

Exploring the behavioural base
for the Swiss energy transition:
The role of attitudes and heterogeneity
in the preferences of electricity consumers

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*Mi vuoi dire, caro Sancho, che dovrei tirarmi indietro
Perché il male ed il potere hanno un aspetto così tetro?*
[F. Guccini]

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1. Introduction

In the context of the international climate change mitigation efforts, several countries have been scaling up the efforts to decarbonize their economies and energy systems in the past decade. The electricity sector has been leading the transition, with substantial increases in the contributions of new renewable-based generation plants. This massive restructuring has brought about new challenges, among which the acceptance of the new infrastructures and technologies among citizens and prospective users (European Commission, 2018; Stadelman-Steffen et al., 2019), and the need of ensuring an optimal level of reliability of the electricity supply at an affordable cost (Larsen et al., 2017; Linares and Rey, 2013; CEPA, 2018; ENTSO-E, 2020).

Switzerland has engaged in the energy transition process, and is facing the additional challenge of phasing out by 2035 its nuclear generation capacity, historically supplying around 40% of inland consumption (Swiss Federal Office for Energy, 2018).

Ensuring the acceptance of the new energy scenarios and infrastructures is particularly important within the Confederation. Indeed, Swiss citizens are entitled to participate in the definition of energy policies and the approval of infrastructural projects through referenda that can be called at a national, cantonal, or municipal level. Topics related to energy and sustainability are thus often discussed not only among the political and industrial stakeholders, but also among the general public, and opinions, preferences, and attitudes may shape and polarize as a consequence of the ongoing debates. By the same reasoning, any decision concerning the desirable level of security of the electricity supply and the best investments and technical options to achieve it may greatly benefit from a careful assessment of the reliability levels required by the different kinds of end users. This information is crucial to ensure that the magnitude and kind of planned investments efficiently meet the expectations and needs of the various consumption segments.

My thesis contributes to the debate concerning the evolution of the Swiss electricity system by providing an insight into the preferences of Swiss electricity consumers with respect to the origin and reliability of their electricity supply in the context of the energy transition.

The thesis comprises three contributions:

- The first contribution evaluates the preferences of Swiss households with respect to different primary energy sources used for generating electricity, and explores the possible role of attitudinal drivers in shaping households' choices;

- The second contribution studies the willingness-to-accept of Swiss households for electricity blackouts. After detecting a substantial amount of heterogeneity in this value, the analysis explores the connections between the different preference patterns observed among households and the relevant behavioural and attitudinal traits characterizing each household;
- The third contribution focusses instead on business electricity consumers located in Canton Ticino. The analysis explores the impact of blackouts on production activities, the strategies adopted to prevent or reduce blackout damage, and finally the willingness-to-accept of business consumers for an electricity blackout with given characteristics, as well as the heuristic processes underlying the decision-making process with respect to this topic.

The three analyses rely on stated preference data collected by means of two original surveys distributed among Swiss households (chapters 2 and 3) and business consumers located in Canton Ticino (chapter 4). The methods used belong to the family of discrete choice models: the first contribution exploits a discrete choice model with latent variables (Walker, 2001; Abou-Zeid and Ben-Akiva, 2014), the second one a discrete choice model with latent classes described by means of class membership functions (Gopinath, 1995; Bhat, 1997; Greene and Hensher, 2003; Hurtubia et al., 2014), and the third one a random parameter discrete choice model accommodating lexicographic preferences (Hess et al., 2010; Hess et al., 2012; Carlsson et al., 2020).

