P}_0, M + EV) = v(\mathbf{P}_1, M) = u_1 \quad (3)$$

Contrary to CV, in this case EV is equal in magnitude to WTA when utility increases (price decrease), and it equals WTP when utility decreases (prices increase). In terms of the expenditure function it takes the form:

$$EV = m(\mathbf{P}_0, u_1) - m(\mathbf{P}_1, u_1) \quad (4)$$

In the grid power example, an increase in the price of grid power from \mathbf{P}_0 to \mathbf{P}_1 would be “felt” by the household in the same way as an income decrease by an amount EV. Similarly, when purchasing green power the EV tells us that the same utility improvement experienced when moving from u_0 to u_1 could alternatively be achieved by not switching supply and receiving an additional payment of EV.

The measure of WTP can thus be estimated as both CV or EV depending on the context, with a crucial difference: when CV equals WTP it corresponds to the payment that would exactly cancel out the benefit of lower prices, whereas when it equals EV it corresponds to the reduction in income that would exactly equal an increase in prices. To join an EC and invest in a PV system, a household faces the prospect of increased expenditures. Until recently, choosing a green electricity rate through a

commercial retailer also involved paying a premium, although this is no longer true in all cases.⁵² As a result, it is the EV that best mirrors WTP in our context.

The problem with using CV and EV as measures of welfare is that they are based on the unobservable Hicks compensated demand functions, while the one measure based on the observed Marshallian demand functions is flawed as a welfare indicator (Freeman III et al., 2014).

3.3 Proposed solution

Being derived from indirect utility functions, CV and EV express exogenous compensations in money terms only. Electricity being a homogenous good, our overall utility for consuming a given amount is only affected by the price we pay to secure it. However, if electricity is not a homogenous good and the differences in utility and price are not exogenous but rather proportional to an individual's WTP for them, different compensation measures may apply.

We define the **Hedonic Compensating Variation (HCV)** as the change in hedonic attributes required to return an individual who is faced with a new set of *hedonic attributes and prices* to a previous level of utility. In terms of the indirect utility function HCV can be formulated as

$$v(\mathbf{P}_0, h_0, M) = v(\mathbf{P}_1, h_1, M - HCV) = u_0 \quad (5)$$

where \mathbf{h}_0 and \mathbf{h}_1 are the initial and final level of hedonic attributes, respectively. In contrast to the original CV the HCV equals WTP in any of three scenarios, all of which result in higher utility:

- i. Prices and attributes rise, with the attribute effect overwhelming the price effect.
- ii. Prices stay constant while attributes rise.
- iii. Attributes stay constant while prices decrease.
- iv. Prices and attributes decrease, with the price effect overwhelming the (negative) attribute effect.

Analogously the HCV equals WTA under three possible scenarios, all of which result in lower utility:

- v. Prices and attributes rise, with the price effect overwhelming the attribute effect.
- vi. Prices stay constant while attributes decrease.
- vii. Attributes stay constant while Prices rise.
- viii. Prices and attributes decrease, with the attribute effect overwhelming the price effect.

Likewise, we define the **Hedonic Equivalent Variation (HEV)** to represent the money equivalent of a change in *hedonic attributes and prices* between two utility levels. The HEV can serve to rank individual well-being under different attribute levels keeping prices constant. It can be formulated as:

$$v(\mathbf{P}_0, h_0, M + HEV) = v(\mathbf{P}_1, h_1, M) = u_1 \quad (6)$$

⁵² In France and other countries, green rates have become price-competitive in recent years, being offered at equal or lower prices than conventional power.

The same three HCV scenarios affect the HEV in the opposite direction, so that HEV is equal in magnitude to the WTA when the attribute-price combination leads to a utility increase, and it equals WTP when the attribute-price combination decreases utility. See Table 2. Under certain conditions identified by (Willig, 1976) the differences between the three measures of CV, EV and CS can be small enough to be negligible, making it possible to use the CS as a reasonable approximation of CV and EV.

Table 2. Comparison between the HCV and HEV measures.

Variables	Utility increases HCV = WTP ; HEV = WTA	Utility decreases HCV = WTA ; HEV = WTP
$P_1 > P_0$ $h_1 > h_0$	$v(P_0, h_1) > v(P_1, h_0)$ Prices and attributes rise, with the attribute effect overwhelming the price effect. Catchphrase: "Expensive but worth it"	$v(P_1, h_0) > v(P_0, h_1)$ Prices and attributes rise, with the price effect overwhelming the attribute effect. Catchphrase: "High prices not justified"
$P_1 = P_0$	$v(P_0, h_1) > v(P_0, h_0)$ Prices stay constant while attributes rise. Catchphrase: "More value for money"	$v(P_0, h_0) > v(P_0, h_1)$ Prices stay constant while attributes decrease. Catchphrase: "Less value for money"
$h_1 = h_0$	$v(P_0, h_0) > v(P_1, h_0)$ Attributes stay constant while prices decrease. Catchphrase: "More value for money"	$v(P_0, h_0) > v(P_1, h_0)$ Attributes stay constant while prices rise. Catchphrase: "Less value for money"
$P_0 > P_1$ $h_0 > h_1$	$v(P_1, h_0) > v(P_0, h_1)$ Prices and attributes decrease, with the price effect overwhelming the attribute effect. Catchphrase: "Cheap by comparison"	$v(P_0, h_1) > v(P_1, h_0)$ Prices and attributes decrease, with the attribute effect overwhelming the price effect. Catchphrase: "Expensive by comparison"

Broadly three conditions must be met:

- i. The good in question is a normal good, i.e. one whose income elasticity of demand is positive, even if not necessarily constant.
- ii. The income effect should be small, since the differences between CS and CV or EV arise from an income effect on the quantity of the good (i.e., electric power) demanded.
- iii. The price elasticity of demand and the proportion of income **M** spent on the good should be small, as they both affect the change in CS as a percentage of income.

Given that these conditions appear to hold for electric power in the short term, the implication is that in **the short-term CS can be a reasonable approximation of social welfare in the electricity sector**, if the demand functions are unknown. In our case we need to proceed in this direction since without the demand function we cannot calculate the values for CV and EV directly (Hausman, 1981).

3.4 Redistribution

According to the efficiency criterion, the objective of social policy is to maximize the aggregate value of the goods and services people receive, including environmental and resource services (Freeman III et al., 2014). Most literature on surplus aggregation has accordingly focused on the distributional effects of interventions and attempts to provide guidance on how to make decisions where some members stand to win and others to lose by a given policy or project. (Freeman III et al., 2014) has summarized the four main approaches to social surplus aggregation thus:

- **Pareto criterion.** Only policy changes that make at least one person better off and make no individual worse off should be approved.
- **Kaldor-Hicks compensation test.** The Kaldor version (Kaldor, 1939) asks whether those who stand to gain from a policy can fully compensate those who stand to lose from it. If the answer is yes the policy should be accepted. The Hicks version is the opposite, and asks whether those who stand to lose could compensate the gainers for the decision not to proceed. If the answer is yes the policy should be rejected. In the electric power context this means, for example, that by adjusting the compensatory payment an individual could be made indifferent between consuming electric power or receiving a cash transfer instead.
- **Little criterion.** In addition to the Kaldor test this criterion advanced by (Little, 1957) requires policies to improve the distribution of income. However, it does not provide clear guidelines on what constitutes an improvement.
- **Weighted social welfare function.** The weighted social welfare function aims to rank and compensate individuals based on their relative merit or 'worthiness', and in so doing increase overall equity of outcomes. The main problem with this approach is the determination of an appropriate weighting function.

Since members of an EC are assumed to have joined voluntarily, there are *a priori* no losing parties nor compensations to perform. This is also the reason for focusing only on the surplus generated by and for market participants within the energy community and excluding other stakeholders, e.g., the grid operator and non-participating households.

4. EC MODEL

This study compares two options faced by individual households for procuring their electricity: the conventional grid, and an EC. P2P exchanges within an EC avoid most of the transmission (wheeling) and distribution charges, capacity and balancing costs, ancillary services, ISO/ITO fees, supplier margins and taxes that make up ca. 40 percent of regulated rates. In contrast, they are dominated by hedonic attributes, of which three are considered: renewable or 'green', local and autonomy; in addition to two sources: P2P and individual PV. Six scenarios serve to capture different variants: two for strict consumers, two for individual prosumers and two for energy communities. The consumer and market surpluses produced in each scenario are then compared to estimate the value produced and captured by the EC. The variables used and their values are shown in Table 317. All power flows are expressed in kWh and all prices in euros.

Table 317. Values used in the case study and their source

Variable	Value (range)	Unit	Description	Definition, Source
Nominal				
$i \in [1 \dots n]$	55	No.	Electric power consumer	European Low Voltage Test Feeder (IEEE, 2015)
$j \in [1 \dots k]$	8	No.	Electric power generator	(IEEE, 2015) using ARA data from (Enedis, 2022)
r	3	%	Discount rate of solar PV system	Projected Costs of Generating Electricity (IEA, 2020)
t	25	year	Useful life of solar PV system	Projected Costs of Generating Electricity (IEA, 2020)
Energy				
$q_j (Q_j)$	[0.11 - 0.68]	kWh	Individual (total) demand	Pondered avg. of 0-3, 3-6, 6-9 and 9-12 kVA for ARA, (Enedis, 2022)
$q_j^u (Q_j^u)$	[0 - 8.38]	kWh	Individual (total) deficit purchased from EC	Consumers: equal to demand less surplus sold to EC
$q_j^e (Q_j^e)$	C [0.16 - 32.34] P [0 - 5.50]	kWh	Individual (total) deficit purchased from grid	Consumers: demand less surplus purchased from EC Prosumers: demand less self-consumption and storage
$q_i (Q_i)$	[0 - 10.91]	kWh	Individual (total) prosumer generation	Assumed zero if surplus is zero; equal to demand plus surplus if surplus > zero. Surplus pondered as avg. of 0-3, 3-6, 6-9 and 9-12 kVA for ARA, Enedis 2021
$q_i^0 (Q_i^0)$	[0 - 5.23]	kWh	Individual (total) prosumer self-consumption	Assumed zero if surplus is zero; equal to demand if surplus > zero
$q_i^s (Q_i^s)$	[0 - 8.38]	kWh	Individual (total) prosumer storage	Equal to generation less self-consumption if no sale is allowed
$q_i^u (Q_i^u)$	[0 - 8.38]	kWh	Individual (total) surplus sold to / traded in EC	Equal to generation less total self-consumption
$q_i^e (Q_i^e)$	0	kWh	Individual (total) surplus sold to grid (retail & spot)	Prosumer surplus sold to EC less consumer deficit purchased from EC
Prices				
p_r	0.1567	€/kWh	Retail rate (regular)	EdF <i>tarif bleu</i> pondered avg. of 3, 6 and 9 kVA, 2021
p_r^g	0.1618	€/kWh	Retail rate (green)	EdF <i>tarif vert</i> pondered avg. of 6 and 9 kVA, 2021
p_e	0.1092	€/kWh	Spot market price	<i>Bilan Electrique France</i> , (RTE, 2022)
p_{FIT}	0.10	€/kWh	Feed-in-Tariff	<i>Arrêté du 6 octobre 2021, JORF no. 0235 du 8 octobre 2021</i> . Applicable 09.10.22 – 08.10.23.
p_i	0.0628	€/kWh	Solar PV LCOE ⁵³ (no attributes)	Calculated following (IEA, 2020; Kost et al., 2018)
p_0^x	0.0638	€/kWh	Self-consumed LCOEA ⁵⁴	LCOE plus green, local, autonomy and DER/PV attributes (Chapter 3)
p_μ^x	0.0651	€/kWh	Traded LCOEA.	LCOE plus green, local and P2P attributes (Chapter 3)
p_i^s	0.085	€/kWh	Prosumer levelized cost of storage (LCOS)	(Comello and Reichelstein, 2019a)
x_{PV}	0.002	€/kWh	Attribute (source = PV)	LCOE * 2.43%, estimated by author (Chapter 3)
x_{P2P}	0.004	€/kWh	Attribute (source = P2P)	LCOE * 6.25%, estimated by author (Chapter 3)
x_g	0.007	€/kWh	Attribute (green)	LCOE * 11.80%, estimated by author (Chapter 3)
x_l	-0.003	€/kWh	Attribute (local)	LCOE * -5.32%, estimated by author (Chapter 3)
x_a	0.008	€/kWh	Attribute (autonomy)	LCOE * 12.18%, estimated by author (Chapter 3)

⁵³ LCOE stands for *Levelized Cost of Electricity*.

⁵⁴ LCOEA stands for *Levelized Cost of Electricity and Attributes*.

4.1 Characteristics of the model

The model is based on the following assumptions and characteristics:

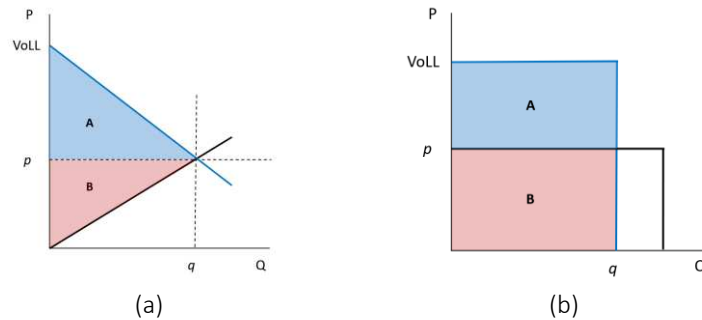
- **Objective.** The goal of the model is to estimate the surplus value created and captured by an energy community from the participating households' perspective. It does not attempt to estimate the total welfare effect on all stakeholders, maximize the profit of producers, quantify the transfers between agents, or enforce network constraints. It is not a partial equilibrium model to the extent that it does not attempt to find an equilibrium price or quantity to clear the market.
- **Households.** Households can be either strict consumers or prosumers. They are assumed to be risk-neutral expected utility maximizers. All the axioms of consumer preference, order and regularity from consumer theory apply to them (Autor, 2010; Hauser, 1977). Only households within ECs are assumed to value hedonic attributes.
- **Approach.** The model is counter-factual. It estimates the market surplus as the difference between an EC participating in a dual market and the same number of individual households without an EC, i.e., with access to the national grid only.
- **Simplifications**
 - i. Income and electricity demand are assumed to remain fixed in the short term. This is necessary to maintain the assumption of CS as a proper proxy of welfare.
 - ii. All prosumers are assumed to possess similar solar PV systems, and hence to generate electricity at roughly the same time and cost.
 - iii. The model assumes no losses, congestion nor other physical limitations in the network.
 - iv. Behind-the-meter consumption is assumed to have autarkic attributes, which have been found to be valued higher by generators than the energy traded with third parties (Ecker et al., 2017) It may be stored for self-consumption but is not considered for balancing or settlement purposes. The higher valuations assigned to self-consumption are accounted for by including the additional attributes 'autonomy' and 'PV' (rather than 'P2P') as the source.
- **Market clearing.** Instead of making supply and demand bids in every period, agents fix their prices in advance to reflect their individual valuations for the underlying hedonic sources and attributes. Individual preferences (and their corresponding WTP) are assumed to be stable over time following the axioms of consumer preference. Since the average *levelized cost of electricity* (LCOE) of solar PV without storage is on average lower than the regulated rate, it is in principle possible to include premiums for the relevant hedonic attributes and still remain price competitive w.r.t. grid supply.

Since EC prosumers are assumed to possess similar solar PV systems, and hence to produce electricity at roughly the same time and cost, they are also assumed not to act strategically. Eliminating strategic behavior overcomes the main drawback of pay-as-bid (PAB) pricing, in

which agents have been known to engage in collusive practices over time (Zou, 2009). In this model EC market clearing will use PAB pricing to match pre-fixed supply and demand bids based on households' average WTP for specific attributes.

- **Prices.** The model considers only the variable cost of electricity when assessing costs and benefits. In the case of solar PV the LCOE estimated over the expected lifetime of the systems is taken as the amortized variable cost. Average retail and spot market prices in the relevant one-year period are used.
- **Elasticity.** The social surplus varies considerably with the elasticity of supply and demand. Figure 33 exhibit (a) shows market clearing under elastic (exhibit a) and inelastic (exhibit b) conditions, with p and q the equilibrium price and quantity, respectively. Consumer surplus is represented by area A and producer surplus by area B.

Figure 3. Equilibria and surplus in elastic and inelastic markets.



The market surplus is the sum of A and B. In both cases only variable costs for a single household are considered (fixed costs would shift the intercept with the ordinate axis). Exhibit (a) corresponds to a market under perfect competition with large numbers of buyers and sellers and zero transaction costs. Exhibit (b) more closely resembles typical retail electricity markets with few sellers and high transaction costs, and will therefore be selected as our model for this study. In both cases the value of lost load (VoLL) represents the upper bound of the consumer surplus.

- Electricity being a staple good individual demand is assumed to be inelastic in the short term, while appearing as elastic for the entire market. See below.
- **Operation.** The dual markets are interconnected and clear sequentially. The EC is assumed to have a single point of common coupling (PoCC) to balance deficits and surpluses with the grid. In the spot market the EC is a price taker. Different scenarios are used to assess the influence of a flat (supplier) and variable (spot market) rate.
- **Market Surplus.** The market surplus depends on the relative prices of electricity from different sources. Our estimates have produced the following ranking: $p_i < p_0^x < p_\mu^x < p_{FiT} < p_e < p_r < p_r^g$.

- **Redistribution.** The distribution of surpluses among households is assumed to take place automatically following pre-defined rules. These rules, alas, constitute a whole different subject that requires in-depth analysis and will not be further discussed here.

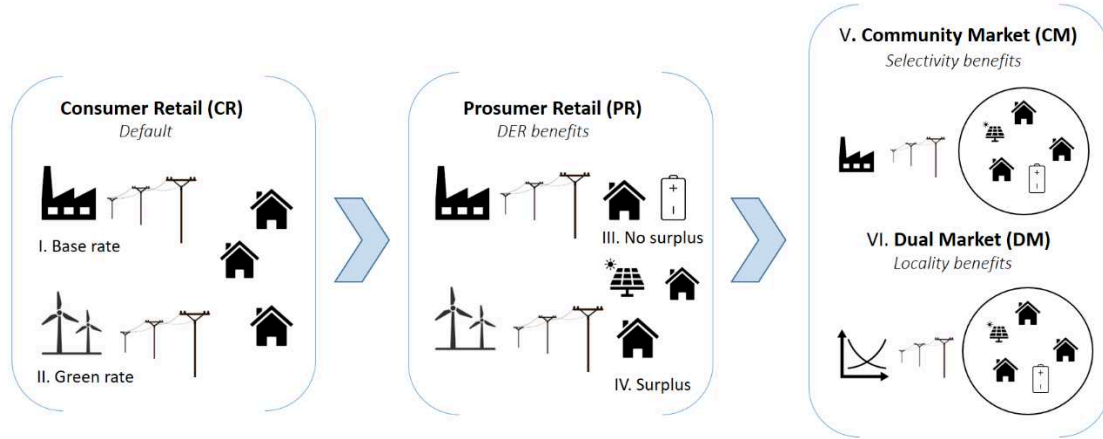
4.2 Scenarios

The objective of the model is to quantify the magnitudes and relative dominance of DER, locality and selectivity benefits in an energy community. The premise is that this can be done by designing appropriate scenarios, calculating their surplus welfare and contrasting the results.

Six scenarios were conceived to assess the relative importance of DER benefits, locality benefits and selectivity benefits separately (see Figure 15), all of which contribute to the total market surplus generated by an EC:

- I. **Consumer retail (CR).** The main grid is the default alternative for most households outside an EC and is therefore the benchmark against which to measure EC benefits. In CR all households are strict consumers with unidirectional supply from the grid. The CR market includes two scenarios for conventional (I) and green (II) electricity.
- II. **Prosumer retail (PR).** In this scenario households are dispersed prosumers that operate independently from one another and have two-way exchanges with the grid to balance differences with a supplier as intermediary. The purpose of the PR market is to quantify individual DER benefits, i.e., the benefits that accrue to individual households from installing a DER system, potentially including cost savings and enhanced attributes. Two scenarios are again included in this market, for cases where surplus power is stored for later use (III) and sold back to the grid (IV) in exchange for a feed-in tariff (FiT). An additional option available in France where all generation is sold back to the grid at a preferential rate was not included.
- III. **Energy Community Market (ECM).** This scenario (V) aims to quantify locality benefits, i.e. the value of a local P2P energy market above that of the simple PR scenario. The ECM is assumed to remain connected to the grid for back-up at all times, avoiding the need to invest in overcapacity and storage. Under net metering electricity fed back to the grid is remunerated at the regular rate.
- IV. **Dual market (DM).** The dual market (VI) is the combination of the ECM with access to an external spot market to balance differences. This scenario is aimed at quantifying selectivity benefits.

Figure 15. Illustration of the different scenarios



4.2.1 Consumer retail (CR)

The base case assumes all households have bilateral contracts with commercial suppliers. The curve describing a single generator with elastic supply is:

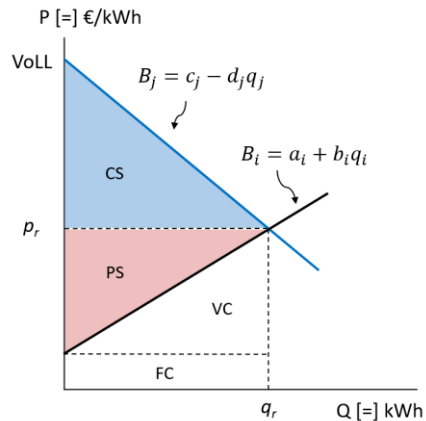
$$B_i = a_i + b_i q_i \quad (7)$$

where a_i is a constant, b_i a coefficient and q_i the amount of energy in kWh. a_i and $b_i q_i$ represent the fixed and variable cost components of generator i , respectively. For a single consumer with elastic demand the corresponding curve is:

$$B_j = c_j - d_j q_j \quad (8)$$

The intercept c_j represents the maximum price consumer j is WTP for his or her electric power. It usually corresponds to the 'value of lost load' (VoLL) which is the maximum price households would be willing to pay rather than go without electricity. Coefficient d_j determines the marginal rate at which consumption q_j increases with a decreases in price. In Figure 5, CS represents the consumer surplus, PS the producer surplus; and FC and VC the fixed and variable generation costs, respectively. p_r and q_r are the retail and quantity, respectively. Most electricity markets are optimized using uniform pricing (UP) where all generators receive the marginal price. In some cases pay-as-bid pricing (PAB) is used and generators receive their bid prices instead.

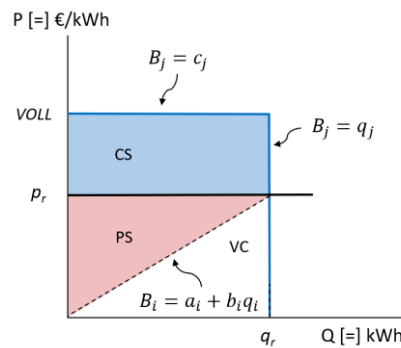
Figure 5. Consumer and producer surplus under elastic supply and demand



Although retail consumers as a whole can exert considerable pressure on prices, at the individual level their influence is negligible. The benefits and costs to the grid that result from the households that make up an EC will therefore not be considered in this study.

Since individual retail consumers are price takers the supply curve can be considered perfectly elastic from their perspective. This is of course a simplification, since rates often increase after exceeding certain thresholds. Electricity being a staple good it is safe to assume its demand is mostly inelastic in the short-term, turning the demand curve vertical. Figure 66 presents the equivalent market equilibrium under inelastic demand ($d_j = 1$). Since optimization is usually performed considering variable costs only area FC disappears (fixed costs are often compensated in separate capacity markets). Notice that in both figures households only capture the consumer surplus CS, whereas third parties capture and share the producer surplus PS.

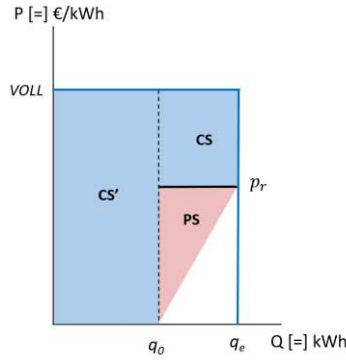
Figure 6. Consumer and producer surplus under inelastic demand



4.2.2 Prosumer retail (PR)

An isolated prosumer with inelastic demand can be represented by Figure 7, where CS' is the additional consumer surplus resulting from the self-consumed power. The deficit $q_r - q_0$ is purchased from the grid at rate p_e as before.

Figure 7. Prosumer and producer surplus



Use attributes in DERs

Although conventional economic dispatch considers only variable costs, in the case of solar and wind doing so would imply assigning no value to energy in the short-term. Instead, the price floor for power generated with zero variable costs is their LCOE calculated over the expected lifetime of the system (typically 20-25 years) allowing the initial investment to be amortized. Following (Kost et al., 2018) the general form of the LCOE for an individual power generation system is given by:

$$LCOE_i = \left[I_i + \sum_{t=1}^n \frac{A_{i,t}}{(1+r)^t} \right] / \left[\sum_{t=1}^n \frac{(q_{i,t}^0 + q_{i,t})}{(1+r)^t} \right] \quad (9)$$

where

$LCOE_i$	Levelized cost of electricity in €/kWh	n	Economic lifetime in years
I_i	Initial investment in €	$q_{i,t}$	Surplus energy in kWh/year
$A_{i,t}$	Annual cost in € per year t	$q_{i,t}^0$	Self-consumed energy in kWh/year
r	interest rate in percent	t	Year of system lifetime (1, 2, ... n)

The term $A_{i,t} = 0$ if we assume prosumers have solar PV installations with no running costs. The electric power produced is also bounded by $q_0 + q_i < q_i^{max}$ where q_0 is the power instantly self-consumed, q_i is surplus power that can be stored or fed back to the grid, and q_i^{max} is the maximum output of the system. It is important to remember that the initial cost of the DER has been incurred and its amortized equivalent per hour, day or year can be known precisely regardless of whether it produces any power or not. The LCOE formula does not provide this insight as an energy output of zero in the denominator makes the cost appear infinite.

Hedonic attributes in DERs

Hedonic attributes are an important motivation to produce and consume electric power from DERs. The hedonic attributes considered in this study are linked to their generation source, and are therefore 'originated' every time electric power is produced.⁵⁵ Since their value derives from

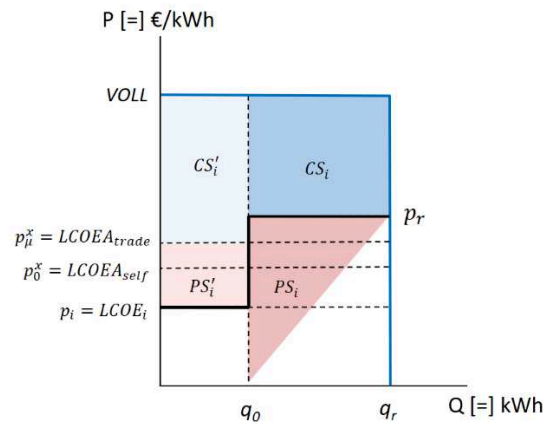
⁵⁵ This is not true for certain hedonic attributes based on conspicuous consumption, e.g. the desire for DER visibility to enhance social standing. See (Dastrup et al., 2012a).

households' WTP they cannot be measured directly and must instead be estimated empirically. In order to account for hedonic attributes in the average cost of the power produced we define:

$$LCOEA_i = \frac{I_i}{\sum_{t=1}^n \left[\frac{(q_{i,t}^0 + q_{i,t})}{(1+r)^t} + x_{i,t}^0 q_{i,t}^0 + x_{i,t} q_{i,t} \right]} \quad (10)$$

where $LCOEA_i$ is the levelized cost of electricity and attributes in €/kWh. The hedonic attributes associated with the self-consumption of generator i in year t are represented as $x_{i,t}^0$ and those associated with the attributes traded by the same generator in the same year as $x_{i,t}$. Note that the magnitude of the additional terms is proportional to the electricity that is self-consumed and traded, respectively. As mentioned before, autarky (autonomy) is one of the most highly valued attributes by prosumers. It is only present in the electricity consumed behind-the-meter, but not in that traded with or purchased from third parties and may partly explain the 'endowment effect' (Kahneman et al., 1991). The price curves resulting from the LCOE and LCOEA are shown in Figure 8.

Figure 8. Individual prosumer surplus under LCOE and LCOEA



Notice that the investment cost remains unchanged at $p_i = LCOE$ regardless of which attributes are considered; what changes is the share of the surplus that is allocated to the prosumer acting as producer or consumer, i.e., $CS'_i + PS'_i$ is constant but the individual shares shift. If only electricity is considered during self-consumption the prosumer as producer 'sells' to itself at cost $p_i = LCOE$ (the minimum without incurring losses) and captures the entire surplus as consumer, i.e., $PS'_i = 0$. When attributes are self-consumed the lower boundary shifts from p_i to p_0^x , so now $PS'_i = p_0^x - p_i$ and $CS'_i = VOLL - p_0^x$. Finally, when attributes are traded the lower boundary becomes p_μ^x so $PS'_i = p_\mu^x - p_i$ and $CS'_i = VOLL - p_\mu^x$. At the individual level demand is inelastic up to q_r .

Case CR I: self-consumption

The value of self-consumption lies in its displacement of demand up to q_0 , and is equivalent to including a prior long-term bilateral commitment (in this case to oneself) that restricts the amount of energy that is bid into the market (Zou, 2009).

The different prices that arise from applying LCOE and LCOEA are only theoretical in the case of self-consumption, since no money is actually transferred between a buyer and a seller, and no producer surplus results. Instead, the value of self-consumption stems from its displacement of demand that would otherwise have to be purchased from the grid, thus increasing consumer surplus between p_i and the VoLL.

The (lower) LCOEA price p_0^x contains the autonomy attribute, being sourced from a specific PV system. This price merely provides an indication of the relative distribution of value between use and non-use attributes in area CS', and the size of the discontinuity between DER and grid prices.

Case CR II: surplus generation

It is important to note that the same energy is perceived to contain less attributes when traded than when self-consumed. Most notably, the autarky (autonomy) attribute is missing from traded power.

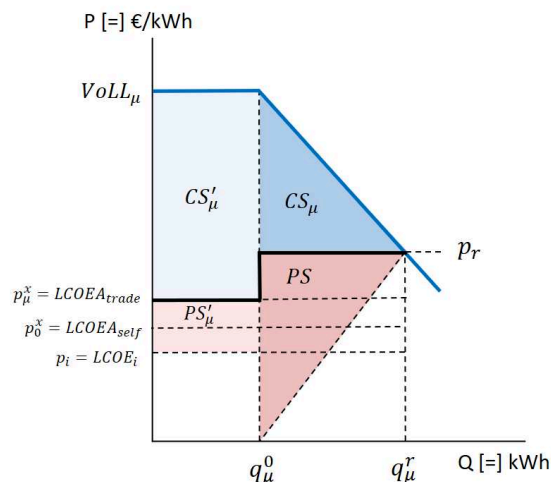
In this case the (higher) LCOEA price p_μ^x lacks the autonomy attribute but includes the higher-valued “P2P” source, which is the equivalent of including a profit margin. The price p_μ^x has practical implications: it serves as a reference against which to compare the FiT and the spot market price.

4.2.3 Energy Community Market (ECM)

Case ECM I: Supplier back-up

The ECM is designed to maximize value (utility) rather than minimize cost. Although the power produced and delivered in the community has the same physical characteristics as grid power, it is valued more highly by its members, who have different piecewise-constant valuations over its attributes (Chen et al., 2013). While the underlying valuations do not affect its physical distribution, they govern the financial settlements between agents. An ECM can exist provided participants have different production and consumption patterns, so surpluses and deficits can be mutually compensated. The households in our ECM are either strict consumers or prosumers. Prosumers do not have a distinct representation but are instead treated as net generators or net consumers depending on their mode of operation in each period (bids cannot overlap).

Figure 9. ECM (Dual) market equilibrium and surplus



Energy produced and traded within the ECM has an inelastic demand curve since it is always prioritized and consumed in its entirety. Its demand is therefore not diminished up to q_j^u . In contrast, residual demand q_j^e for grid supply is variable among households and can be sorted from high to low, producing 'less inelastic' downward sloping demand curve as shown in Figure 9.

The market surplus for the ECM is represented in this diagram by the sum of areas $CS'_\mu + PS'_\mu + CS_\mu$. CS'_μ is the collective consumer surplus from P2P trades inside the community, which reflects both the utility of consumption and the displacement of external supply; PS'_μ is the producer surplus captured by prosumers from both self-consuming and trading their power at price $p_\mu^x = \sum p_i^x / q_\mu^0$; and CS_μ is the collective surplus from purchasing energy from an external supplier.

The advantage introduced by an ECM lies in the sharing of benefits between prosumers and strict consumers, the fact that the price of electricity within the ECM is lower than that purchased from the grid, and the capture of more value through hedonic attributes. On the other hand, prosumers are unable to sell their surplus energy directly at the (higher) regulated feed-in-tariff because all that surplus is consumed within the ECM. Without this compromise, however, the ECM would only be viable with energy storage, which would significantly raise the costs to prosumers.

Case ECM II: Spot Market back-up

In this case the ECM balances its deficits and surpluses with the spot market rather than a supplier, i.e., at the spot market equilibrium quantity q_μ^e and price P_e .

Although as a market participant the DM would be required to place supply and demand bids every hour in the spot and day-ahead markets, being a price-taker it will be assumed to purchase and sell electricity at the average spot market price in every period. This is a largely hypothetical exercise, as the size of an actual EC would not allow it to trade directly in these markets.⁵⁶

4.3 Surplus Assessment

Once the values of the individual scenarios have been computed, estimating the value they produce and capture w.r.t. others requires comparing their overall market surplus as well as its distribution between strict consumers and prosumers. The value of **DER benefits**, i.e., the surplus value of installing DER systems, can be assessed by comparing the CR and PR scenarios. **Locality benefits**, i.e. the benefits of a P2P market, requires comparing the PR and ECM scenarios. The value of **selectivity benefits**, or the benefits of accessing the spot market, can be estimated by comparing the ECM and DM scenarios.

The last stage involves conducting a sensitivity analysis to determine the influence of external factors on the relative prices of electric power within and outside the EC, which in turn affect the market surplus. Four incentives will be considered that affect the variable costs of electricity, all of them listed in the prevailing French legislation (JORF no.0235 du 6 octobre, 2021): Subsidies on capital

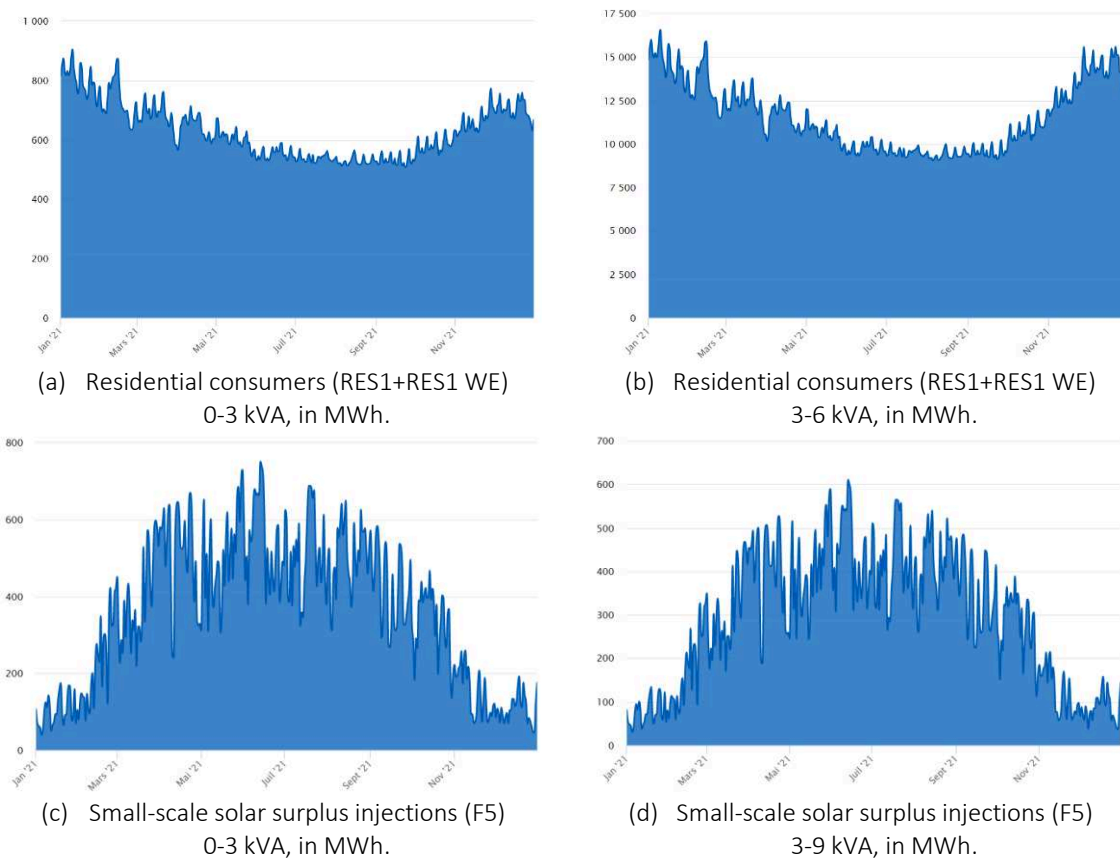
⁵⁶ According to (Enedis, 2022) the typical collective self-consumption operation in France involves two producers, twelve consumers and an average installed capacity of 4,399 kVA.

expenditures for self-consumption (€/Wc); feed-in-tariffs (€/kWh); and subsidies for the installation of new capacity (€/Wc).⁵⁷

5. CASE STUDY

The model presented previously is tested on an EC of equivalent size to the IEEE European Low Voltage Test Feeder (IEEE, 2015), a radial distribution grid containing 55 nodes. For the case study the average electricity flows of 55 residential consumers were considered during the year 2021 at 30 minute intervals: RES1 rate at the 0-3 kVA and 3-6 kVA levels, and small-scale F5 solar producers at the 0-3 kVA and 9-12 kVA levels in the same proportions as they are present in the French region of Auvergne-Rhône-Alpes (ARA). Their demand profiles for 2021 are shown below.

Figure 10. Small-scale demand and supply profiles in the ARA region. Source: Enedis Open Data, <https://data.enedis.fr/>



Data collected previously by the author on the valuations of individual attributes and sources in the ARA region was incorporated for self-consumption and trade within the energy community (see Chapter 3).

⁵⁷ Known in France as '*Prime d'investissement pour l'autoconsommation*', '*Rémunération de l'énergie injectée*' and '*Prime à l'intégration paysagère*', respectively.

5.1 Consumer Retail Scenarios (I and II)

The CR scenario is the base case in which all households are assumed to be price-takers with inelastic demand. Each of the 55 households in the network demand on average 4,912.09 kWh/y. When combined their total demand equals 270,164.79 kWh/y. Applying a flat, regular residential rate of 0.1567 €/kWh⁵⁸ amounts to **42,334.89 €/y (Scenario I)**. For context a study by CEPA (Cambridge Economic Policy Associates Ltd., 2018) estimated France's VoLL at 6.92 €/kWh. Adjusted for inflation this is equivalent to 7.14 €/kWh in 2021. This would imply an average consumer surplus of 6.99 €/kWh; 3.92 €/h or 19,241 €/household in a year. However VoLL values a use attribute (electric power) rather than a hedonic attribute and will thus not be further discussed here.

The equivalent using a flat green residential rate of 0.1618 €/kWh⁵⁹ is **43,723.08 €/y (Scenario II)**. This last comparison is interesting, as previous work by the author (see Chapter 3) found that respondents' WTP for the green attribute in the ARA region is on average 7.56 €/m or 11.80% of their monthly bill. This would imply that the average participant with a demand of 4,912.09 kWh/y or 409.34 kWh/m who is already purchasing at the base rate and has an average bill of 64.14 €/m would in principle be WTP an additional 7.57 €/m to receive green power from his or her supplier, which for 55 households over the course of a year amounts to 4,993.59 €/y. The fact that they are only paying an additional 1,388.19 €/y suggests that the **green rate is underpriced by a factor of 3.6**. In other words, the 'true' valuation for green derived from respondents' WTP is 4,993.59 €/y above the base scenario and 3,605.40 €/y above the current green market rate. Since overall utility has increased this surplus corresponds to the Hedonic Compensating Variation (HCV) for the households in question.

5.2 Prosumer Retail Scenarios

To mirror the generator-to-consumer ratio in energy communities reported by Enedis (Enedis, 2022) eight of the 55 households were assigned to be prosumers, while the remaining 47 were strict consumers. To account for prosumer surpluses Enedis data for solar 'F5' rates at the 0-3 kVA and 3-9 kVA levels was used, also in the same proportions as they are present in the ARA region, for the same year and interval resolution (30 min). Since no records exist for self-consumption (which takes place behind the meter) and the prosumer profiles were artificially recreated by combining the separate power flows of isolated consumers and solar generators of similar sizes rather than measuring the flows of actual prosumers, it was assumed that whenever surplus power was zero self-consumption was also zero, and whenever surplus power was positive the entire demand for that period had already been covered by self-consumption.