The results emerging from the three analyses suggest that attitudinal, behavioural, and cognitive factors play an important role in shaping the preferences of electricity consumers toward the origin and reliability of their supply. The use of an appropriate modelling framework allowing the assessment of the role of attitudinal traits – not directly observable as such from the data - and cognitive drivers is thus particularly important to ensure both an unbiased estimation of the parameters of interest, and a sound understanding of consumer behaviour (Hess et al., 2010; Abou-Zeid and Ben-Akiva, 2014). Moreover, even if attitudes per se can hardly be targeted by specific policies (Chorus and Kroesen 2014), assessing their role and demographic or behavioural determinants may be useful in order to design policies that elicit consensus by targeting awareness, habits, or behaviour (Vij and Walker 2016), as well as to define contracts that fit the needs and preferences of residential and business consumers. With consumers increasingly at the hearth of the energy transition, a better knowledge of the expectations and needs of citizens and companies is key to ensure a timely and efficient decarbonisation process.

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2. Consumer acceptance of the energy transition in Switzerland: the role of attitudes explained through a hybrid discrete choice model

Abstract

While several countries progress in the energy transition, the social acceptance of new infrastructures becomes increasingly important. We focus on market acceptance, and study the preferences of Swiss households with respect to selected energy sources used for electricity generation. By applying a hybrid discrete choice model with latent variables on stated preference data, we assess households' preferences with respect to the price, origin, and reliability of their electricity supply, and evaluate the impact of demographic, behavioural, and attitudinal drivers thereon. Latent variables representing attitudes allow us to explicitly model psychological traits otherwise unobservable from the data, evaluate their impact on individual choices, and connect them with demographic or behavioural variables. We find that households evaluate variations in the price and reliability of supply differently, depending on the energy source used. Environmental concern is associated to a stronger interest in a generic 100% renewable-based supply, informed optimism to a higher acceptance of nuclear generation. Energy illiteracy and environmental-friendly habits are more frequent among environmentally conscious households, less so among the informed optimists. Measures to foster energy literacy and ensure transparency of energy supply contracts are recommended in order to elicit or maintain consensus, and achieve the desired energy policy goals.

Keywords

Consumer attitudes; Consumer preferences; Rnergy transition; Hybrid discrete choice model; Latent variables.

Abbreviations

DC: discrete choice; HDCM: hybrid discrete choice model; LV: latent variable; MNL: multinomial logit; RP: random parameter; WTP: willingness to pay.

2.1 Introduction

In the context of international climate change mitigation efforts several countries are investing to decarbonize their electricity systems. Besides presenting technical and financial problems, this massive

restructuring also poses the challenge of social acceptance of new projects, technologies, and commercial options (European Commission, 2018, Stadelman-Steffen et al., 2019).

Social acceptance is a multifaceted problem (Batel, 2020). So far, it has mainly been explored by considering the three intertwined dimensions of socio-political, community, and market acceptance (Wüstenhagen et al., 2007) and investigating the psychological, cognitive, and contextual factors driving acceptance among citizens or consumers (Huijts et al., 2012). This analysis focusses on the dimension of the market acceptance of the energy transition: we consider individuals as consumers, and investigate the choices they make on the retail electricity market and the factors that influence their decisions. More precisely, we study the preferences of Swiss households towards alternative electricity supply contracts based on different primary energy sources, and the role of demographic, behavioural, and attitudinal drivers.

We recognize that both the political and institutional setting of a country, and the structure of its energy system influence consumer preferences. Indeed, they define the reference scenario against which the alternative options are evaluated, and contribute to the formation of attitudinal traits that may induce an inclination or aversion toward specific technologies.

The case of Switzerland is particularly interesting in this respect. The Swiss electric system is already based on low-carbon technologies: nuclear and hydroelectric generation contribute to around 40% and 55% of inland productions¹. However, nuclear generation will be phased out in the medium term, according to the Swiss “Energy Strategy 2050”, and investments in low-carbon generation plants will be needed in order to ensure the security and sustainability of the future energy supply².

Secondly, although the Swiss retail electricity market has not been completely liberalized yet, several electricity providers have been offering to their captive customers alternative contracts with certified renewable-based or locally sourced electricity for many years, even before the partial market opening (Wüstenhagen et al., 2003; Litvine and Wüstenhagen, 2011). Some retailers have even set a basic renewable-based contract as the default option for their residential customers. Despite not being entitled to choose their electricity suppliers, most households are used to choose among a bundle of alternative contracts characterized by a different generation mix.