The LCOE was calculated using equation (9). The values for the initial investment I_i (1,445 €/kWp), discount rate r (3%), useful life t (25 y) and capacity factor (18%) applicable in France were taken from the IEA's 2020 *Projected Costs of Generating Electricity* (IEA, 2020). Enedis statistics on the size of small PV systems in the ARA region revealed accurate estimates of their size and contractual

⁵⁸ This is a composite rate that applies the same proportion of contracted power by demand bracket in the region to their equivalent base rate (*tarif bleu*) in 2021: 8.79% for 0-3 kVA; 72.05% for 3-6 kVA; 14.62% for 6-9 kVA; and 4.53% for 9-12 kVA.

⁵⁹ The green composite rate was calculated followed the same procedure as the base rate above, for the 6 kVA and 9 kVA brackets.

regime. Since the cost per kWp installed is constant, the **LCOE of $p_i = 0.0628 \text{ €/kWh}$** was the same regardless of system size. Using the appropriate average size was nevertheless useful to estimate overall energy and financial flows.

Table 4 Solar PV in the ARA region by capacity range and contract regime.
Source: Enedis Open Data, <https://data.enedis.fr/>

Regime	Range	MW	No.	Avg kWp
No net surplus	0-1 kWp	2.42	4,290	1.82
	1-3 kWp	21.49	8,855	
	3-6 kWp	6.92	1,623	4.69
	6-9 kWp	1.67	207	
Surplus	0-1 kWp	0.4	425	2.75
	1-3 kWp	124.64	44,992	
	3-6 kWp	107.34	21,666	5.25
	6-9 kWp	17.58	2,068	

The LCOE calculation was also confirmed using NREL's *LCOE calculator* (NREL, 2022). This result is broadly in line with previous estimates⁶⁰ from the United States that placed the cost of unsubsidized PV systems for energy communities in the range 0.065 - 0.128 €/kWh, but below those for residential rooftop PV systems which fell in the range 0.159 – 0.271 €/kWh (LAZARD, 2017), and estimates produced by the National Renewable Energy Laboratory in 2016 of around 0.1012 - 0.1675 €/kWh (NREL, 2018). A conversion rate of 1 EUR = 0.85 USD was used following (IEA, 2020), which is below current rates but still a good approximation for 2021. However, these estimates employed higher discount rates of between 6-8% and ignored the continued downward trend in capital costs. A 2018 review of LCOE values by (Jäger-Waldau et al., 2018) found an average cost of direct current (DC) power from residential PV systems below 0.02 €/kWh in central Europe.

The prosumer retail scenarios include two variants, under balanced (no net surplus⁶¹, with storage) and surplus conditions. The LCOE is the same in both cases, but the energy is stored and self-consumed in the first and sold at the prevailing FiT rate in the second.

5.2.1 Isolated prosumers, no net surplus (III)

The inability to sell surplus energy means it would either have to be stored, wasted or fed back to the grid for free. That is why, to mitigate losses, the size of PV systems *in this scenario only* was assumed to lie in the 0-3 kVA range rather than the 0-9 kVA range employed for the other scenarios. If the capacity of solar PV systems mirrored the proportion of small producers in the ARA region, the eight prosumers in this scenario would generate a combined $Q_i = 48,765.02 \text{ kWh/y}$ while consuming 58,116.37 kWh/y. The generation was further split into an instantly self-consumed fraction $Q_i^0 = 29,945.35 \text{ kWh/y}$ and a stored fraction $Q_i^S = 18,819.67 \text{ kWh/y}$. A deficit of 9,351.35 kWh/y remained to be purchased from the grid. It was assumed that whenever household demand and generation were positive self-consumption would be prioritized.

⁶⁰ The original ranges were 76-150 US/MWh for energy communities and 187-319 US/kWh for rooftop solar, respectively.

⁶¹ This arrangement corresponds to the French *autoconsommation sans injection (ACSI)*.

In terms of costs the original LCOE of 0.0628 produced two different LCOEA values, depending on whether the electricity was self-consumed or stored:

- If self-consumed, it was assumed to contain the PV, green and local attributes, adding 0.006 €/kWh to the original LCOE to produce $p_0^x = 0.0688$ €/kWh and a total valuation of $Q_i^0(p_i + p_0^x) = 2,299$ €/y for this fraction. Notice that consistent with the findings of Chapter 3 the local attribute is negative.
- If stored, a flat levelized cost of storage (LCOS) of $p_i^S = 0.085$ €/kWh (Comello and Reichelstein, 2019b) was added to the original LCOE before conversion into LCOEA. Stored PV electricity was assumed to contain the PV, green, local and autonomy (autarky) attributes ($p_0^x = 0.0758$ €/kWh LCOEA), producing a total valuation of $Q_i^S(p_i + p_0^x + p_i^S) = 3,404$ €/y.

Instant and deferred consumption thus had an estimated value of 5,703 €/y to the eight prosumers, which is still lower than the 7,641 €/y it would have costed if purchased at the base rate.

Since green power from a supplier is more undervalued than that from DERs, it provides a proportionately larger surplus. Covering the remaining deficit of 9,351.35 kWh/y with green rather than regular power would have costed prosumers only 48.05 €/y more, yet boosting their hedonic surplus by 172.85 €/y. Of course, since the HCV surplus per unit is the same for every kWh purchased from the grid, its inclusion only shifts the totals without modifying the underlying dynamics. Since this surplus can be obtained without recourse to DERs or ECs it will only be of secondary interest in this study.

The 47 strict consumers that did not participate in this scenario and remained unaffected.

5.2.2 Isolated prosumers, surplus (IV)

For the net surplus scenario we will adopt the same PV system distribution as the ARA region, where 0-3 kVA systems account for 73.03% of the total and the remaining 26.97% is made up of 3-9 kVA systems. In contrast to the previous case the surplus is now sold back to the grid at rate $p_{FiT} = 0.10$ €/kWh which is the prevailing FiT in France for small producers (JORF no.0235 du 6 octobre, 2021). The new total production Q_i is 54,910.04 kWh/y, of which 29,989.33 kWh/y were self-consumed and 24,920.70 kWh/y were sold back to the grid.

While the self-consumed fraction can be treated as in the preceding scenario, self-produced electricity accrues only financial benefits to prosumers when traded or sold to third parties. The associated attributes are instead allocated to consumers/buyers, i.e., in this case the grid. This is akin to repeating the previous scenario with increased PV generation capacity, removing the stored fraction and adding the FiT revenue. In effect this implies that the energy and P2P, green and local attributes produced at a cost of $p_\mu^x = 0.0708$ €/kWh are sold to the grid in exchange for a FiT of $p_{FiT} = 0.10$ €/kWh.

In this scenario the self-consumed fraction has a value of $Q_i^0(p_i + p_0^x) = 2,303$ €/y; the surplus fraction sold back to the grid $Q_i^e p_{FiT}$ amounted to 2,492.07 €/y; and the deficit from the eight prosumers was $q_j^e p_r = 1,458.47$ €/y for a total prosumer balance of 2,834.82 €/y. Adding to this the

cost to the additional 47 strict consumers, $q_i^e p_r = 36,177.08 \text{ €/y}$, for a grand total of **39,012 €/y (Scenario IV)**.

If deficits are covered with green electricity instead the price for prosumers would rise by 47.82 €/y (and hedonic surplus by 172 €/y), while strict consumers would pay 1,186.27 €/y more in exchange for a potential HCV gain of 4,267 €/y.

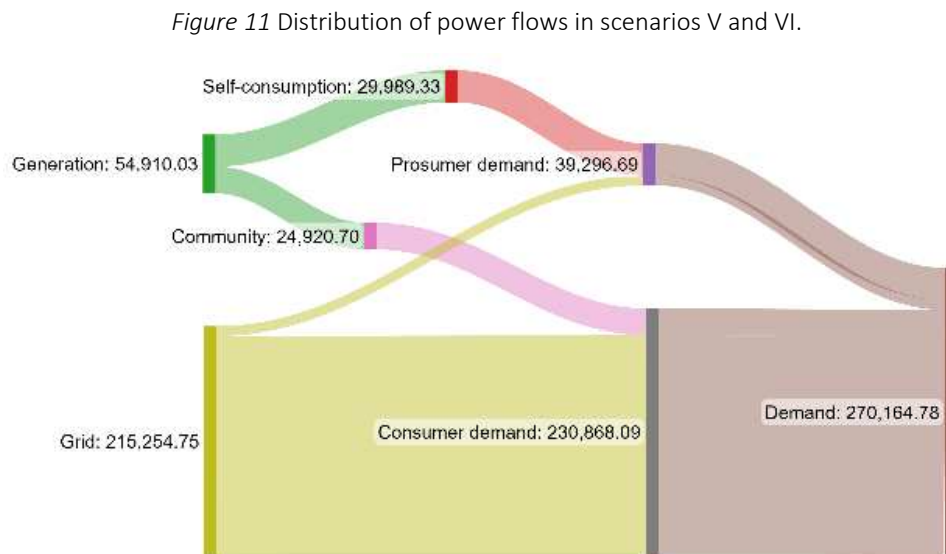
5.3 Energy Community Scenarios

In the EC scenarios there are two settlement periods. In the first prosumer surpluses are balanced against the deficits of strict consumers in the P2P market, while in the second EC deficits are balanced against the grid. The two scenarios vary only in their choice of back-up: the first uses a regular supplier, whereas the second has access to the spot market. The distribution of power flows in the two EC scenarios is presented in Figure 11 below.

5.3.1 EC with supplier back-up (V)

In this scenario prosumers generate $Q_i = 54,910.04 \text{ kWh/y}$ of which $Q_i^0 = 29,989.33 \text{ kWh/y}$ is self-consumed at a value of $Q_i^0 p_0^x = 2,700 \text{ €/y}$ displacing grid power with an equivalent cost of 357 €/y. The remaining $Q_i^H = 24,921 \text{ kWh}$ are sold to the EC at a rate of $p_\mu^x = 0.0708 \text{ €/kWh}$ for a total profit of $Q_i^H p_\mu^x = 1,765 \text{ €/y}$. The prosumer deficit of $Q_j - Q_i^0 = 9,307.36 \text{ kWh/y}$ is covered from the grid at rate $p_r = 0.1567 \text{ €/kWh}$ for a total cost of 1,458.47 €/y. The total cost to the eight prosumers is therefore $Q_i^0 p_0^x - Q_i^H p_\mu^x + (Q_j - Q_i^0) p_r = 1,280 \text{ €/y}$.

Strict consumers, on the other hand, now have an additional source of affordable power in the community's P2P market. This power contains the P2P, green and local attributes. Their original demand of $Q_{j(47)} = 230,868.09 \text{ kWh/y}$ is partly covered with energy from the EC market $Q_i^H p_\mu^x = 1764.92 \text{ €/y}$ with the difference $Q_i p_r = 32,272 \text{ €/y}$ drawn from the grid. The total paid by consumers is therefore $Q_i^H p_\mu^x + Q_i p_r = 34,534 \text{ €/y}$. The grand total for Scenario V is hence **35,814 €/y**.



Again, consumers would benefit most from covering deficits with green power, spending only 1,058.22 €/y more in exchange for an increase in value of 3,807 €/y.

5.3.2 EC with spot market back-up (VI)

In this final scenario the EC can cover deficits by interacting directly with the spot market. In the two energy community scenarios the entire surplus sold by prosumers is consumed within the EC market, so nothing is sold back to the grid. Importantly, this scenario does not include the various fees and taxes associated to the transmission and distribution of power purchased in the spot market.

For prosumers the power flows remain unchanged from the previous scenario, with the only difference being that the deficit $Q_j - Q_i^0 = 9,307.36$ kWh/y is purchased at the (lower) average spot market price of 2021, i.e. $p_e = 0.1092$ €/kWh for a total of 1,016.08 €/y. For strict consumers the corresponding deficit $Q_i - Q_j^H = 205,947.39$ kWh/y has a cost of 22,483.28 €/y. Considering the value of the different fractions the total value for the EC participants is **25,583 €/y (Case VI)**.

6. RESULTS

A summary of the power flows, use attributes and hedonic attributes for the different scenarios are presented in Annex I to III. In the annexes and tables below outflows of energy, money and attributes (from the household perspective) are indicated by negative signs, while positive signs are reserved for their equivalent gains.

Using money measures alone scenario II is the most expensive, closely followed by scenarios I and III. Scenarios IV and V offer total savings of 12.5% and 16.3%, respectively w.r.t. the base scenario. Scenario VI produced the least costs, at only 60.4% of the original cost, due mostly to the effect of cheaper wholesale market supply. In other words, the retail consumer scenarios are on average the most expensive, followed by the isolated consumer/prosumer scenarios, which are in turn undercut by the EC scenarios. The distribution of benefits is highly unequal between prosumers and consumers – a result that is expected in the case of isolated households (scenarios I-IV) but not in the case of energy communities, and merits further research. A comparison with the green supply scenario (II) follows the same pattern. The physical deficits of prosumers and consumers are identical in energy terms in scenarios V and VI, yet lower grid prices in VI erode prosumer surplus while benefiting consumers. Table 5 presents the financial surpluses between scenarios, considering use attributes only. When moving from Scenario I to Scenario II, for example, the 55 households incur an additional cost of 1,388 €/y on average, while at the other extreme when moving from Scenario II to Scenario VI the savings amount to 18,142 €/y.

Table 5. Surplus, use attributes only, €/y

SCENARIOS		FROM				
		I	II	III	IV	V
TO	II	- 1,388				
	III	29	1,417			
	IV	5,307	6,695	5,278		
	V	5,307	8,308	6,891	1,612	
	VI	16,753	18,142	16,724	11,446	9,834

Taking hedonic attributes into account (Annex III) changes the surplus landscape drastically. The shift from Scenario II to Scenario III now becomes the most ‘expensive’, while that from Scenario I to VI the most attractive. The possibility of selling energy surpluses to an EC instead of a supplier, i.e., the difference between Scenarios III and IV, produces a total surplus of 4,657 €/y for EC participants, as shown in Table 6. Their equivalents as percentage w.r.t. the base scenario I are shown in Table 7187.

Table 6 Surplus, use & non-use attributes, €/y

SCENARIOS		FROM				
		I	II	III	IV	V
TO	II	3,605				
	III	1,069	- 2,536			
	IV	5,726	2,121	4,657		
	V	6,223	4,230	6,766	2,109	
	VI	17,669	14,064	16,600	11,943	9,834

Table 718 Surplus, use & non-use attributes, %

SCENARIOS		FROM				
		I	II	III	IV	V
TO	II	8.52%				
	III	2.53%	-5.80%			
	IV	13.53%	4.85%	11.01%		
	V	14.70%	9.67%	15.99%	5.70%	
	VI	41.74%	32.17%	39.24%	32.25%	27.77%

Recalling the original objective of the study, our objective was to estimate three types of benefits: DER benefits (Scenarios III & IV), locality benefits (Scenario V) and selectivity benefits (Scenario VI).

- DER benefits.** DER benefits can be estimated by comparing the scenarios with individual DERs (III, IV) against the baseline scenarios (I, II). As shown in Tables 6 and 7 above, owners of DER systems with storage and no surplus are able to capture only 1,069 €/y (2.53%) more value with respect to the base scenario, and actually ‘miss out’ on 2,536 €/y (5.80%) when compared to the green rate option. Being able to generate and sell surplus power makes a big difference. The foregone autonomy attributes are overwhelmingly compensated by savings on storage, making benefits jump by 5,726 €/y (13.53%) when moving from I to IV and remain positive when moving from II to IV. These results are only relevant for prosumers, as strict consumers are excluded from the calculations.
- Locality benefits.** These are the benefits derived from having access to a P2P market (Scenario V) but not a wholesale market (Scenario VI). Locality benefits can be estimated with respect to the isolated DER scenarios III and IV. Individually prosumers capture more of the surplus than consumers, especially when they self-consume (III) rather than selling their surplus at a rate lower than the FiT, but consumers also gain from sourcing part of their energy from cheaper sources. Globally the creation of an EC with a P2P marketplace offers potential benefits that range between 6,766 €/y (15.99%) compared to the no surplus scenario, and 2,109 €/y (5.70%) when compared to selling at the current FiT.

- **Selectivity benefits.** As defined by the EU's More Microgrids project (Schwaegerl et al., 2009) selectivity benefits refer to the opportunities to optimize dispatch decisions in real-time to maximize profits. In the context of our EC this translates as exposure to a spot market. The comparison is then between an EC with access to a wholesale market (scenario VI) and one without (scenario V). At 0.10 €/kWh the FiT in France was almost the same as the average spot price in 2021, which stood at 0.1092 €/kWh. It is therefore not surprising that prosumers gained little from accessing the spot market rather than selling through an intermediary. That also explains why almost the entire selectivity benefits accrue to consumers, presenting a clear example of split incentives: prosumers must generate a large enough surplus of power in order to access the spot market, yet most of the benefits from doing so would accrue to consumers. For the EC as a whole selectivity benefits amount to an estimated 9,834 €/y (27.77%), or 179 €/y for every participating household.

7. DISCUSSION

The first hypothesis of the study was that agents in microgrids are able to capture more value than either conventional consumers or independent prosumers. A model was proposed to test these hypotheses, and a case study conducted following the broad outline of a Citizen Energy Community. Using actual production and consumption data from households and small DERs in the ARA region in 2021 the model explored the surplus produced in six scenarios. With the exception of the shift from green rate to a non-surplus DER (from scenario II to III), which was unfavorable to prosumers, the results suggest that the successive addition of DERs, an EC market and access to the spot market successively increase the surplus (reduce the costs) associated to electric power consumption for all participants. In particular, households in ECs consistently outperformed both isolated consumers and combinations of isolated prosumers and consumers, confirming the first hypothesis.

The second hypothesis of the study was that the value captured from exposure to a dual market structure, at least one market of which contained hedonic attributes, exceeded that of either market considered alone. This refers specifically to Scenario VI, which has access to the EC and wholesale markets. The value of the EC market corresponds to the locality benefits in the preceding section, and ranges between 2,109 €/y - 6,766 €/y while the value of the wholesale market corresponds to the selectivity benefits, and is estimated at 9,834 €/y. Their combination therefore lies between 8,875 €/y and 16,600 €/y. Comparing the surplus of moving from Scenario I to VI we see that it amounts to 17,699 €/y, and exceeding the value captured by the two markets taken in isolation. This, in effect, is the maximum value that can theoretically be captured by an EC under the assumptions of this study. The second hypothesis can therefore be rejected on this basis.

Although there is ample scope to expand on this research, refining valuations and grid modeling stand out. The factors that influence individual attribute valuations and their monetary equivalents need to be better understood and should be corroborated to reflect current local preferences, including the value assigned to green retail rates as substitutes. The grid model employed here is also rudimentary and does not reflect the physical realities and costs of setting up and operating a physically-bound energy community. More accurate results would be obtained from, among other things, including

the physical constraints of low voltage networks, DER intermittency and the hourly prices of the spot market for the whole year, which were not available for this study.

8. CONCLUSION

The progressive introduction of various elements into an energy community has made it possible to estimate the value afforded by DERs, a local P2P market and a spot market to its members. According to these estimates investments in isolated DERs for exclusive self-consumption are the least attractive, being only marginally superior to the value provided by grid supply. The possibility of selling surplus energy back to the grid at the prevailing FiT boosts profitability, and adding a local P2P market increases it further. However, it is access to the spot market that provides the largest financial profit.

This study also introduced modified versions of the CV and EC welfare measures to account for the differences in utility that result from changes in hedonic attributes, in addition to prices. These measures, named Hedonic Compensating Variation (HCV) and Hedonic Equivalent Variation (HEV), respectively, serve as tools to estimate the extent to which the value of an increase (or decrease) in the quality of hedonic attributes affects overall utility. The relationship between hedonic attributes and (indirect) utility is established through the stated WTP for those attributes. Including these adjustments tended to have a positive effect on valuations, albeit a modest one. The hedonic surplus of electricity attributes produced a modest 419 – 1,040 €/y in the scenarios with isolated prosumers, and only 916 €/y for energy communities. Ironically, it was the scenario where all households purchased green electricity from the grid that produced the largest hedonic boost of 4,994 €/y.

A special effort was made to draw on data for power flows, prices and household preferences from the same region and time period, in the hope of making the analysis as accurate as possible. Nevertheless, the final values obtained should be considered preliminary and need to be corroborated by more detailed models that take into account the physical constraints of the grid and more granular price data for the spot market. Another important caveat in these results is that the regulated rates charged by suppliers include various items that would persist in the absence of a supplier, including transmission and distribution charges, ancillary services, some taxes, and possibly system operator fees, which would still apply to spot market purchases. Nevertheless, since most of these charges are fixed or affect all transfers equally, they do not affect the overall conclusions.

In the longer term it remains to be seen whether a price increase in the 30-40% range is necessary to incentivize more people to consider installing solar panels or joining an energy community, or whether adoption can instead be stimulated by materializing their stated WTP for the hedonic attributes they confer.

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General Conclusion

The transition toward cleaner energy sources holds great promise to mitigate climate change and improve the quality of life for millions of people. The value ascribed by individuals to the services that electricity offers is uncontroversial. Why they value attributes that they cannot measure or experience at the point of consumption is less well understood. What is clear is that for a fraction of the population in every country studied so far paying a premium for those attributes is an attractive option. Understanding what lies behind their preferences, how much they are willing to invest and how much value they perceive to gain from those transactions is of particular importance to stimulate future investment in renewable technologies and accelerate the energy transition.

A clear understanding of the motivations behind consumer choices is a prerequisite to designing effective incentives, be they public policy interventions or business strategies. The exploration of *why* and *how much* people value the hedonic attributes of electricity has been the central theme behind this thesis.

The first two chapters were devoted to assessing, theoretically and empirically, the value of the hedonic attributes of electricity at present. The third chapter provided a general overview of past research on the subject, while the fourth chapter offered a practical way hedonic values could be aggregated in the future. Together, they present a coherent narrative of the present, past and future of hedonic attribute valuation in the electricity sector.

Chapter 1

The first chapter was devoted to reviewing the most well known theories of behavior to find clues about the motivations behind individual choices that would otherwise appear random, and offering a more or less comprehensive mind map of the various competing explanations. After researchers began studying the motivations behind consumer choices it became increasingly clear that financial profit and self-interest alone could not account for the utility experienced by individuals and households from ‘consuming’ these non-use, hedonic attributes. Neoclassical economists, and more recently behavioral economists, then had to borrow from other disciplines in order to better explain their findings. The methods they used, in turn, produced new biases that are only now starting to be understood.

Chapter 2

The second chapter put this theoretical knowledge into practice by conducting a field experiment to gather data on the preferences of households in the Auvergne-Rhône-Alpes region of France regarding their energy preferences. It made the unexpected discovery that the ‘local’ attribute was

negatively perceived by a large fraction of the population. Despite its preeminent standing in many spheres, there are remarkably few primary studies on willingness to pay for green electricity in France, once reports from international bodies and industry-sponsored market surveys are removed. The study in this chapter aimed to fill this gap and should be followed by similar – and if possible, more comprehensive – studies in the future.

Chapter 3

The third chapter put the previous findings into perspective as the latest in a long list of studies that have documented the willingness-to-pay for ‘green’ electricity around the world since the early 1990s. A meta-analysis of primary studies was complemented by a review of the eight prior meta-analyses identified in the literature, reaching the conclusion that most of the independent variables selected appear to play no role in explaining peoples’ preferences and choices. Only after employing various regression techniques did one of them (a random effects model) find statistical significance for a few of the regressors, some of them relating to the specific methods used by researchers to elicit preferences, and others to specific technologies.

Individual-specific variables, especially the demographic and attitudinal sort, were deliberately excluded from the meta-analysis. This was partly because they should already have been controlled for in the original studies, and partly because including them would have increased the number of regressors exponentially with respect to the number of studies collected, yielding even less statistically significant results. With the information available it is therefore not possible to say whether including these variables, even on a binary basis, would have improved the model fit. An effective benefit transfer model that allows the findings of meta-regressions to be adapted to specific (new) contexts - thus transforming it from a descriptive to a predictive tool - is still elusive and should be the focus of future research.

Chapter 4

If the meta-analysis in the third chapter helped to provide theoretical coherence to the disparate findings in the literature, the fourth chapter offered a practical way to do so. Energy communities offer people who share similar affinities for green electricity (and other attributes) a way to pool and share their electricity, allowing households to capture more of the benefits of their distributed energy resources provided they meet the minimum required financial, legal and technical criteria. Creating or joining an energy community appears to make sense even if only financial valuations are considered, and make even more sense when hedonic valuations are included.

The same attitude-behavior gap observed in individual households that provide high theoretical valuations for renewables but fail to make the corresponding purchases can be observed in the absence of energy communities, albeit at a smaller scale. Both markets, individual and collective, continue to be underutilized as means to enhance the capture of benefits that go beyond the valuations presented here to include benefits to the grid and society at large.

Limitations

Several limitations were also encountered during the research. The available methods to map individual preferences are either impractical at large scale (focus groups) or only scratch the surface (stated and revealed preference). Aside from the fact that any model will always be incomplete, the preference axioms assumed by economists can hardly be relied upon to apply everywhere at all times; preferences are often formulated on short notice, they shift often, are incomplete and vary with context. Once preferences and choices are elicited, different research methods can draw different conclusions from the same data and can hardly be replicated precisely.

Efforts should be made to regularly update meta-analyses as more studies become available. Publication bias, whereby only statistically significant results are published, seems not to affect previous meta-analyses, but should continue to be monitored in future updates. The lack of certain critical pieces of information in the primary studies, such as the standard error in some measurements, also limited the range of models that could be used.

Finally, the energy community in our study was highly idealized and lacked the legal, economic and technical constraints that limit their real life counterparts. Actually building and operating an energy community will most certainly pose more challenges than are acknowledged here, which could partly explain their slow adoption to date.

It is the hope of the author that the information and insights shared here will help the reader to make better informed decisions, and make decision makers in the field more aware of potential caveats. A better understanding is a prerequisite to better interventions, and better interventions are in turn essential if societies are to transition to a clean energy future and reap the economic and social benefits it promises.

A APPENDIX TO CHAPTER 1

ANNEX I. Theories of Behavior

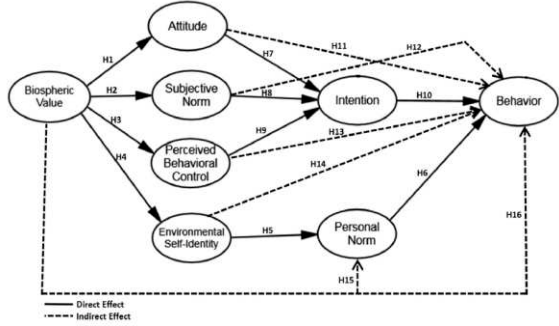
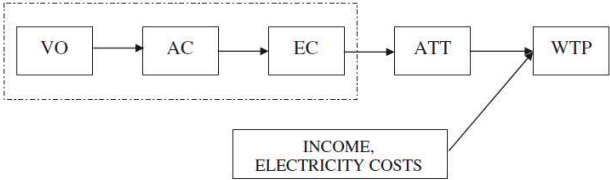
Theory or model	Objective	Brief description	Authors
Value-Belief-Norm theory (VBN)	Explains what predisposes individuals to take certain action	The root cause of pro-environmental behavior lies in values and emphasizes the importance of altruism directed at other humans (social altruism) and altruism directed at other species and the biosphere (biospheric altruism). The full VBN model posits a causal chain in which values shape general beliefs about human-environmental relationships (ecological worldview), which in turn influence beliefs about the impact of environmental problems on the things one values (awareness of consequences). These beliefs then affect the sense of responsibility one feels to address those consequences (ascription of responsibility) and one's sense of moral obligation to act (personal norms). VBN focuses on internal normative factors (personal norms) and emphasizes the benefit to others (altruism) over self-interest. It is an extension of the Norm-Activation model/theory.	Main author: (Stern et al., 1999). Others: (Akitsu and Ishihara, 2018; Brosch et al., 2014b; Ghazali et al., 2019; Wolske et al., 2017)
Theory of Planned Behavior (TPB)	Explains and helps to predict individual behavioral choices.	TPB posits that the intention to perform a behavior is the outcome of a rational decision making process that involves considering (1) one's attitudes toward the behavior, (2) perceived social pressure to do the behavior (subjective norms), and (3) an assessment of one's ability to perform it (perceived behavioral control). Each of these is the outcome of an expectancy-value calculation that involves assigning weights to the costs and benefits of each option. Attitudes form from beliefs about the consequences of a behavior and the expected likelihood of those outcomes occurring. TPB focuses on external influences (subjective norms) and self-interested behavior. Does not measure peoples' sense of morality.	Main author: (Ajzen, 1991). Others: (Akitsu and Ishihara, 2018; Ateş, 2020; Brosch et al., 2014b; Hansla et al., 2008a; Wolske et al., 2017)
Appraisal-Emotion theory (AE)	A theoretical integration of cognitive and affective processes with a focus on emotions to explain	Appraisal theory holds that emotions reflect the integration of the relevance of an event or object in the context of a person's concerns, goals, needs, and values. Emotional processes and emotional experience may thus be an appropriate mechanism for the integration of several classes of motivational considerations. The model predicts that the following appraisals are important for the elicitation of emotions and the prediction of	Main author: (Brosch et al., 2014b).

Theory or model	Objective	Brief description	Authors
	decisions and behaviors.	individual differences: 1. Relevance, 2. Implication, 3. Coping potential, and 4. Value-congruence.	
Value-Identity- Personal Norm (VIP) Model	Understand behavior by investigating the relationship between values, self-identity and personal norm.	The VIP model postulates that environmental behaviors are affected by feelings related to moral obligation to act in a behavior (personal norms). The model postulates that “the stronger one’s biospheric values, the stronger one’s environmental self-identity (ESI), and the stronger personal norm, the more one is likely to actually participate”. It is based on various the VBN model but focuses on general altruistic motives, rather than behavior-specific antecedents. It is suitable for examining indirect association among constructs and can have higher explanatory power.	Main author: (van der Werff and Steg, 2016) Others: (Ateş, 2020)
Norm-Activation (NAM) Model / Theory	This theory is about an exploration of the functions of anticipated pride and guilt in altruistic and pro-environmental behavior.	The NAM poses three types of antecedents to predict pro-social behavior: awareness of consequences, ascription of responsibility, and personal norm. Norm activation begins with an individual’s awareness of conceivably detrimental consequences and his or her ascription of responsibility for not acting pro-environmentally. The anticipated pride and guilt cause individuals to behave themselves in a manner that is in line with personal norms.	Main author: (Schwartz, 1977) Others: (Ateş, 2020; Klöckner, 2013a; Onwezen et al., 2013; Steg and Groot, 2010)
Diffusion of Innovations Theory (DOI)	Describes the process by which an innovation diffuses through a social system as a result of information being communicated through media and person-to-person channels.	The theory proposes that the process for adopting an innovation occurs in five stages: individuals become aware of an innovation (knowledge), form attitudes about it (persuasion), decide whether to adopt it (decision), implement the innovation (implementation), and then decide whether to continue using it (confirmation). The speed at which this process occurs is thought to be influenced by several factors, including specific beliefs and attitudes about the technology. The process involves profiling individual characteristics and motivations.	Main author: (Wolske et al., 2017)

Theory or model	Objective	Brief description	Authors
Theory of Reasoned Action (TRA)	Explain behavior as a function of intention	The TRA asserts that the most important determinant of a person's behavior is a person's behavioral intention (comprised of attitude and subjective norms associated with the behavior). In contrast to previous theories, it distinguishes between attitude toward an object and attitude toward a behavior/action with respect to that object.	Main author: (Fishbein and Ajzen, 1975) Others: (DeNicola et al., 2016; Fishbein and Ajzen, 2010)
Integrated Behavior Model (IBM)	A general theory of behavioral prediction that is assumed to be applicable to the understanding of any behavior	The IBM proposes that intentions (as the function of attitudes, subjective norms, and perceived self-efficacy) are the primary determinant of behavior. Four additional components directly affect behavior: knowledge, salience of the behavior, environmental constraints, and habit. The IBM has also been named the Integrative Model of Behavioral Prediction.	Main author: (Yzer, 2012) Others: (Montaño and Kasprzyk, 2008)

ANNEX II. Hybrid Constructs

Construct	Components	Brief description	Structure
<p>Integrated Framework (IF)</p> <p>Proponent: (Wolske et al., 2017)</p>	<p>VBN-TPB-DOI</p>	<p>The integrated framework illuminates the relationships among theories and highlights the ways in which each is important. VBN explains what predisposes individuals to take pro-environmental action. TPB helps explain why the individual chooses particular behaviors. DOI adds further insight by characterizing individuals who may be motivated to consider RPV. SC: social curiosity, IT: Interest in Talking to an installer</p>	
<p>Energy Literacy Model (ELM) using Exploratory Factor Analysis (EFA)</p> <p>Proponent: (Akitsu and Ishihara, 2018)</p>	<p>VBN-TPB</p>	<p>Approach based on the TPB and VBN theories. The goal is to examine the causal relationship between knowledge, beliefs, norms, attitudes, intentions, and behaviors within a single model. In particular, combine the “self-interest aspect” of the TPB with the “social motivation” of the VBN. It facilitates the interpretation of links between variables by introducing mediation variables and target predictors. An EFA can contribute to the formulation of a useful strategy for model specification in cases in which a substantive theoretical model has not been defined</p>	

Construct	Components	Brief description	Structure
<p>Robust Model (RB)</p> <p>Proponent: (Ateş, 2020)</p>	<p>TPB-VIP</p>	<p>Compared to TPB, the predictive ability of proposed model increased 2% after adding constructs of VIP (i.e., biospheric value, personal norm and ESI). However, adding constructs of TPB (i.e., attitude, subjective norm, PBC) increased 8% of total variance of the proposed model when compared to VIP. In general, even though TPB and VIP demonstrated a good efficiency in understanding pro-environmental behaviors, the predictive power of integrated proposed model was superior to the original TPB and VIP models.</p>	
<p>Model of determinants of WTP (MD)</p> <p>Proponent: (Hansla et al., 2008b)</p>	<p>VBN-TPB-WTP</p>	<p>A positive attitude towards green electricity (ATT) was related to environmental concern (EC), awareness-of-consequences (AC) beliefs, and altruistic or self-transcendence (ST) values. As expected, stated WTP for green electricity was furthermore related to partly the same determinants as ATT, but WTP was also negatively affected by electricity costs. Income did not have any effect on WTP contrary to the findings of previous research. An agent's WTP often serves as proxy for its measure of value (Yevdokimov et al., 2019).</p>	 <p>Fig. 1. Hypothesized model of determinants of willingness to pay (WTP) for green electricity. (VO = value orientation, AC = awareness-of-consequences beliefs, EC = environmental concern, ATT = attitude towards green electricity.)</p>

Construct	Components	Brief description	Structure
<p>Comprehensive Action Determination Model (CADM)</p> <p>Proponent: (Klöckner, 2013a)</p>	<p>TPB-NAM-VBN with a focus on habits</p>	<p>Intentions have strong influence on sporadic behaviors but weaken for behaviors that are repeated often. Frequent behaviors are best explained by the strength of habits – the automatic performance of behavioral patterns triggered by context cues. The model can serve as a general framework in identifying important proximal and distal predictors of varying kinds of environmentally relevant behavior. The key constructs are attitudes, personal norms, perceived behavioral control, and social norms, which together form the intention.</p> <p>All exogenous variables (ST, SE, AR, AC, ATT, PBC, SN) are specified to covariate. Awareness of consequences (AC); AR, ascription of responsibility (AR); Attitudes (ATT); Behavior (BEH); Habit (HAB); Intention (INT); New ecological paradigm (NEP); Perceived behavioural control (PBC); Personal norm (PN); Social norm (SN); Self-transcendence values (ST); Self-enhancement values (SE).</p>	
<p>Theory of Reasoned Action and Planned Behavior (TRAPB)</p> <p>Proponent: (Ajzen, 1985)</p>	<p>TPB-TRA</p>	<p>The theory of reasoned action and planned behavior asserts that behavioral intention is the most robust predictor of behavior, and this relationship is moderated by an individual's attitude, subjective norms, and perceived behavioral control (PBC) relating to that behavior</p>	

B APPENDIX TO CHAPTER 2

ANNEX I. Ngene Code Used for the Choice Cards

For the MNL

```
? U = b1[ASC] + b2*A[Price,5] + b3*B[Green,4] + b4*C[Local,3] +  
b5*D[Control,3]  
? A = price -> -0.016 (Heng)  
? B = green -> 0.02 RE meta (Grilli)  
? C = local -> 0.002 jobs (Heng)  
? D = control -> 0.17 independence (Claudy)
```

Design

```
;alts = grid, p2p, pv, SQ  
;rows = 15  
;eff = (mnl,wtp(ref1))  
;wtp = ref1(*b2)
```

;model:

```
U(grid) = b1[-1.86] +  
          b2[-0.016]*A[1,2,3,4,5] +  
          b3[0.02]*B[1,2,3,4] /
```

```
U(p2p) = b1 +  
         b2*A +  
         b3*B +  
         b4[0.002]*C[1,2,3] /
```

```
U(pv) = b1 +  
        b2*A +  
        b3*B +  
        b4*C +  
        b5[0.001]*D[1,2,3]
```

?eval =

```
C:\Users\BlockchainMaster\Documents\Ngene\Design_eval_MNL_2.xlsx
```

\$

For the Mixed Multinomial Logit (not implemented)

? U = b1[ASC] + b2*A[Price,5] + b3*B[Green,4] + b4*C[Local,3] +
b5*D[Control,3]
? + s2[ec,] + s3[ec,ok] + s4[ec,ok] +
s5[ec,]

? Manual p.106

? ASC -> Log-normal = Ln(tarif bleu, 0.1558) à -1.86

? A[price] -> Normal [-0.63296, -1.34608] (Goett)

? B[green] -> Normal [0.67112, 2.70272] (Goett)

? C[local] -> Normal [0.12392, 0.46481] (Goett)

? D[control] -> Normal [0.59763, 0.51999] (Goett)

? D-Error -> 0.0013 (Street & Burgess) ; 0.0042 (Gracia)

? Standard Errors:

? s2 -> 0.2037 (Scarpa, p.134) ; 0.47 (Navrud, p.12)

? s3 -> 0.0866 (Gracia, p.22) ; 0.004 (Komarek, p.7)

? s4 -> 0.5384 (Gracia, p.22)

? s5 -> 0.1393 (Scarpa, p.135) ; 0.08 (Longo, p.37)

Design

;alts = grid, p2p, pv, sq

;rows = 100

;eff = (ecpanel,d)

;rep = 100

;rdraws = halton(100)

;model:

U(grid) = b1[-1.86] +
b2[n,-0.6,-1.3]*A[1,2,3,4,5] +
b3[n,0.7,2.7]*B[1,2,3,4] +
s2[ec,0.2037]+s3[ec,0.0866] /

U(p2p) = b1 +
b2*A +
b3*B +
b4[n,0.1,0.5]*C[1,2,3] +
s2 + s3 + s4[ec,0.5384] /

U(pv) = b1 +
b2*A +
b3*B +
b4*C +
b5[n,0.6,0.5]*D[1,2,3] +
s2 + s3 + s4 + s5[ec,0.1393]

;eval =

C:\Users\BlockchainMaster\Documents\Ngene\Design_eval_RPL_1.xlsx

\$

ANNEX II. Household, Psychological and Demographic Variables and Attributes

<i>Variable</i>	<i>Description</i>	<i>Type</i>	<i>Values</i>
<i>PAY</i>	Respondent pays for electricity at home	Dichotomous (for screening)	1 = Yes (continue) ; 2 = No
<i>DECIDE</i>	Respondent decides on electricity supply	Dichotomous (for screening)	1 = Yes (continue) ; 2 = No
<i>TYPE[†]</i>	Household type	Nominal	House ; Apartment
<i>PROP[†]</i>	Household tenure (property)	Nominal	Owner or first time buyer ; Rent ; Shared
<i>OCCUP</i>	Number of occupants	Ordinal	1 ; 2 ; 3 ; 4 ; 5 and more
<i>BILL</i>	Electricity bill in €/month, all taxes included, as noted by respondent	Continuous	Between 4 to 300
<i>CONT[†]</i>	Type of electricity contract	Nominal	Conventional with supplier ; Green with supplier ; Partly self-produced ; Don't know ; Other
<i>AREA</i>	Household area	Ordinal	0 = < 35 m ² ; 1 = 36-50 m ² ; 2 = 51-60 m ² ; 3 = 61-70 m ² ; 4 = 71-80 m ² ; 5 = 81-90 m ² ; 6 = 91-100 m ² ; 7 = 101-120 m ² ; 8 = 121-150 m ² ; 9 = 151-200 m ² ; 10 = > 200 m ²
<i>HEAT</i>	Heating type	Dichotomous	1 = Electric ; 0 = Other
<i>WHEAT</i>	Water heating type	Dichotomous	1 = Electric ; 0 = Other
<i>INF_PRI</i>	Influence of price on decision	Ordinal	0 = Not at all ; 1 = Somewhat disagree ; 2 = Indifferent ; 3 = Somewhat agree ; 4 = Very much
<i>INF_ENV</i>	Influence of environmental concern on decision	Ordinal	0 = Not at all ; 1 = Somewhat disagree ; 2 = Indifferent ; 3 = Somewhat agree ; 4 = Very much
<i>INF_LOC</i>	Influence of local community on decision	Ordinal	0 = Not at all ; 1 = Somewhat disagree ; 2 = Indifferent ; 3 = Somewhat agree ; 4 = Very much
<i>INF_IND</i>	Influence of energy independence (autonomy) on decision	Ordinal	0 = Not at all ; 1 = Somewhat disagree ; 2 = Indifferent ; 3 = Somewhat agree ; 4 = Very much
<i>INF_BEL</i>	Influence of belonging to like-minded group on decision	Ordinal	0 = Not at all ; 1 = Somewhat disagree ; 2 = Indifferent ; 3 = Somewhat agree ; 4 = Very much
<i>AFFIN_PV</i>	Affinity for solar pv panels at home	Ordinal	0 = Undesirable ; 1 = Somewhat undesirable ; 2 = Indifferent ; 3 = Somewhat desirable ; 4 = Very desirable
<i>AFFIN_ST</i>	Affinity for energy storage system at home	Ordinal	0 = Undesirable ; 1 = Somewhat undesirable ; 2 = Indifferent ; 3 = Somewhat desirable ; 4 = Very desirable