Finally, in line with the country’s long-standing tradition of direct democracy, Swiss citizens have a direct voice in the evolution of the national energy system. They are indeed entitled to approve or repeal

¹ Source: Swiss Federal Office for Energy, 2019. “Zeitreihen - Schweizerische Elektrizitätsbilanz – Monatswerte”.

² Source: Swiss Federal Office for Energy, 2018, “Chronologie der Energiestrategie 2050”; Swiss Federal Office for Energy, 2019, “Energiestrategie 2050 Monitoring-Bericht 2019, Kurzfassung”.

legislative items through referenda that can be called at a national, cantonal, and municipal level. Moreover, they can propose amendments to the federal Constitution through the so-called “popular initiatives”, that must be approved in a referendum. Popular initiatives have often been used to participate in the definition of general principles for energy and climate policies; the federal Parliament may respond by means of a direct or indirect counter-proposal, the former also subject to the citizens’ approval. In the case of an indirect counterproposal and a repealed initiative, the indirect counterproposal is enacted: this helps to understand why, despite the frequent repeals, policy change is possible.

Eleven federal referenda have been called since 2000 on topics related to the electricity sector, and one might be called in the near future (Table 2.1). The debate that referenda kindle within society, together with the views expressed by political parties, stakeholders, and institutions, often shape attitudes among the citizens who are invited to take a stance on topics that would otherwise be debated mainly among the industrial and political stakeholders.

Year	Title	Object	Outcome
2000	Popular initiative "Solar cent"	The organizing committee asks for the introduction of a tax on non-renewable energy in order to finance new incentives for solar energy.	Repealed
2000	Counter-proposal "Incentives for renewables"	As an alternative to the "Solar cent" initiative, this counter-proposal from the Parliament puts forward a tax on non-renewable energy to foster renewables in general.	Repealed
2000	Counter-proposal "Energy and environment"	As an alternative to the "Energy and environment" initiative (withdrawn), this counter-proposal from the Parliament puts forward a tax on non-renewable energy to foster efficiency in energy use, and finance a reduction of labour taxes.	Repealed
2001	Popular initiative "Taxing energy, not work"	The organizing committee asks for the introduction of a tax on non-renewable energy and large hydro to finance a reduction of the old-age and survivors insurance.	Repealed
2002	Referendum on the new energy market law	The new energy market law provides for the creation of a Swiss transmission system operator, the introduction of regulated third party access for the national electricity transmission grid, and a gradual opening of the retail electricity market. In the optional referendum Swiss citizens are asked to approve or reject the new law.	Repealed
2003	Popular initiative "Electricity without nuclear"	The organizing committee asks for the dismantling of existing nuclear plants 30 years after their commissioning and at the expense of their owners. Imports should moreover exclude electricity generated abroad via nuclear	Repealed
2003	Popular initiative on a "Stop to nuclear" moratorium	The organizing committee asks for: 1) a 10 year ban for new nuclear plants and expansions of the existing ones, 2) the introduction of a mandatory declaration of origin for any electricity import.	Repealed
2015	Popular initiative "Energy tax instead of energy VAT"	The organizing committee asks for the replacement of the VAT on electricity with a variable tax on non-renewable electricity imported to or generated in Switzerland. The amount of the new tax should depend on the environmental impact of the electricity and on the fiscal needs of the Confederation.	Repealed
2016	Popular initiative for a "Green economy"	The organizing committee asks the promotion of a sustainable economy: by 2050 the ecological footprint of Swiss residents, if compared to the world's population, should not exceed the Earth yearly resource limits.	Repealed
2016	Popular initiative for a "Nuclear phase-out"	The organizing committee demands that while progressing towards the implementation of the Energy Strategy 2050, the Confederation should decommission the existing nuclear plants within 45 years since their commissioning (i.e. faster than in the original Strategy).	Repealed
2017	Referendum on the new law on energy	The new law on energy describes the first implementation package of the Energy Strategy 2050. The main measures concern energy efficiency, the promotion of renewable energies, and the nuclear phase-out. The optional referendum asks Swiss citizens to approve or reject the new law.	Passed
Pending	Popular initiative "Glaciers initiative"	The organizing committee demands that the Federal Constitution is modified to include: 1) an engagement into international negotiations to limit risks and consequences of climate change, 2) carbon neutrality in Switzerland by 2050, possibly also through carbon sinks, 3) the phase out from fossil fuels by 2050, with the exception of special unavoidable uses that need however to be compensated via carbon sinks, 4) measures to foster technology innovation.	-

Table 2.1 – Federal referenda impacting the electricity market since year 2000

The context and the influence of peers and institutions have been recognized as important drivers of attitudes and individual decision-making processes (Ben-Akiva et al., 2012). While accounting for the heterogeneity in individual behaviour already improves model fit, investigating the sources of heterogeneity by including psychological and attitudinal drivers improves the behavioural realism of the analysis and the understanding of consumer behaviour (Abou-Zeid and Ben-Akiva, 2014, Mariel and Meyerhoff, 2016). In a setting characterized by ongoing confrontation and mediation among the advocates of different strategies for the evolution of the energy system, individual attitudes may evolve or even polarize, and heavily influence consumer choices. Thus, we decided to investigate the preferences of Swiss household by means of a hybrid discrete choice model (HDCM) with latent variables (LVs). The use of a discrete choice (DC) model allows us to compare alternative energy sources and other features of an electricity supply contract that may matter to the consumers. The inclusion of LVs allows us to explicitly model attitudinal drivers within the DC model, going beyond the description of behavioural patterns that would be obtained through a DC model with latent classes.

Considering attitudes in a model explaining individual behaviour is particularly important in the case of Switzerland, but also increasingly useful in any country that has embraced the energy transition, and where consumers are faced with new supply options.

Our results concerning consumer preferences and their drivers may support both the definition of an energy transition path that kindles the least opposition, and the design of electricity supply contracts that elicit a favourable response. A sound understanding of consumer behaviour, including individual attitudes and their drivers, may help preventing opposition to specific policies and projects, and thus facilitate the achievement of the energy policy goals.

Our contribution develops as follows. Paragraph 2.2 collects the relevant suggestions from the economic literature. Paragraphs 2.3 and 2.4 describe our econometric method, survey, and data. Paragraph 2.5 presents our results, and paragraph 2.6 discusses the resulting policy implications.

2.2 Literature review

Individual preferences toward selected primary energy sources have received increasing attention in the last twenty years, in parallel with the liberalization wave in the retail electricity markets, the growing concern for sustainability, and the spreading of renewable-based generation.

Several studies have investigated the preferences of consumers, citizens, and investors toward renewable-based electricity supplies, while a smaller number of analyses have focussed on the acceptance of nuclear generation. These investigations have mostly relied on stated preferences, expressed through DC experiments, in contingent valuation surveys, or as an intention to purchase a given energy mix or engage in renewable generation projects. This paragraph provides an overview of the main findings emerging from the surveyed literature: detailed references are provided in the text and within Table 2.2.

2.2.1 Preferences towards renewable energy sources

Objective of the surveyed studies

The studies concerning consumer preferences toward renewable energy sources focus either on electricity coming from renewable sources in general, or on electricity coming from a specific primary source or generation technology (Table 2.2). The former studies usually analyse the willingness to pay (WTP) for a higher share of renewables in the own electricity supply contract or, more generally, the diffusion of “green” energy contracts among residential consumers. The latter investigate instead whether consumers would be willing to pay different amounts of money for different renewable sources, for example within their electricity supply contract or through direct investments, or focus on the acceptance of specific renewable generation projects either in general, or among the local communities.