<i>Variable</i>	<i>Description</i>	<i>Type</i>	<i>Values</i>
<i>ENV</i>	Self-identification as environmentalist	Ordinal	0 = Not at all ; 1 = Somewhat disagree ; 2 = Indifferent ; 3 = Somewhat agree ; 4 = Very much
<i>FAM[†]</i>	Familiarity with green electricity	Nominal	Familiar and interested ; Familiar and not interested ; Familiar but does not understand ; Not familiar
<i>OP_EXP</i>	Opinion : green electricity is expensive	Dichotomous	1 = Yes ; 2 = No
<i>OP_ENV</i>	Opinion : green electricity is good for the environment	Dichotomous	1 = Yes ; 2 = No
<i>OP_PER</i>	Opinion : green electricity has lower performance	Dichotomous	1 = Yes ; 2 = No
<i>OP_MKT</i>	Opinion : green electricity is a marketing ploy	Dichotomous	1 = Yes ; 2 = No
<i>OP_RICH</i>	Opinion : green electricity is only for the rich	Dichotomous	1 = Yes ; 2 = No
<i>OP_REL</i>	Opinion : green electricity is unreliable	Dichotomous	1 = Yes ; 2 = No
<i>K_NUC</i>	Knowledge : is possible to exclude nuclear when consuming electricity from the grid	Dichotomous	1 = True ; 0 = False
<i>K_SUP</i>	Knowledge : changing supplier changes the underlying energy mix	Dichotomous	1 = True ; 0 = False
<i>K_AUT</i>	Knowledge : it is legal to self-produce/consume	Dichotomous (with opt-out)	1 = Yes ; 0 = No ; 2 = Don't know
<i>KT_CEN</i>	Knowledge : selling self-produced electricity to a utility is legal	Dichotomous (with opt-out)	1 = Yes ; 0 = No ; 2 = Don't know
<i>KT_SYN</i>	Knowledge : selling self-produced electricity to a real estate agent (<i>syndic</i>) is legal	Dichotomous (with opt-out)	1 = Yes ; 0 = No ; 2 = Don't know
<i>KT_MUN</i>	Knowledge : selling self-produced electricity to a municipal government is legal	Dichotomous (with opt-out)	1 = Yes ; 0 = No ; 2 = Don't know
<i>KT_COO</i>	Knowledge : selling self-produced electricity to an association / cooperative is legal	Dichotomous (with opt-out)	1 = Yes ; 0 = No ; 2 = Don't know
<i>KT_NEI</i>	Knowledge : selling self-produced electricity to your neighbor is legal	Dichotomous (with opt-out)	1 = Yes ; 0 = No ; 2 = Don't know
<i>N_KNOW</i>	Familiarity / acquaintance with neighbors	Ordinal	0 = Not at all ; 1 = Only in passing ; 2 = Rather well

<i>Variable</i>	<i>Description</i>	<i>Type</i>	<i>Values</i>
<i>N_RAP</i>	Degree of affinity / empathy toward neighbors	Ordinal	0 = Dislike ; 1 = Avoids ; 2 = Indifferent ; 3 = Polite ; 4 = Close
<i>AGE</i>	Year of birth	Continuous	Age calculated as 2022 – year of birth
<i>GEN</i>	Gender	Dichotomous (with opt-out)	1 = Male ; 2 = Female ; 3 = Undisclosed
<i>EDU</i> [†]	Education [†]	Ordinal	General Education Certificate ; Professional training ; Bachelor's degree ; Higher education / short ; Higher education / long
<i>JOB</i> [‡]	Employment [‡]	Nominal	Agriculture ; Freelance ; Higher-level ; Middle-level ; Employee ; Blue collar ; Retired ; Unemployed
<i>INC</i>	Household income	Ordinal	0 = < 1000 €/m ; 1 = 1000 - 1800 €/m ; 2 = 1800 - 3000 €/m ; 3 = 3000 - 4000 €/m ; 4 = 4000 - 6000 €/m ; 5 = 6000 €/m and more

† These categories are taken from the French educational system : General Education Certificate = *Brevet des collèges* ; Professional training = *CAP, BEP ou équivalent* ; Bachelor's degree = *Baccalauréat ou équivalent* ; Higher education / short = *Diplôme supérieur court, bac+2* ; Higher education / long = *Diplôme supérieur long, >bac+2*.

‡ These categories are taken from the French occupation category system (*Professions et Catégories Socioprofessionnelles, PCS*).

ANNEX III. Descriptive Statistics

Variable	No.	Mean	s.d.	Median	Min	Max	Range	Skew	Kurtosis	St. Error
Electricity consumption										
PAY	503	1.992	0.089	2	1	2	1	-11.047	120.266	0.004
DECIDE	503	1.966	0.181	2	1	2	1	-5.144	24.513	0.008
TYPE [†]	503	1.312	0.464	1	1	2	1	0.808	-1.349	0.021
PROP [†]	503	2.596	0.526	3	1	3	2	-0.757	-0.667	0.023
OCCUP	503	2.604	1.229	2	1	5	4	0.328	-0.964	0.055
BILL	455	70.516	48.240	54	1	300	299	1.783	4.026	2.262
CONT [†]	503	2.942	0.475	3	1	5	4	-0.728	6.193	0.021
AREA	479	6.351	2.623	7	1	10	9	-0.389	-1.065	0.120
HEAT	503	1.260	0.439	1	1	2	1	1.088	-0.817	0.020
WHEAT	503	1.384	0.487	1	1	2	1	0.477	-1.776	0.022
Psychological										
INF_PRI	503	2.879	1.831	3	1	5	4	0.093	-1.850	0.082
INF_ENV	503	3.819	1.685	5	1	5	4	-0.853	-1.125	0.075
INF_LOC	503	3.517	1.456	4	1	5	4	-0.225	-1.630	0.065
INF_IND	503	3.441	1.425	4	1	5	4	-0.244	-1.460	0.064
INF_BEL	503	3.151	1.283	3	1	5	4	0.248	-1.336	0.057
AFFIN_PV	503	2.682	1.726	3	1	5	4	0.262	-1.673	0.077
AFFIN_ST	503	2.708	1.688	3	1	5	4	0.240	-1.613	0.075
ENV	503	3.584	1.851	5	1	5	4	-0.588	-1.602	0.083
FAM [†]	503	3.175	0.816	3	1	4	3	-0.593	-0.558	0.036
OP_EXP	503	1.652	0.477	2	1	2	1	-0.637	-1.598	0.021
OP_ENV	503	1.869	0.338	2	1	2	1	-2.178	2.749	0.015
OP_PER	503	1.072	0.258	1	1	2	1	3.314	9.001	0.012
OP_MKT	503	1.250	0.434	1	1	2	1	1.148	-0.683	0.019
OP_RICH	503	1.231	0.422	1	1	2	1	1.275	-0.375	0.019
OP_REL	503	1.173	0.379	1	1	2	1	1.724	0.975	0.017
K_NUC	503	1.781	0.659	2	1	3	2	0.266	-0.766	0.029

<i>Variable</i>	<i>No.</i>	<i>Mean</i>	<i>s.d.</i>	<i>Median</i>	<i>Min</i>	<i>Max</i>	<i>Range</i>	<i>Skew</i>	<i>Kurtosis</i>	<i>St. Error</i>
<i>K_SUP</i>	503	1.763	0.761	2	1	3	2	0.424	-1.171	0.034
<i>K_AUT</i>	503	2.177	0.577	2	1	3	2	-0.027	-0.261	0.026
<i>KT_CEN</i>	503	2.082	0.906	2	1	3	2	-0.160	-1.764	0.040
<i>KT_SYN</i>	503	2.135	0.943	3	1	3	2	-0.271	-1.824	0.042
<i>KT_MUN</i>	503	2.300	0.851	3	1	3	2	-0.613	-1.346	0.038
<i>KT_COO</i>	503	2.342	0.787	3	1	3	2	-0.682	-1.067	0.035
<i>KT_NEI</i>	503	2.221	0.917	3	1	3	2	-0.448	-1.664	0.041
<i>N_KNOW</i>	503	1.666	0.901	1	1	3	2	0.704	-1.400	0.040
<i>N_RAP</i>	503	1.708	1.342	1	1	5	4	1.810	1.703	0.060
<i>Demographic</i>										
<i>AGE</i>	503	1978.5	11.4	1980.0	1950	1999	49	-0.376	-0.723	0.507
<i>GEN</i>	503	1.730	0.479	2	1	3	2	-0.589	-0.603	0.021
<i>EDU*</i>	503	4.064	1.421	5	1	5	4	-1.367	0.371	0.063
<i>JOB*</i>	503	3.199	1.562	3	1	7	6	0.966	-0.036	0.070
<i>INC</i>	503	3.346	1.174	3	1	6	5	0.191	-0.704	0.052

Variables marked with an asterisk * are unordered categorical.

ANNEX IV. Complete list of Statistically Significant GLM Correlations

Dependent	Independent	Coef	p-value	0.05	0.01	0.001
Base scenario : Regular	BILL	0.00016464	0.04765685	*		
	INC : 4000 - 6000 €/m	-0.05220186	0.04342433	*		
	INF_LOC : Rather not	-0.03611806	0.04812267	*		
	N_RAP : Indifferent	-0.02207729	0.02449233	*		
	N_RAP : Avoids contact	-0.04666328	0.02126576	*		
	PROP : Owner	0.06334671	0.01262527	*		
	INF_LOC : Indifferent	-0.05011926	0.00276686	*	**	
	PROP : Tenant	0.06691006	0.0096466	*	**	
	INF_LOC : Rather yes	-0.05632815	0.00073008	*	**	***
	INF_LOC : Very much	-0.08662175	7.2137E-05	*	**	***
	INF_PRI : Very much	0.0621867	0.00066291	*	**	***
Base scenario : Green	BILL	0.00016464	0.04765685	*		
	INC : 4000 - 6000 €/m	-0.05220186	0.04342433	*		
	INF_LOC : Rather not	-0.03611806	0.04812267	*		
	N_RAP : Indifferent	-0.02207729	0.02449233	*		
	N_RAP : Avoids contact	-0.04666328	0.02126576	*		
	PROP : Owner	0.06334671	0.01262527	*		
	INF_LOC : Indifferent	-0.05011926	0.00276686	*	**	
	PROP : Tenant	0.06691006	0.0096466	*	**	
	INF_LOC : Rather yes	-0.05632815	0.00073008	*	**	***
	INF_LOC : Very much	-0.08662175	7.2137E-05	*	**	***
	INF_PRI : Very much	0.0621867	0.00066291	*	**	***
Premium	ENV : Rather yes	-0.00825672	0.02902273	*		
	INF_IND : Rather yes	0.01395909	0.021913	*		
	INF_LOC : Indifferent	0.01842442	0.01373865	*		
	KT_CEN : Yes	0.01001815	0.02204979	*		
	OP_ENV : Yes	0.01153124	0.01389721	*		
	INF_IND : Very much	0.02695783	0.00102652	*	**	
	INF_LOC : Rather yes	0.0231031	0.00193039	*	**	
	PROP : Owner	-0.03701563	0.00116876	*	**	
	INF_LOC4-Beaucoup	0.03802145	9.8053E-05	*	**	***
	INF_PRI : Rather yes	-0.02708718	0.00053565	*	**	***
	INF_PRI : Very much	-0.04722233	1.3026E-08	*	**	***
PROP : Tenant	-0.03829312	0.00096741	*	**	***	
Autonomy	INF_IND : Rather yes	0.03380625	0.01030481	*		
	OP_ENV : Yes	0.01992837	0.04881519	*		
	OP_RICH : Yes	-0.01886697	0.01198313	*		
	PROP : Owner	-0.06272013	0.01068203	*		
	PROP : Tenant	-0.07190569	0.00406994	*	**	
	INF_IND : Very much	0.08999459	5.3023E-07	*	**	***
	INF_PRI : Rather yes	-0.06344591	0.00017955	*	**	***
INF_PRI : Very much	-0.07979302	7.2137E-06	*	**	***	
Green	AFFIN_PV : Not desirable	-0.07272764	0.03682712	*		
	BILL	-0.00029311	0.02285836	*		
	ENV : Indifferent	-0.05936	0.03640003	*		
	INC : 1000 - 1800 €/m	0.08006388	0.03204763	*		
	INC2 : 1800 - 3000 €/m	0.07686743	0.0388611	*		
	INC3 : 3000 - 4000 €/m	0.07614217	0.04931962	*		
	INC4 : 4000 - 6000 €/m	0.09133582	0.02254702	*		
	INC5 : 6000 €/m and above	0.09645681	0.04107725	*		
	INF_IND : Very much	0.06899067	0.01476791	*		
	INF_LOC : Rather not	0.0556777	0.04902931	*		
	INF_LOC : Indifferent	0.06430992	0.0129151	*		
	INF_PRI : Rather yes	-0.05556685	0.03887977	*		
	KT_CEN : Yes	0.03197299	0.03454963	*		
N_RAP : Avoids contact	0.06184553	0.04834277	*			

Dependent	Independent	Coef	p-value	0.05	0.01	0.001
	OP_ENV : Yes	0.04140104	0.01070245	*		
	INF_LOC : Rather yes	0.07196765	0.00517178	*	**	
	INF_LOC : Very much	0.1096657	0.00111645	*	**	
	PROP : Tenant	-0.12436536	0.00192773	*	**	
	PROP : Owner	-0.12205801	0.00195562	*	**	
	INF_PRI : Very much	-0.13729182	1.4882E-06	*	**	***
Grid	EDU : Higher degree (long)	0.03095392	0.0440814	*		
	ENV : Indifferent	-0.05123972	0.04542741	*		
	INF_BEL : Very much	-0.05678171	0.02782597	*		
	INF_ENV : Rather yes	0.09340533	0.01358939	*		
	INF_PRI : Rather not	0.05747318	0.02645974	*		
	N_RAP : Indifferent	0.03171346	0.02082547	*		
	INF_ENV : Very much	0.11109467	0.00644311	*	**	
	INF_PRI : Rather yes	0.07596408	0.00184721	*	**	
Grid : Premium	INC : 4000 - 6000 €/m	0.00628927	0.03096467	*		
	N_RAP : Indifferent	0.00235713	0.03307092	*		
	INF_PRI : Rather not	0.00538714	0.00999358	*	**	
	INF_PRI : Rather yes	0.00518058	0.00832627	*	**	
Grid : Green	EDU : Higher degree (long)	0.02905925	0.0412939	*		
	ENV : Indifferent	-0.04800016	0.04302844	*		
	INF_BEL : Very much	-0.0528608	0.02703704	*		
	INF_ENV : Rather yes	0.08939475	0.01078955	*		
	INF_PRI : Rather not	0.05208604	0.02985281	*		
	N_RAP : Indifferent	0.02935633	0.02089401	*		
	INF_ENV : Very much	0.1049214	0.0054793	*	**	
	INF_PRI : Rather yes	0.07078351	0.00173385	*	**	
Local	INF_IND : Rather yes	0.03881402	0.04133348	*		
	INF_IND : Very much	0.05704561	0.02559791	*		
	OP_ENV : Yes	0.02894377	0.04789523	*		
	INF_LOC : Indifferent	0.06184145	0.00820149	*	**	
	INF_PRI : Rather yes	-0.06857733	0.00491307	*	**	
	PROP : Tenant	-0.10347754	0.00425925	*	**	
	PROP : Owner	-0.09363996	0.00843177	*	**	
	INF_LOC : Rather yes	0.08112974	0.00050819	*	**	***
	INF_LOC : Very much	0.13796569	6.682E-06	*	**	***
	INF_PRI : Very much	-0.13223117	3.1024E-07	*	**	***
P2P	CONT : Supplier, 100% green	0.15435864	0.03669508	*		
	CONT : Supplier, regular	0.14452506	0.04052755	*		
	EDU : Higher degree (long)	0.05973204	0.03234586	*		
	INF_BEL : Rather yes	0.07961335	0.01150415	*		
	INF_LOC : Rather yes	0.09892268	0.01879768	*		
	K_NUC : Does not know	-0.0374956	0.04446198	*		
	N_RAP : Indifferent	0.05369791	0.03095718	*		
	N_RAP : Close	0.05815203	0.0391226	*		
	OP_EXP : Yes	0.03440854	0.03642813	*		
	OP_RICH : Yes	0.03909484	0.04672755	*		
	INF_PRI : Very much	-0.12699185	0.00596862	*	**	
	N_RAP : Avoids contact	0.13603686	0.00819706	*	**	
	INF_LOC : Very much	0.21700656	8.8022E-05	*	**	***
P2P : Premium	INF_BEL : Very much	0.00879837	0.02034967	*		
	INF_LOC : Rather yes	0.0072907	0.03226808	*		
	N_RAP : Avoids contact	0.01068433	0.01027538	*		
	INF_BEL : Rather yes	0.00662538	0.00938712	*	**	
	INF_LOC : Very much	0.01856714	3.4739E-05	*	**	***
	INF_PRI : Very much	-0.01377094	0.00024517	*	**	***
P2P : Green	CONT : Supplier, 100 % green	0.08408018	0.0417776	*		
	EDU : Higher degree (long)	0.03499957	0.02495367	*		
	INF_LOC : Rather yes	0.05110599	0.02982618	*		

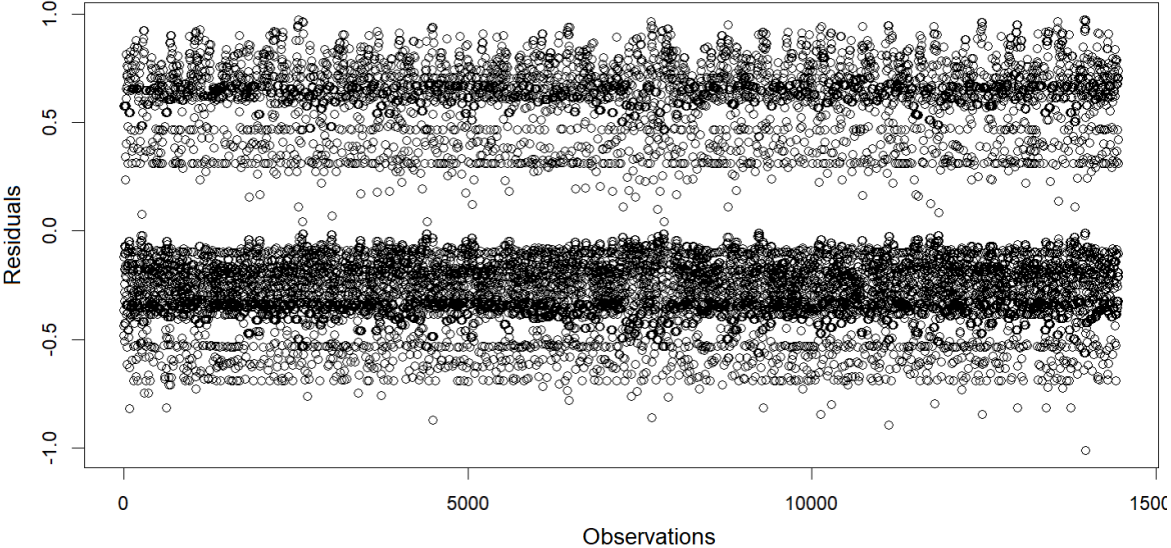
Dependent	Independent	Coef	p-value	0.05	0.01	0.001
	K_NUC : Does not know	-0.02276554	0.02916421	*		
	N_RAP : Indifferent	0.0300589	0.03075347	*		
	N_RAP : Close	0.03166651	0.04447779	*		
	OP_EXP : Yes	0.01870966	0.04184348	*		
	INF_BEL : Rather yes	0.0463011	0.00859979	*	**	
	INF_PRI : Very much	-0.07522598	0.00360163	*	**	
	N_RAP : Avoids contact	0.07854371	0.00634663	*	**	
	INF_LOC : Very much	0.11253426	0.00026931	*	**	***
P2P : Local	CONT : Supplier, 100% green	0.05953592	0.03060661	*		
	CONT : Supplier, regular	0.05863452	0.02580836	*		
	EDU : Higher degree (long)	0.02059685	0.04752158	*		
	INF_BEL : Rather yes	0.02668688	0.02287079	*		
	INF_PRI : Very much	-0.03799494	0.02693822	*		
	N_RAP : Indifferent	0.02005922	0.03052541	*		
	N_RAP : Avoids contact	0.04680882	0.01454378	*		
	N_RAP : Close	0.02212019	0.03522265	*		
	OP_EXP : Yes	0.01350358	0.02760582	*		
	OP_RICH : Yes	0.01666909	0.02298069	*		
	INF_LOC : Rather yes	0.04052599	0.00984783	*	**	
	INF_LOC : Very much	0.08590516	3.1791E-05	*	**	***
Self (PV)	CONT : Partial self-production	-0.45168525	0.0448672	*		
	INF_LOC : Rather yes	0.14543534	0.04242689	*		
	OP_ENV : Yes	0.09302608	0.03965471	*		
	OP_RICH : Yes	-0.07907403	0.01838807	*		
	PROP : Tenant	-0.28733917	0.01011604	*		
	PROP : Owner	-0.2636517	0.0162774	*		
	INF_IND : Very much	0.34419703	1.6061E-05	*	**	***
	INF_PRI : Rather yes	-0.2871894	0.00014869	*	**	***
INF_PRI : Very much	-0.36796994	3.7322E-06	*	**	***	
Self (PV) : Premium	CONT : Partial self-production	-0.04018051	0.0489696	*		
	INF_LOC : Rather yes	0.01353975	0.03716333	*		
	OP_ENV : Yes	0.00876029	0.03260664	*		
	OP_RICH : Yes	-0.00735316	0.01559307	*		
	PROP : Tenant	-0.02592853	0.01045253	*		
	PROP : Owner	-0.02414444	0.01521447	*		
	INF_IND : Very much	0.03122454	1.5806E-05	*	**	***
INF_PRI : Rather yes	-0.02771432	5.5141E-05	*	**	***	
INF_PRI : Very much	-0.03419663	2.1491E-06	*	**	***	
Self (PV) : Autonomy	INF_IND : Rather yes	0.03380625	0.01030481	*		
	OP_ENV : Yes	0.01992837	0.04881519	*		
	OP_RICH : Yes	-0.01886697	0.01198313	*		
	PROP : Owner	-0.06272013	0.01068203	*		
	PROP : Tenant	-0.07190569	0.00406994	*	**	
	INF_IND : Very much	0.08999459	5.3023E-07	*	**	***
	INF_PRI : Rather yes	-0.06344591	0.00017955	*	**	***
INF_PRI : Very much	-0.07979302	7.2137E-06	*	**	***	
Self (PV) : Green	CONT : Partial self-production	-0.20464558	0.03724967	*		
	INF_LOC : Rather yes	0.06587433	0.03514039	*		
	INF_LOC : Very much	0.08153219	0.04553816	*		
	OP_ENV : Yes	0.04110288	0.03717788	*		
	OP_RICH : Yes	-0.03394127	0.02031849	*		
	PROP : Tenant	-0.12282197	0.01170965	*		
	PROP : Owner	-0.11573935	0.01561079	*		
	INF_IND : Very much	0.13961755	5.8441E-05	*	**	***
	INF_PRI : Rather yes	-0.12437833	0.00016533	*	**	***
	INF_PRI : Very much	-0.15974405	4.1341E-06	*	**	***
Self (PV) : Local	INF_LOC : Rather yes	0.04060375	0.02898949	*		
	INF_LOC : Very much	0.05206053	0.03182211	*		

Dependent	Independent	Coef	p-value	0.05	0.01	0.001
	OP_ENV : Yes	0.02323454	0.04748842	*		
	OP_RICH : Yes	-0.01891262	0.02956449	*		
	PROP : Tenant	-0.06668297	0.02123214	*		
	PROP : Owner	-0.06104779	0.03177992	*		
	INF_IND : Very much	0.08336035	5.4431E-05	*	**	***
	INF_PRI : Rather yes	-0.07165083	0.0002599	*	**	***
	INF_PRI : Very much	-0.09423624	4.878E-06	*	**	***

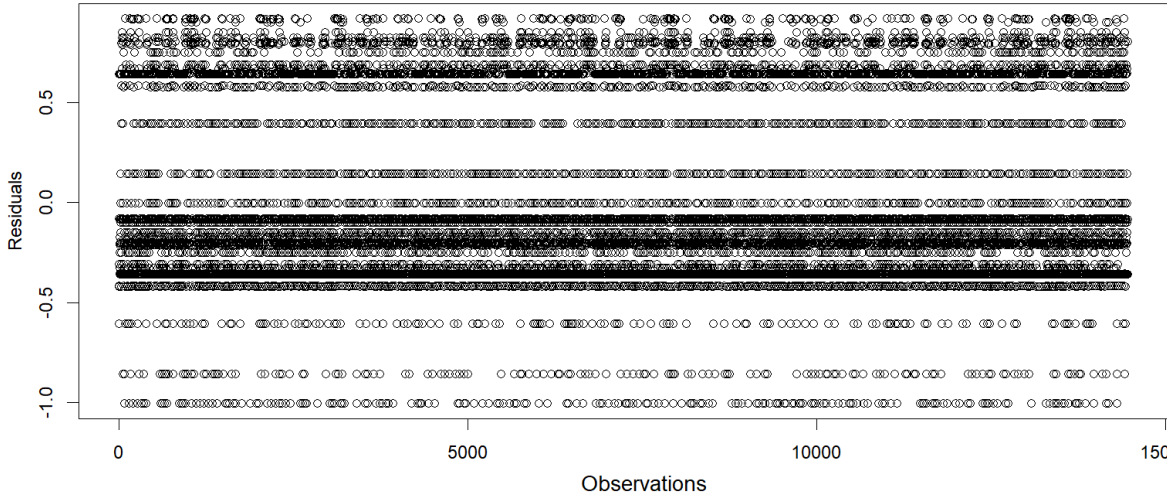
ANNEX V. Correlation Matrix (Heat map)

	DECIDE	OCCUP	BILL_CAP	AREA	HEAT	WHEAT	INF_PRI	INF_ENV	INF_LOC	INF_IND	INF_BEL	AFFIN_PV	AFFIN_ST	ENV	OP_EXP	OP_ENV	OP_PER	OP_MKT	OP_RICH	OP_REL	K_NUC	K_SUP	K_AUT	KT_CEN	KT_SYN	KT_MUN	KT_COO	KT_NEI	N_KNOW	N_RAP	AGE	GEN	INC		
DECIDE	100.00 %	-0.10%	5.60%	-7.06%	2.94%	3.89%	-1.98%	8.08%	-1.88%	-3.80%	-1.52%	2.60%	5.66%	-3.68%	5.32%	9.73%	-7.02%	3.26%	-1.69%	3.97%	-5.89%	-7.39%	-2.51%	-0.01%	1.31%	2.90%	3.77%	6.94%	2.11%	5.49%	3.55%	-3.46%	7.94%		
OCCUP	-0.10%	100.00 %	29.74%	10.99%	-2.34%	-7.34%	2.54%	-5.27%	-6.59%	5.42%	-4.81%	12.95%	5.21%	11.27%	5.28%	-2.81%	-7.32%	10.90%	-9.34%	-6.26%	3.04%	-3.01%	14.93%	-4.34%	-0.38%	-0.16%	2.34%	-8.61%	6.44%	-0.97%	9.20%	-9.61%	41.36%		
BILL	5.60%	29.74%	100.00 %	21.89%	41.87%	36.49%	3.96%	-7.99%	-2.84%	12.67%	-2.76%	5.45%	6.12%	5.70%	-0.42%	1.95%	-0.25%	-3.44%	0.26%	-5.22%	-0.74%	-0.12%	14.33%	-8.62%	-0.20%	-1.35%	2.46%	-3.04%	8.27%	4.85%	-9.47%	1.81%	22.75%		
AREA	-7.06%	10.99%	21.89%	100.00 %	-4.19%	-5.02%	-3.05%	1.78%	0.46%	-3.24%	-3.65%	5.71%	2.26%	4.75%	-9.49%	6.79%	2.53%	7.67%	10.42%	-1.60%	-3.88%	3.31%	-1.83%	-7.27%	-7.33%	-4.80%	-2.99%	12.24%	16.51%	-0.34%	-3.06%	26.03%			
HEAT	2.94%	-2.34%	41.87%	-4.19%	100.00 %	64.99%	3.04%	-5.91%	-8.81%	-0.07%	-6.62%	-0.34%	-0.21%	-3.92%	4.16%	1.95%	-3.85%	-0.38%	2.69%	-2.99%	1.12%	5.87%	7.26%	-4.56%	5.49%	4.54%	0.71%	4.56%	-1.79%	4.62%	8.07%	-0.27%	0.22%		
WHEAT	3.89%	-7.34%	36.49%	-5.02%	64.99%	100.00 %	-0.18%	-4.34%	-1.88%	12.94%	5.11%	5.33%	10.82%	-3.22%	1.87%	4.61%	-2.16%	-2.58%	7.25%	-7.69%	3.93%	6.51%	3.60%	-0.52%	-1.30%	-2.87%	-0.47%	0.41%	-3.57%	2.39%	7.00%	3.52%	-3.54%		
INF_PRI	-1.98%	2.54%	3.96%	-3.05%	3.04%	-0.18%	100.00 %																												
INF_ENV	8.08%	-5.27%	-7.99%	1.78%	-5.91%	-4.34%	33.55%	100.00 %																											
INF_LOC	-1.88%	-6.59%	-2.84%	0.46%	-8.81%	-1.88%	32.76%	42.01%	100.00 %																										
INF_IND	-3.80%	5.42%	12.67%	-3.24%	-0.07%	12.94%	25.31%	23.12%	34.42%	100.00 %																									
INF_BEL	-1.52%	-4.81%	-2.76%	-3.65%	-6.62%	5.11%	36.75%	28.90%	47.86%	100.00 %																									
AFFIN_PV	2.60%	12.95%	5.45%	-2.34%	-0.34%	5.33%	-9.61%	16.39%	42.71%	22.36%	100.00 %																								
AFFIN_ST	5.66%	5.21%	6.12%	5.71%	-0.21%	10.82%	-4.64%	18.03%	51.94%	25.03%	62.58%	100.00 %																							
ENV	-3.68%	11.27%	5.70%	2.26%	-3.92%	-3.22%	14.32%	30.68%	17.26%	13.55%	24.38%	14.51%	100.00 %																						
OP_EXP	5.32%	5.28%	-0.42%	4.75%	4.16%	1.87%	10.80%	-4.51%	-2.45%	-2.23%	-5.62%	3.96%	2.68%	9.50%	100.00 %																				
OP_ENV	9.73%	-2.81%	1.95%	-9.49%	1.95%	4.61%	-7.72%	27.69%	7.28%	12.92%	17.61%	17.45%	6.86%	10.46%	6.17%	100.00 %																			
OP_PER	-7.02%	-7.32%	-0.25%	6.79%	-3.85%	-2.16%	2.52%	12.97%	-5.61%	-6.31%	-9.15%	11.96%	-6.92%	8.76%	3.50%	36.12%	100.00 %																		
OP_MKT	3.26%	10.90%	-3.44%	2.53%	-0.38%	-2.58%	3.41%	14.97%	-3.81%	-6.04%	11.43%	11.34%	-0.92%	6.33%	1.21%	17.26%	100.00 %																		
OP_RICH	-1.69%	-9.34%	0.26%	7.67%	2.69%	7.25%	11.97%	-3.70%	-2.52%	0.07%	-3.69%	2.70%	7.02%	6.35%	10.43%	3.87%	-6.58%	-6.26%	100.00 %																
OP_REL	3.97%	-6.26%	-5.22%	10.42%	-2.99%	-7.69%	-5.72%	-1.33%	-0.18%	-3.38%	-4.49%	10.01%	-8.26%	8.65%	-1.01%	15.69%	17.79%	5.91%	-5.52%	100.00 %															
K_NUC	-5.89%	3.04%	-0.74%	-1.60%	1.12%	3.93%	5.37%	-0.44%	4.13%	3.23%	7.61%	3.16%	3.87%	-5.58%	3.42%	8.40%	17.64%	-7.75%	2.66%	18.88%	100.00 %														
K_SUP	-7.39%	-3.01%	-0.12%	-3.88%	5.87%	6.51%	5.57%	7.40%	0.26%	-2.75%	4.07%	0.28%	-0.40%	21.71%	-0.06%	9.02%	11.06%	-2.57%	0.60%	14.57%	24.00%	100.00 %													
K_AUT	-2.51%	14.93%	14.33%	3.31%	7.26%	3.60%	0.19%	6.92%	2.06%	-4.42%	3.57%	0.92%	-6.83%	-0.06%	-0.16%	12.26%	-7.35%	-0.72%	2.08%	-8.62%	9.22%	9.24%	100.00 %												
KT_CEN	-0.01%	-4.34%	-8.62%	-1.83%	-4.56%	-0.52%	4.90%	-4.07%	0.75%	-1.33%	-2.14%	3.78%	-0.76%	3.91%	0.84%	2.88%	-7.57%	8.19%	2.16%	3.22%	10.84%	3.01%	24.46%	100.00 %											
KT_SYN	1.31%	-0.38%	-0.20%	-7.27%	5.49%	-1.30%	-2.03%	4.57%	2.81%	4.34%	2.54%	5.93%	4.81%	-2.31%	-6.80%	3.02%	-5.37%	2.80%	0.47%	-5.01%	16.90%	8.38%	25.20%	50.38%	100.00 %										
KT_MUN	2.90%	-0.16%	-1.35%	-7.33%	4.54%	-2.87%	4.40%	-0.99%	-2.04%	-0.77%	-4.87%	4.68%	1.32%	-0.29%	0.86%	5.89%	-7.45%	4.33%	3.03%	-0.32%	9.62%	5.01%	27.35%	45.96%	67.42%	100.00 %									
KT_COO	3.77%	2.34%	2.46%	-4.80%	0.71%	-0.47%	3.34%	-3.47%	-4.39%	4.09%	-2.27%	10.85%	12.15%	-1.06%	1.88%	1.03%	-7.87%	7.88%	2.76%	-0.53%	9.53%	-0.64%	21.47%	37.40%	61.37%	70.53%	100.00 %								
KT_NEI	6.94%	-8.61%	-3.04%	-2.99%	4.56%	0.41%	1.07%	-2.87%	2.49%	2.89%	0.88%	4.90%	4.67%	-4.57%	-0.97%	6.93%	10.13%	4.01%	2.93%	-4.55%	7.31%	4.30%	27.10%	42.12%	59.92%	57.89%	58.87%	100.00 %							
N_KNOW	2.11%	6.44%	8.27%	12.24%	-1.79%	-3.57%	10.39%	7.16%	9.08%	0.80%	6.25%	1.60%	0.12%	3.69%	-6.89%	7.15%	-4.40%	-2.66%	-3.58%	0.26%	-7.47%	3.67%	0.13%	-7.03%	-2.67%	-9.28%	-5.90%	-3.48%	100.00 %						
N_RAP	5.49%	-0.97%	4.85%	16.51%	4.62%	2.39%	-3.53%	8.03%	8.23%	-3.03%	9.54%	8.53%	1.96%	-6.04%	-8.64%	8.31%	-4.38%	1.90%	-4.93%	2.38%	-0.60%	4.97%	1.47%	-1.28%	5.65%	-0.76%	5.27%	1.96%	40.14%	100.00 %					
AGE	3.55%	9.20%	-9.47%	-0.34%	8.07%	7.00%	5.56%	13.49%	-4.99%	-0.49%	15.01%	19.95%	16.03%	20.78%	8.39%	3.18%	-3.72%	10.57%	7.64%	-4.20%	12.33%	-0.18%	9.06%	9.10%	11.54%	11.31%	10.60%	9.02%	25.41%	-3.15%	100.00 %				
GEN	-3.46%	-9.61%	1.81%	-3.06%	-0.27%	3.52%	11.98%	-2.06%	-0.67%	-2.25%	-0.06%	-3.80%	1.81%	-2.48%	4.88%	4.80%	12.98%	-2.43%	4.82%	18.12%	11.86%	10.91%	3.96%	10.94%	3.59%	6.80%	3.32%	2.80%	-5.83%	-7.05%	7.33%	100.00 %			
INC	7.94%	41.36%	22.75%	26.03%	0.22%	-3.54%	-2.10%	7.40%	-5.72%	-3.50%	-8.59%	-4.23%	11.52%	8.51%	-2.82%	-0.43%	1.67%	-2.00%	16.64%	12.81%	-8.48%	-4.87%	19.05%	14.62%	-2.63%	-2.77%	1.05%	-9.20%	12.91%	7.13%	0.32%	18.31%	100.00 %		

ANNEX VI. Residual plot for the conditional logit regression



(a) Residual plot, money premium



(b) Residual plot, percent premium

ANNEX VII. Questionnaire Used for the Survey (English translation)

Study on residential electricity consumption

Thank you for agreeing to participate in our survey. This study is conducted by the Laboratory of Applied Economics of Grenoble (GAEL) of the University of Grenoble Alpes (UGA), as part of a public research program. It focuses on consumer preferences regarding the way to obtain electricity.

The duration of the questionnaire is approximately 30 minutes. You can take as long as you want to answer the questions. If you have a recent electricity bill with you, this may help you answer more accurately. Please stay focused for the duration of the study and complete the questionnaire in one go.

People who have answered the entire questionnaire carefully will receive a bonus of €10. This bonus will be paid in the month following your participation. This amount will be paid to you from the Lydia payment application, via a GAEL service provider. The payment procedure is very simple: at the end of the questionnaire, you must give us your mobile number to receive your bonus.

Do you have 30 minutes in front of you? No one will bother you? Warning ! It is not possible to go back on a question that you have already answered.

So here we go, click on “next”

Text1

General Data Protection Regulation

By checking this box, I certify that I have read, understood and accepted the terms of the information leaflet for this study.

Exit1

{ If Text1 box is not checked }

** You cannot proceed without agreeing to the terms of the survey.*

Please correct your answer or leave the questionnaire

Text2

Oath of honor

I undertake to answer honestly and sincerely to all the questions of the study.

Your answers could be used to inform the choices of public decision-makers.

Exit2

{ If Text2 box is not checked }

** You cannot proceed without agreeing to the terms of the survey.*

Please correct your answer or leave the questionnaire

Text3

Part 1

Electricity Consumption

Q1 Do you pay for or participate in the payment of electricity bills in your home?

- Yes
- No

Q2 If you had to change electricity supplier for your home, would you participate in the choice of the new supplier?

- Yes
- No

Exit3 { If neither Q1 nor Q2 apply }

** We are sorry but you cannot participate in this study.*

** You may be asked for other studies carried out by our laboratory in the future.*

Q3 What type of accommodation do you live in?

- A detached house
- An apartment in a collective building

Q4 Are you:

- Owner or first-time buyer
- Tenant
- Roommate

Q5 Including yourself, how many people live in your home?

- 1
- 2
- 3
- 4
- 5 and more

Q6 Do you know the amount of your monthly electricity bill (in €/month including VAT)?

- No
- Yes _____

Q7 What type of electricity do you buy for your home?

- Conventional offer with a supplier
- 100% green offer from a supplier
- You produce part of the electricity you consume and you buy the rest from a supplier
- You do not know
- Other :

Q8 What is the area of your home (in m2)?

- <= 35 m2
- 36-50 m2
- 51-60 m2
- 61-70 m2
- 71-80 m2
- 81-90 m2
- 91-100 m2
- 101-120 m2
- 121-150 m2
- 151-200 m2
- > 200 m2

Q9 Is the main heating in the home electric?

- Yes
- No

Q10 Is the water heater electric? *

- Yes
- No

Text4

Part 2

Consumption Preferences

Text5 **Electricity Self-consumption**

Electricity plays an essential role in our societies. Electricity gives us light, it heats our homes, our food, the water we use for our toilets. It allows us to work but also to relax via the various electrical equipment that we use on a daily basis. In France, grid electricity is produced with nuclear (74%), renewable or “green” technologies (18%) and fossil fuels (8%) (Source: RTE 2017-2021).

There are different ways to generate electricity. Even if we do not perceive it at the time of its consumption, the way in which we produce electricity has an impact on our societies and on the environment. This study distinguishes:



“Green” electricity. It is produced from renewable sources: hydraulic, wind, solar or biomass (such as wood or biomethane). It is the technology used that determines whether the electricity is green or not.



“Local” electricity. This is electricity produced near its place of consumption with any technology. In this study, we consider as local the electricity produced in the same region as

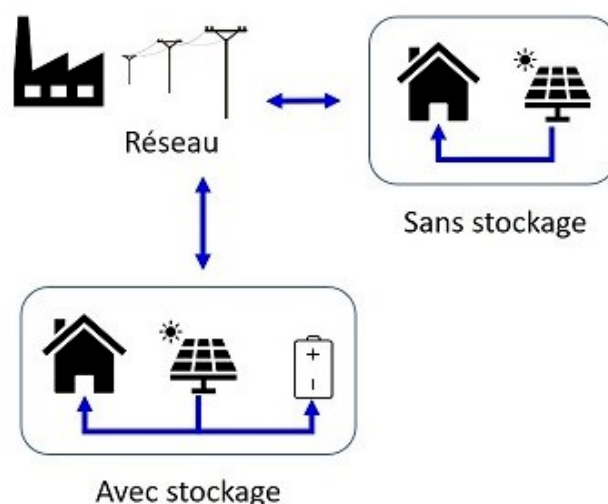
the place of consumption. It is the location of production that determines whether an electricity is qualified as local or not.



Electrical self-sufficiency (autonomy) does not depend on technology or location, but on having produced one's own electricity. In practice, autonomy is all the more important as we avoid consuming electricity from the grid. For this, it is necessary to produce its own electricity, store it if necessary, and shift its consumption if necessary.

Text6 **Individual Self-consumption**

Small-scale means of production, such as solar panels, make it possible to produce the electricity consumed oneself; we then speak of individual self-consumption. The electricity thus produced will always be local and can also be green depending on the technology used. For some, becoming less dependent on the electricity grid is also an important motivation to produce their own electricity.



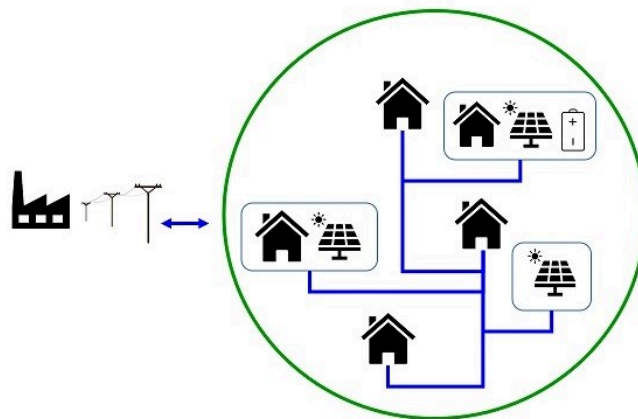
Text7 **Self-consumption Communities**

If several entities producing electricity (households, communities, farmers, small businesses, etc.) join forces to exchange electricity, we then speak of a self-consumption community. Some will produce more than they consume and some will consume more than they produce.

Like a condominium, a self-consumption community is a recognized legal entity. It will be able to contract with an external supplier to sell the surplus when the community's production is greater than the need or to buy electricity in the opposite case. Costs and revenues are shared among community members. Note that in this situation the members of the community no longer have an individual contract with an external supplier.

The interest of a self-consumption community is to jointly produce electricity for the members of the community. It is not necessary to produce electricity to participate in a self-consumption community. It is often possible to participate as an investor or even as a simple consumer.

As in the previous case, the electricity thus produced will always be local and can also be green depending on the technology used. Autonomy vis-à-vis the national electricity grid is also a possible motivation for joining a self-consumption community: part of the electricity that we consume is produced by the members of the community.



Text8 **Suppose you are in the following situation**

Suppose you currently have a traditional supply contract with a supplier. Given the current electricity production methods in France, the share of electricity from renewable sources does not exceed 25%, while the share of local electricity and the share of autonomy in your contract is 0%.

You are responsible for buying electricity for your home and you must decide how to supply electricity for the next few years.

After carrying out a study, you have identified three possible choices:

- You supply 100% from your current supplier or from another supplier on the market.
- Have an individual production system installed (e.g. solar panels) to produce part of your electricity and thus be in a situation of individual self-consumption.
- Join a self-consumption community near you.

Individual self-consumption and the self-consumption community make it possible to reduce your dependence on the national grid, but your home will in any case remain connected to the grid under a contract with a supplier to ensure supply at all times or to sell surplus production.

These three modes of supply are equally reliable in relation to each other and there are no additional costs to be paid to terminate the contract, change supplier or have new equipment installed.

Text9

Last points

- Several electrical supply choice scenarios will be presented to you.
- Each scenario is made up of three offers that differ according to four characteristics:



The additional cost to be paid (compared to your current bill). If you produce your own electricity, the investment for the means of production is taken into account in the additional cost.



The share of green electricity in your supply. It can vary between 25% and 100%.



The local electricity share of your supply. It can vary between 0% and 50%.



The level of autonomy of your supply. It can vary between 0% and 50%.

- The cost is expressed relative to your current monthly bill. For example, for an average household in France consuming 435 kWh and paying €68 per month, an increase of 5% would represent an additional cost of €3.4, while an increase of 20% would correspond to an additional cost of €13.6 . Over one year, this increase would correspond to €40.8 and €163.2 respectively.
- A total of ten scenarios will be successively presented to you, i.e. ten choices. Each scenario is unique and independent of the others.
- For each scenario, you will have to choose the offer you prefer without taking into account the previous choices. The quality of the electricity you will receive is considered to be identical regardless of the mode of supply chosen.
- Make your choice sincerely, according to your preferences. There are no right or wrong answers.
- Keep in mind that in this kind of survey respondents tend to overestimate what they are really willing to pay.




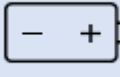

- Also consider that the money you would spend choosing one option would no longer be available for other expenses.

Text10

Now the choice is yours!

Keep in mind that according to your previous answers your monthly consumption is estimated at {insert} kWh and your bill at {insert} €




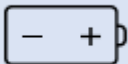

Scenario 1

Offer	Offer A	Offer B	CURRENT
 Supply mode	Supplier (national grid)	Self-consumption community (P2P)	Supplier (national grid)
 Green	50 %	50 %	< 25 %
 Local	0 %	50 %	0 %
 Autonomy	0 %	0 %	0 %
 Additional Cost <small>(w.r.t. current bill)</small>	+0 % {insert}	+15 % {insert}	+0 % {insert}

Your choice:

- A
- B
- Current




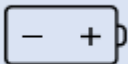

Scenario 2

Offer	Offer A	Offer B	CURRENT
 Supply mode	Self-consumption community (P2P)	Supplier (national grid)	Supplier (national grid)
 Green	75 %	75 %	< 25 %
 Local	25 %	0 %	0 %
 Autonomy	0 %	0 %	0 %
 Additional Cost <small>(w.r.t. current bill)</small>	+10 % { insert }	+5 % { insert }	+0 % { insert }

Your choice:

- A
- B
- Current




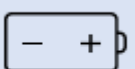

Scenario 3

Offer	Offer A	Offer B	CURRENT
 Supply mode	Supplier (national grid)	Individual self-consumption	Supplier (national grid)
 Green	25 %	25 %	< 25 %
 Local	0 %	25 %	0 %
 Autonomy	0 %	25 %	0 %
 Additional Cost <small>(w.r.t. current bill)</small>	+0 % { insert }	+5 % { insert }	+0 % { insert }

Your choice:

- A
- B
- Current




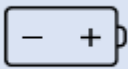

Scenario 4

Offer	Offer A	Offer B	CURRENT
 Supply mode	Individual self-consumption	Supplier (national grid)	Supplier (national grid)
 Green	75 %	50 %	< 25 %
 Local	50 %	0 %	0 %
 Autonomy	50 %	0 %	0 %
 Additional Cost <small>(w.r.t. current bill)</small>	+15 % { insert }	+5 % { insert }	+0 % { insert }

Your choice:

- A
- B
- Current




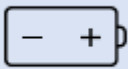

Scenario 5

Offer	Offer A	Offer B	CURRENT
 Supply mode	Supplier (national grid)	Individual self-consumption	Supplier (national grid)
 Green	75 %	75 %	< 25 %
 Local	0 %	50 %	0 %
 Autonomy	0 %	50 %	0 %
 Additional Cost <small>(w.r.t. current bill)</small>	+10 % { insert }	+20 % { insert }	+0 % { insert }

Your choice:

- A
- B
- Current




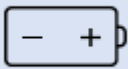

Scenario 6

Offer	Offer A	Offer B	CURRENT
 Supply mode	Individual self-consumption	Self-consumption Community	Supplier (national grid)
 Green	75 %	25 %	< 25 %
 Local	25 %	25 %	0 %
 Autonomy	0 %	0 %	0 %
 Additional Cost <small>(w.r.t. current bill)</small>	+10 % { insert }	+5 % { insert }	+0 % { insert }

Your choice:

- A
- B
- Current




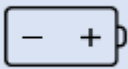

Scenario 7

Offer	Offer A	Offer B	CURRENT
 Supply mode	Self-consumption Community	Individual self- consumption	Supplier (national grid)
 Green	75 %	75 %	< 25 %
 Local	50 %	50 %	0 %
 Autonomy	0 %	50 %	0 %
 Additional Cost <small>(w.r.t. current bill)</small>	+10 % { insert }	+15 % { insert }	+0 % { insert }

Your choice:

- A
- B
- Current




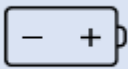

Scenario 8

Offer	Offer A	Offer B	CURRENT
 Supply mode	Individual self-consumption	Self-consumption Community	Supplier (national grid)
 Green	75 %	25 %	< 25 %
 Local	25 %	25 %	0 %
 Autonomy	25 %	0 %	0 %
 Additional Cost <small>(w.r.t. current bill)</small>	+15 % { insert }	+0 % { insert }	+0 % { insert }

Your choice:

- A
- B
- Current




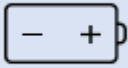

Scenario 9

Offer	Offer A	Offer B	CURRENT
 Supply mode	Self-consumption Community	Individual self- consumption	Supplier (national grid)
 Green	75 %	50 %	< 25 %
 Local	25 %	50 %	0 %
 Autonomy	0 %	0 %	0 %
 Additional Cost <small>(w.r.t. current bill)</small>	+5 % { insert }	+10 % { insert }	+0 % { insert }

Your choice:

- A
- B
- Current

Scenario 10

Offer	Offer A	Offer B	CURRENT
 Supply mode	Individual self-consumption	Self-consumption Community	Supplier (national grid)
 Green	75 %	50 %	< 25 %
 Local	50 %	50 %	0 %
 Autonomy	50 %	0 %	0 %
 Additional Cost <small>(w.r.t. current bill)</small>	+20 % { insert }	+10 % { insert }	+0 % { insert }

Your choice:

- A
- B
- Current

Reminder :

“**Green**” is the share of electricity produced from renewable sources.

“**Local**” is the share of electricity produced near you with any technology.

“**Autonomy**” is the part of the electricity that you produced yourself.

“**Supplier**” is the company that supplies electricity from the national grid, e.g. EdF, GEG, Engie, etc.

“**Individual self-consumption**” refers to the situation where the household produces all or part of the electricity it consumes, using a production system, e.g. ex. solar panels.

“**Self-consumption community**” refers to the situation where the household is part of a community whose members share the electricity produced.

Text11

The second part of the study is now complete.

Thank you for your answers, they have been correctly recorded.
We now ask you to answer a few more questions. All information will be treated anonymously.

Text12

Part 3

Supplementary Questions

P1 To what extent did the following criteria influence your choices?

Not at all Rather no Indifferent Rather yes A lot

The choice with the lowest price

Reduce environmental impact

Support the local community

Become more network independent

Join a group with the same attitudes and beliefs

P2 Regarding energy management in your home...

Undesirable Somewhat Undesirable Indifferent Somewhat Desirable Desirable

Do you find the idea of generating your own electricity using a solar panel system on your roof desirable?

Do you find the idea of storing electricity at home

desirable to
become
more
independent
of the grid?

P3 Are you sensitive to environmental issues?

- Not at all
- Rather not
- Indifferent)
- Rather yes
- Many

P4 Have you ever heard of green electricity? *

- Yes, you know what it is and you have subscribed or would like to subscribe to an offer of this type
- Yes you know what it is but do not wish to subscribe to an offer of this type
- Yes but you don't know what it is
- No

P5 According to you, renewable energies are (tick the proposals that correspond to your opinion, several possible choices): *

- More expensive
- More environmentally friendly
- Less efficient
- A sales argument
- A privilege for the rich
- Less reliable due to intermittency in generation

P6 In France, when we are connected to the network, we can choose not to consume electricity produced by nuclear power plants.

- True
- False
- You do not know

P7 When we change electricity supplier, we also change the origin of the electricity consumed and therefore the technologies used to produce this electricity.

- True
- False
- You do not know

P8 If you produced electricity at home, would you be allowed¹ to consume this electricity?

- Yes
- No
- You do not know

¹ In this context “to be authorized” means that no authority can legitimately prevent you from doing so.

P9 Are you allowed² to

Yes	No	Do not know
-----	----	-------------

Buy or sell electricity directly to a power plant

Buy or sell electricity to your trustee⁶²

Buy or sell electricity to your municipality

Buy or sell electricity to an association or cooperative

Buy or sell electricity to a neighbor who is equipped with solar panels

² In this context “to be authorized” means to be able to sign a contract with someone.

P10 Would you say you know your neighbors:

- Not at all
- Just in passing
- Pretty good

P11 What is your relationship with your neighbors?

- I don't like my neighbors at all
- I avoid contact
- Indifferent, I don't really know them
- Cordial and respectful
- Close, I can trust them

⁶² The agency that administers your building

Text13

Personal information

We want to know more about you. Please complete the following questions.

D1 In what year were you born?

D2 Are you? *

- A man
- A woman
- You prefer not to answer

D3 What is your highest level of education? *

- College diploma
- CAP, BEP or equivalent
- Baccalaureate, professional certificate or equivalent
- Short higher education diploma (bac + 2 level)
- Long higher education diploma (higher than bac + 2)

D4 What is your current socio-professional situation? *

- Farmer/operator
- Craftsmen, merchants or company directors
- Executive and higher intellectual profession
- Intermediate occupation
- Employee)
- Worker
- Retired
- Unemployed

D5 On average, what is your net monthly household income?

- Less than 1000 €/month
- From 1000 to 1800 €/month
- From 1800 to 3000 €/month
- From 3000 to 4000 €/month
- From 4000 to 6000 €/month
- 6000 €/month and more

Text14

Final comments

If you wish, you can use the space below to leave us your comments or suggestions. Please write your answer here:

Thank you for your participation. The study is over.

C APPENDIX TO CHAPTER 3

ANNEX I. Literature collected and screened for the meta-analysis

Author	Survey	Country	Sample	Format	Elicitation	Model	Type	Tech	Frame	WTP	Min	Max
(Abdullah and Markandya, 2012)	2007	Kenya	200	F	CVB	LOG	A	S	R	29.63	20.30	38.95
(Alam and Bhattacharyya, 2017)	2015	Bangladesh	300	F	CV, DCE	LOG	A	G, S, F	R	28.87	5.56	52.17
(Aldy et al., 2012)	2011	United States	1,010	W	CV	LOG	M	G	PO, RE	15.53	12.27	24.93
(Amador et al., 2013)	2010	Spain	376	F	DCE	LOG	M	G	CO, RE	0.68	0.36	1.08
(Andor et al., 2016)	2013	Germany	2,303	W	CV, OE	LIN, PRO	M	G	CO, RE	18.43	17.42	19.14
	2015	Germany	5,676	W	CVB	LIN, PRO	M	G	CO, RE	-8.37	-14.33	-6.10
(Aravena et al., 2012b)	2008	Chile	711	F	CVB	LOG	M	S, W, B, H, F	PR	12.41	11.24	13.36
(Bärenbold et al., 2020b)	2020	Switzerland	610	W	DCE	LIN	A	H	CO, RE	11.71		
(Bakkensen and Schuler, 2020)	2018	Viet Nam	14,304	F	CV	LOG	M	G, F	PR	0.23		
(Balezentis et al., 2021)	2020	Lithuania	814	F, W	CV, OE	O	M	S, W, B, H	CO, RE	44.14	35.95	80.20
(Batley et al., 2000)	1999	UK	746	M	OE	U	M	G	CO, RE	12.99		24.34
(Batley et al., 2001)				M	CV	O	M	G	CO, RE	12.54		23.68
(Bergmann et al., 2006a)	2003	UK (Scotland)	211	M	DCE	LOG	M	W, B, H	PO, PR	2.39	1.99	3.23
(Bigerna and Polinori, 2011)	2007	Italy	1,019	W	CV	O, U	M	G	CO, RE	2.56	1.78	3.55
(Andrea Bollino, 2009b)	2006	Italy	1,601	W	CV	PRO	A	G	CO, RE	1.32	0.91	1.36
(Borchers et al., 2007b)	2006	United States	128	F	DCE	LOG	M	G, S, W, B	CO, RE	19.77	13.60	27.65
(Botelho et al., 2013)	2012	Portugal	74	F, M	CV	O	M	W	PR	-2.06		
		Portugal	125	F, M	CV	O	M	W	PR	0.92	0.35	1.48
(Botelho et al., 2015)	2014	Portugal	250	F	DCE	LOG	M	H	PR	15.59	7.62	27.54
(Botelho et al., 2017)	2014	Portugal	61	F	CV, OE	LOG, O	A	S	PR	-53.24	0.00	-83.29
		Portugal	250	F	DCE	LOG	A	S	PR	36.63		
(Byrnes et al., 1999)	1992	United States	492	T	CVB	LIN	M	S, W, B, H	PR	3.69	3.50	3.87
	1994		320	M, T	CVB	LIN	M	S	PR	3.58	2.46	4.70
(Chan et al., 2011b)	2010	South Africa	405	T	DCE	LIN	M	G	CO, RE	22.74		
(Cicia et al., 2012)	2009	Italy	504	T	DCE	LOG	M	S, W, B, N	CO, RE	31.50	11.34	44.64
(Claudy et al., 2011b)	2009	Ireland	1,012	T	CV	PRO	A	S, W, B	PR, MI	6.50	3.28	7.85
(Colbourne et al., 1999)	1997	UK	507	M	CV	O	M	G	CO, RE	9.11		

Author	Survey	Country	Sample	Format	Elicitation	Model	Type	Tech	Frame	WTP	Min	Max
(Dagher and Harajli, 2015)	2013	Lebanon	600	F	CV	TOB	M, A	G, S	CO, RE, MI	7.99	7.61	8.38
(Dimitropoulos and Kontoleon, 2009)	2007	Greece	212	F	DCE	LOG	A	W	PR	-126.15	-74.88	-179.00
(Dogan and Muhammad, 2019)	2019	Turkey	2,500	F	CV	LOG, PRO, TOB	M	G	RE, PO	2.74	2.29	3.18
(Broughel, 2019)	2013	Mexico	75	F	CV, OE	O	A	S	R	5.64	2.91	7.35
(Entele, 2020)	2016	Ethiopia	220	F	CVB	PRO	A	S	R	220.93		1059.04
(Ethier et al., 1997)	1996	United States	719	M, T	DCE	O	M	G	PR	10.19		
(Garces-Voisenat and Mukherjee, 2016)	2013	Chile	334	W	CV	LIN	M	G	PR, RE	44.55		
(Goett et al., 2000)	2000	United States	1,205	M, T	DCE	LOG	M	G, W, H	CO, RE	44.32	37.26	51.39
(Gracia et al., 2012b)	2010	Spain	400	F	DCE	LOG	M	S, W, B	CO, RE	1.18	-2.70	7.25
(Grösche and Schröder, 2010)	2008	Germany	2,948	W	DCE	PRO, TOB	A	G, N, F	CO, RE	18.516	-29.317	18.516
(Guo et al., 2014)	2010	China	571	F	CVB	LOG	M	G	PO, RE	6.37	5.01	8.42
(Hanemann et al., 2010)	2009	Spain	233	T	CV	PRO	M	G	PO, RE, GHG	54.50	51.80	57.21
(Hanley and Ceara, 1999)	1998	UK (Scotland)	45	F	CV	O	M	W, B, H	PR	14.94	15.86	14.04
(Hansla et al., 2008b)	2007	Sweden	855	M	DCE	LIN	M	G	CO, RE	1.83		5.50
(Heng et al., 2020)	2015	United States	304	W	DCE	LOG	M	S	CO, RE, MI	18.02	12.01	24.02
(Hite et al., 2008)	2005	United States	80	T	CV, OE	LOG	M	B	CO, RE	8.81	7.59	10.02
(Ivanova, 2005)	2004	Australia	213	M, OE	CV	LIN	M	G	PO, RE	11.96	10.52	13.41
(Ivanova, 2012b)	2004	Australia	197	M	OE	LOG, TOB	M	G	CO, GHG	12.50	6.16	17.42
(Kaenzig et al., 2013)	2009	Germany	414	W	DCE	LOG	M	S, W, B, H	CO, RE	18.46		
(Kim et al., 2012)	2010	Rep. of Korea	720	F	CV	O	M	S, W, H	PO, RE	2.10	2.07	2.14
(Kim et al., 2013)	2010	Rep. of Korea	490	F	CVB	LOG, O	M	G	PO, RE	1.96	1.77	2.17
(Komarek et al., 2011)	2009	United States	4,079	W	DCE	PRO	M	S, W, B, F	CO, RE	1.41	1.08	1.75
(Kontogianni et al., 2013b)	2010	Greece	240	F	CV, OE	LIN, PRO	A	S, W, T	CO, RE	145.13	60.18	301.83
(Kosenius and Ollikainen, 2013b)	2008	Finland	947	W	DCE	LOG	M	W, B, H	PO, RE	21.80	15.82	29.50
(Kotchen and Moore, 2004)	1998	United States	1,301	M	U	PRO, TOB, O	M	S	PR	11.98	10.46	13.50
	2001	United States	677	M	U		M	W	PR	12.42		
(Koundouri et al., 2009)	2007	Greece	200	T	CVB	LIN	M	W	PR	9.05		

Author	Survey	Country	Sample	Format	Elicitation	Model	Type	Tech	Frame	WTP	Min	Max
(Kowalska-Pyzalska, 2018)	2017	Poland	502	T	CV	LOG, TOB, O	M	G	CO	7.20		16.84
(Ku and Yoo, 2010b)	2006	Rep. of Korea	774	F	DCE	PRO	M	G, S, W	PO, RE	0.013	0.008	0.017
(Ladenburg and Dubgaard, 2007)	2004	Denmark	362	M	DCE	LOG	A	W	PO, PR, RE	1.33	0.74	1.98
(Liu et al., 2013)	2011	China	212	F	DCE	LOG	M	G	CO, RE	0.76	0.28	1.06
(Liu, 2014)	2014	Sweden	132	W	DCE	O	M	G	CO	0.139	0.061	0.245
(Longo et al., 2006)	2005	UK	287	F	DCE	LOG	M	G	PO, GHG	19.64	19.40	19.88
(MacMillan et al., 2006)	2003	UK (Scotland)	165	F, M	CV	U	M	W	PO, RE	4.00	2.95	5.34
(Markantonis and Bithas, 2010)	2007	Greece	30	F	CV	O	A	G	PO	9.49		
(Martinez-Cruz and Nuñez, 2020)	2019	Mexico	199	F	DCE	LOG	M	S, B	PO, RE	4.37	1.36	6.37
(Martínez-Paz et al., 2011)	2009	Spain	169	F	CV, OE	LOG, TOB	M	G	PO, RE	29.97	26.68	33.27
(Merk et al., 2019)	2013	Germany	1,289	W	DCE	U	A	G	CO, RE	107.67		
	2013	UK	1,282	W	DCE	U	A	G	CO, RE	92.52		
(Mozumder et al., 2011)	2008	United States	367	W	DCE, OE	TOB	M	G	CO, RE	21.82	12.23	31.41
(Navrud and Grønvik Bråten, 2007)	2005	Norway	189	F	DCE	LOG	M	W	PR	12.32	6.61	21.67
(Nomura and Akai, 2004)	2000	Japan	379	M	CV	O	M	S	CO	19.86	14.69	23.20
(Ntanos et al., 2018)	2016	Greece	400	F	CV	LOG, O	M	S, W, B, T	CO, RE	16.37	2.16	46.63
(Odam, 2011b)	2009	UK (Scotland)	148	M	DCE	LOG	M	W, H	PO, RE	21.04	13.14	28.93
(Oliver et al., 2011b)	2008	South Africa	405	T	DCE	U	M	S, W	CO	31.08	11.81	53.13
(Sundt and Rehdanz, 2014)	2014	Japan	2,313	F	OE	U	A	G, N	CO, RE	111.16		
(Roe et al., 2001b)	2000	United States	835	F	DCE	LIN	M	G	PO, RE, GHG	0.92	0.01	1.78
(Rowlands et al., 2003b)	2001	Canada	466	M	CV	O	M	G	CO, RE	3.26		58.05
(Scarpa and Willis, 2010b)	2007	UK	1,279	F	DCE	LOG	A	S, W, B, H, F	PR, MI	1.66	0.92	2.08
(Shin et al., 2014b)	2012	Rep. of Korea	500	F	DCE	LOG	M	G	PO, RE	0.929		
(Sims, 2013b)	2003	United States	403	T	CV, OE	TOB, O	M	G	CO, RE	40.16	28.11	67.97
(Soliño et al., 2009c)	2006	Spain	572	F	CVB	LOG	M	B	CO, RE	8.60	7.37	11.10
(Soliño et al., 2009b)	2006	Spain	581	F	CVB	LIN, LOG	M	G	CO, RE	5.53	5.16	5.91
(Strazzera et al., 2012)	2010	Italy	358	F, T	CV	PRO	M	S	CO	40.76		
(Štreimikienė and Baležentis, 2015)	2013	Lithuania	100	F	CV	O	M	G	CO, RE	4.593		
(Su et al., 2018)	2016	Lithuania	104	T	DCE	LOG	A	S, W, B	PR, MI	3.259	-20.50	26.68

Author	Survey	Country	Sample	Format	Elicitation	Model	Type	Tech	Frame	WTP	Min	Max
(Susaeta et al., 2011b)	2008	United States	182	W	DCE	LOG	M	B	CO, EX	65.97	43.08	87.51
(van Putten et al., 2014a)	2012	Netherlands	507	W	DCE	LOG	M	S, W	PR, RE, MI	1.45	1.15	1.76
(Vecchiato and Tempesta, 2015)	2013	Italy	484	W	DCE	LOG	M	S, B	CO, RE	18.55	15.66	21.64
(Whitehead and Cherry, 2007b)	2002	United States	353	T	CV	LOG	M	S, W	CO, EX	38.36	6.10	107.96
(Wiser, 2005)	2005	United States	1,776	M	CV	LOG	M	G	CO, RE	1.78	0.31	3.62
(Yang et al., 2015a)	2012	Denmark	1,012	W	DCE	O	M	W, H	CO, RE	276.68	170.80	743.85
(Yang et al., 2016)				W	DCE	LOG	M	W, H	CO, RE	114.40	109.08	119.72
(Yoo and Ready, 2014)	2011	United States	654	M	DCE	LOG	M	S, W, B	CO, RE	8.33	0.46	20.34
(Yoo and Kwak, 2009)	2006	Rep. of Korea	800	F, M, T	CVB	O	M	G	CO, RE	2.86	2.56	3.16
(Zarnikau, 2003)	1999	United States	2,800	T	CV	TOB	M	G	CO	11.11	10.84	11.38
(Zhang and Wu, 2012)	2010	China	1,139	M, W	CV	LOG	M	G	CO	2.72	2.36	3.07
(Zografakis et al., 2010)	2007	Greece	1,440	F	CVB	LOG	M	G	PR	11.12	10.42	11.83
(Zorić and Hrovatin, 2012b)	2008	Slovenia	450	F, W	DCE, OE	TOB	M	G, H	CO	8.55		51.16

Format: F: face-to-face; W: web (online); T: telephone; M: mail.

Elicitation: CV: contingent valuation; CVB: bounded contingent valuation; DCE: discrete choice experiment; OE: open-ended.

Model: LIN: linear; LOG: logit; PRO: probit; TOB: tobit; O: other; U: unspecified.

Type: M: marginal WTP; A: average WTP.

Technology: G: generic green; S: solar ; W: wind; H: hydro; B: biomass; T: geothermal; F: fossil; N: nuclear.

Frame: CO: conviction; EXT: externalities; PO: policy; PR: project; RE: renewable energy target; GHG: climate target; MI: (domestic) microgeneration; R: rural electrification; WTD: willingness to donate; RD: research and development.

ANNEX II. Review of existing meta-studies

Author	Surveyed period	Studies	Countries	Obs.	Screening Criteria	WTP estimate (range)	Contribution
Sundt, S. et al. (2014)	2000-2011	18	10	85	Excludes: valuations with incompatible, inconvertible units.	13.13 USD/m, (1.00, 43.01) 3.17 USD/kWh Convert WTP/m to WTP/kWh whenever possible. USD ref. year 2010.	<ul style="list-style-type: none"> - Lack of information on the energy source being replaced reduces WTP estimates. - WTP tends to decrease over time. - Hydropower is the least preferred technology. - Some effects disappear when WTP/kWh is used.
Soon, J-J. et al. (2015)	1996-2011	30	13	137	Excludes: imprecise estimates (shares and percentages); incompatible units; marginal valuations (externalities, microgeneration, donations, R&D, etc.); studies without variance estimates: nuclear energy; inaccessible languages.	7.16 USD/m Only WTP/m included. USD ref. year 2013.	<ul style="list-style-type: none"> - Specifies model to identify sources of heterogeneity - Higher WTP associated to face-to-face interviews, metropolitan and North American households. - Lower WTP associated to DCE as compared to CV. - Technology does not influence WTP. - Publication bias not detected.
Ma, C. et al. (2015)	1999-2013	29	14	142	Excludes: studies with unspecific shares of RE; non-RE sources (gas, nuclear); studies with focus on valuating externalities rather than energy; missing key information (survey year, sample size, payment vehicle, etc.).	0.015 USD/kWh (-0.396, 0.169) Convert WTP/m to WTP/kWh whenever possible. USD ref. year 2006.	<ul style="list-style-type: none"> - Study design explains more variation than energy type, consumer demographics or consumption patterns. - Higher WTP for generic green > solar > wind > biomass & hydro; mail & phone > online & face-to-face; DCE > CV; bounded CV > open-ended. Inverse association to household electricity consumption.

Author	Surveyed period	Studies	Countries	Obs.	Screening Criteria	WTP estimate (range)	Contribution
							- Publication bias inconclusive.
Bigerna, S. et al. (2015)	1999-2014	31	15 ⁶³	189	Only includes studies with individual-specific variables, including a policy scenario or a clear project and a link to the local community. Includes negative WTP values and WTA (ca. 10% of results lost during to log transformation).	7.003 EUR/m (WTP, supporters) 7.935 EUR/m (WTA, detractors) Convert WTP/m to WTP/kWh whenever possible. EUR ref. year 2013.	- Hybrid approach combining meta-analysis and local survey that controls for the community's previous experience with similar infrastructure projects. - Highlights differences in valuations by different respondent groups. Confirms the pertinence of including sociological and psychological regressors.
Pokhrel, K.R. (2016) ⁶⁴	2000-2013	21	18	99	Excludes: revealed preferences, non-renewable sources, WTP values per kWh, as percentages or shares.	26.69 USD/m Only WTP/m included. USD ref. year 2008.	- Higher WTP linked to increased awareness of RE, higher national share of RE, higher income, generic green, more recent year of publication. - Refinement of the benefit transfer error.
Grilli, G. (2017)	1998 - 2014	34	16	151	Excludes: valuations with incompatible, inconvertible units; valuations with samples not representative of surveyed population; unspecified survey methods.	13.29 (green); 14.40 (solar); 14.66 (wind); 11.02 (biomass); 9.57 (hydro); 36.90 (geo).	- WTP positively correlated to level of CO ₂ emissions, share of RE and technology. Inversely related to level of energy consumption and share of nuclear.

⁶³ Undisclosed in the study, estimated from references.

⁶⁴ This is a non-peer-reviewed master's thesis.

Author	Surveyed period	Studies	Countries	Obs.	Screening Criteria	WTP estimate (range)	Contribution
						Only WTP/m included. USD ref. year 2010.	
Gao, L. et al. (2020)	1998-2015	17	Japan	18	Includes: studies completed after 2000 to avoid low valuations due to lack of prior public awareness of RE. Excludes: WTP/kWh, nuclear.	1340 JPY/m (139, 3405) Equiv. in 2020 USD PPP: 13.03 US/m (1.35, 33.11)	<ul style="list-style-type: none"> - Provides the basis for a flexible feed-in-tariff adjusted by prefecture and income level using an 'acceptability curve', thus relieving the burden from public finances. - WTP strongly influenced by income and gender.
Chaikumbung, M. (2021)	1992-2018 ⁶⁵	91	27	509	Includes: studies using CV or DCE; RE sources; WTP in money terms; both published and unpublished.	13.69 USD/m (sample data) 9.97 USD/m (model) Convert to WTP/m whenever possible. USD ref. year 2011.	<ul style="list-style-type: none"> - Emphasis on political and economic institutions, the types of RE, along with country-specific and survey-specific factors all affect WTP values. - Higher WTP valuations in countries with democratic and free market systems; lower WTP in countries with higher income inequality (Gini index), high per capita GHG emissions, urban populations and hydro projects. - RE behaves as a luxury good. - No publication bias was detected.

⁶⁵ 2018 is the most recent publication year, not the year of the most recent survey.

ANNEX III. Econometric models of existing meta-studies

Author	Regression model	Dependent and independent variables	Equation
Sundt, S. et al. (2014)	Weighted linear regression with robust standard errors.	Dependent variable: Ln(WTP) for increase of RE in electricity mix, as both USD/m and cUSD/kWh. Ref. year 2000. Independent variables: - Country-specific: 2 - Individual-specific: 5 - Survey/publication-specific: 4	$\ln(y_i) = \alpha + \beta_C X_{Ci} + \beta_S X_{Si} + \varepsilon_i$ <p> α constant term β_C vector of country-specific coefficients X_{Ci} matrix of country-specific variables β_S vector of survey-specific coefficients X_{Si} matrix of survey-specific characteristics ε error term </p>
Soon, J.-J. et al. (2015)	Random-effect meta-regression model, using variances as weights.	Dependent variable: Ln(WTP) in USD/m for ref. year 2013. Independent variables: - Country-specific: 2 - Individual-specific: - - Survey/publication-specific: 12	$\ln(y_i) = X_i \beta + u_i + \varepsilon_i$ <p> X_i vector of characteristics β vector of meta-coefficients u_i between-study variance $\sim N(0, \tau^2)$ ε_i standard error </p>
Bigerna, S. et al. (2015)	Unweighted and weighted OLS.	Dependent variable: Ln(WTP/WTA) for a marginal increase in RE production. Independent variables: - Country-specific: 1 - Individual-specific: 3 - Survey/publication-specific: 8	$\ln(WTP_i) = \alpha + \beta_{RE} \ln(RE_q) + \sum_{i=1}^I \delta_{PU_i} PU_{i,q} + \sum_{j=1}^J \delta_{FAC_j} FAC_{j,q} + \sum_{k=1}^K \delta_{MET_k} MET_{k,q} + \varepsilon_q$ <p> $\ln(RE_q)$ average RE consumption in primary study $PU_{i,q}$ vector of I publication and year dummy variables. $FAC_{j,q}$ vector of J dummy explanatory variables. $MET_{k,q}$ vector of K survey-specific dummy variables ε_q error term with zero mean and variance σ_q </p>

Author	Regression model	Dependent and independent variables	Equation
Ma, C. et al. (2015)	Weighted least squares (WLS) regression on full sample to test fixed effects. Residual maximum likelihood (REML) regression on subset with standard errors to test mixed effects.	Dependent variable: WTP in cUSD/kWh for ref. year 2006. Includes standard error of WTP. Independent variables: - Country-specific: 4 - Individual-specific: 9 - Survey/publication -specific: 9	Not specified
Pokhrel, K.R. (2016)	Unweighted and weighted OLS.	Dependent variable: WTP and Ln(WTP) modelled separately. Ref. year 2008. Independent variables: - Country-specific: 2 - Individual-specific: 1 - Survey/publication-specific: 7	$Y_i = \alpha + \beta_c X_{ci} + \beta_m X_{mi} + \beta_s X_{si} + \beta_d X_{di} + \varepsilon_i$ <p> α constant term $\beta_c, \beta_m, \beta_s, \beta_d$ vectors of coefficients ε_i error term </p>
Grilli, G. (2017)	Weighted least squares (WLS) using sampling weights. Semi-log linear regression	Dependent variable: Ln(WTP/m) for a percentage increase in RE Independent variables: - Country-specific: 5 - Individual-specific: 4 - Survey/publication-specific: 7	$\ln(\text{WTP}) = \alpha + \beta_i X_i + \varepsilon$ <p> α constant term β_i coefficients to be estimated X_i vector of independent variables ε error term </p>

Author	Regression model	Dependent and independent variables	Equation
Gao, L. et al. (2020)	OLS and extrapolation of future prices using an “acceptability curve”	Dependent variable: WTP Independent variables: - Country-specific: - - Individual-specific: 4 - Survey/publication-specific: 2	$WTP = \alpha + \beta_i X_i + \varepsilon$ <p> α constant term β_i coefficients to be estimated X_i vector of independent variables ε error term </p>
Chaikumbung, M. (2021)	Weighted least squares (WLS) using square root of sample size as weight.	Dependent variable: Ln(WTP) as USD/m. Independent variables: - Country-specific: 9+3 institutional - Individual-specific: 6 - Survey/publication-specific: 12	$\ln Y_{ij} = \beta_0 + \beta_1 X_{Iij} + \beta_G X_{Gij} + \beta_C X_{Cij} + \beta_m X_{mij} + \varepsilon_{ij}$ <p> i, j observation and country index, respectively β_0 constant term $\beta_I, \beta_G, \beta_C, \beta_m$ vectors of coefficients ε_{ij} residuals </p>

D APPENDIX TO CHAPTER 4

ANNEX I. Balance of Power Flows, kWh/y

Scenario	I	II	III	Pro	Con	IV	Pro	Con	V	Pro	Con	VI	Pro	Con
Grid (buy)	-270,165	-270,165	-240,219	-9,351	-230,868	-240,175	-9,307	-230,868	-209,397	-3,450	-205,947	-	-	-
Grid (sell)	-	-	-	-	-	24,921	24,921	-	-	-	-	-	-	-
PV self cons.	-	-	-29,945	-29,945	-	-29,989	-29,989	-	-29,989	-29,989	-	-29,989	-29,989	-
PV stored	-	-	-18,820	-18,820	-	-	-	-	-	-	-	-	-	-
P2P (buy)	-	-	-	-	-	-	-	-	-24,921	-	-24,921	-24,921	-	-24,921
P2P (sell)	-	-	-	-	-	-	-	-	24,921	24,921	-	24,921	24,921	-
Spot (buy)	-	-	-	-	-	-	-	-	-	-	-	-215,255	-9,307	-205,947
Spot (sell)	-	-	-	-	-	-	-	-	-	-	-	-	-	-
TOT kWh	-270,165	-270,165	-288,984	-58,116	-230,868	-245,244	-14,376	-230,868	-239,386	-8,518	-230,868	-245,244	-14,376	-230,868

ANNEX II. Balance of Use Attributes, €/y

Scenario	I	II	III	<i>Pro</i>	<i>Con</i>	IV	<i>Pro</i>	<i>Con</i>	V	<i>Pro</i>	<i>Con</i>	VI	<i>Pro</i>	<i>Con</i>
<i>Grid (buy)</i>	-42,335	-43,723	-37,642	-1,465	-36,177	-37,636	-1,458	-36,177	-33,134	-862	-32,272	-	-	-
<i>Grid (sell)</i>	-	-	-	-	-	2,492	2,492	-	-	-	-	-	-	-
<i>PV self cons.</i>	-	-	-1,881	-1,881	-	-1,884	-1,884	-	-2,281	-2,281	-	-2,281	-2,281	-
<i>PV stored</i>	-	-	-2,782	-2,782	-	-	-	-	-	-	-	-	-	-
<i>P2P (buy)</i>	-	-	-	-	-	-	-	-	-1,765	-	-1,765	-1,566	-	-1,566
<i>P2P (sell)</i>	-	-	-	-	-	-	-	-	1,765	1,765	-	1,765	1,765	-
<i>Spot (buy)</i>	-	-	-	-	-	-	-	-	-	-	-	-23,499	-1,016	-22,483
<i>Spot (sell)</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-
TOT kWh	-42,335	-43,723	-42,306	-6,129	-36,177	-37,028	-850	-36,177	-35,415	-1,378	-34,037	-25,582	-1,533	-24,049

ANNEX III. Balance of Use and Hedonic Attributes, €/y

<i>Scenario</i>	<i>I</i>	<i>II</i>	<i>Pro</i>	<i>Con</i>	<i>III</i>	<i>Pro</i>	<i>Con</i>	<i>IV</i>	<i>Pro</i>	<i>Con</i>	<i>V</i>	<i>Pro</i>	<i>Con</i>	<i>VI</i>	<i>Pro</i>	<i>Con</i>
<i>P2P</i>	-	-	-	-	-	-	-	-	-	-	244	-	244	244	-	244
<i>PV</i>	-	-	-	-	186	186	-	114	114	-	114	114	-	114	114	-
<i>Green</i>	-	4,994	-	4,994	901	901	-	554	554	-	1,015	554	461	1,015	554	461
<i>Local</i>	-	-	-	-	-406	-406	-	-250	-250	-	-458	-250	-208	-458	-250	-208
<i>Autonomy</i>	-	-	-	-	359	359	-	-	-	-	-	-	-	-	-	-
<i>TOT kWh</i>	-	4,994	-	4,994	1,040	1,040	-	419	419	-	916	419	497	916	419	497