Reference	Method	Energy sources	Object of the study	Drivers*	Geo
Goett et al., 2000	Discrete choice experiment	Wind; hydro; mix with solar, geothermal, landfill gas	WTP for RES	-	USA
Batley et al., 2001	Regression	RES	WTP for RES	Income (n.s.); environmental awareness (n.s.)	UK
Roe et al., 2001	Regression	Sun and wind; hydro; coal; oil; gas; nuclear	WTP for RES; WTP for % reduction of GHG emissions per kWh	Income (+); education (+); green behaviour (+)	USA
Alvarez-Farizo and Hanley, 2002	Contingent rating; Discrete choice experiment	Wind	WTP for selected features of new wind farms	Income (+); pro-environmental attitude (+)	Spain
Zarnikau, 2003	Regression	Wind; sun	WTP for RES	Income (+); education (+); age (-)	USA
Nomura and Akai, 2004	Contingent valuation	RES; wind; sun	WTP for RES	-	Japan
Ek, 2005	Regression	Wind	Positive attitude toward wind generation	Income (n.s.); education (n.s.), age (-)	Sweden
Menges et al., 2005	Regression	RES; wind; sun; hydro; nuclear; fossil fuels	WTP for RES	Income (+)	Germany
Bergman et al., 2006	Discrete choice experiment	RES	WTP for RES	Age (n.s.), children (n.s.), electricity bill (n.s.); green behaviour (n.s.)	UK
Borchers et al., 2007	Discrete choice experiment	RES; wind; sun; biomass; farm methane	WTP for RES	Income (+); age (- for aged 31-49); pro-environmental attitude (+)	USA
Koetchen et al., 2007	Regression	RES	Participation in green energy programmes	Income (+); male (-); consumption (-); pro-environmental values (+); altruism/warm glow (+)	USA
Hansla et al., 2008	Contingent valuation	RES	WTP for RES	Environmental awareness (+); attitudes toward RES (+)	Sweden
Burkhalter et al., 2009	Discrete choice experiment	Wind; sun; hydro; nuclear	WTP for selected primary sources	-	Switzerl.
Bollino, 2009	Contingent valuation	RES	WTP for RES	Income (+); education (+); male (+)	Italy
Whitmarsh et al., 2010	Regression	Carbon offsets	Intention to purchase carbon offsets	Green behaviour (+); perceived behavioural control (n.s.); pro-environmental values (n.s.); pro-environmental self-identity (+); perceived effectiveness (n.s.); social/subjective norms (n.s.)	UK
Groesche and Schroeder, 2011	Regression	RES; nuclear	WTP for RES, WTP for nuclear	Income (+), consumption (n.s.)	Germany
Hansla, 2011	Regression	RES	WTP for RES	Altruism/warm glow (+)	Sweden
Litvine and Wuestenhagen, 2011	Regression	RES	Intention to purchase RES contract	Perceived effectiveness (+); social norms (n.s.); attitudes toward RES (+)	Switzerl.
Mewton and Cacho, 2011	Regression	RES	Elasticity of demand for green power to the own price (by electricity retailer)	-	Australia
Oliver et al., 2011	Regression	RES	WTP for RES	Income (+); green behaviour (+)	South Africa
Cicia et al., 2012	Discrete choice experiment	Wind; sun; biomass; nuclear	WTP for RES, WTP for nuclear	Age (-); education (+/- depending on latent class); pro-environmental behaviour (+/-); pro-environmental attitude (+); environmental awareness (+)	Italy
Strazera et al., 2012	Discrete choice experiment	Wind	WTA for wind generation	Latent class membership: attachment to candidate wind mill sites, consumerism, land ownership, previous experience with wind mills. Wind mill characteristics: location of the plant; public/private and regional/local property; benefits to the community; bill discount offered	Italy
Zoric and Hrovatin, 2012	Tobit; double-hurdle	RES	WTP for RES	Age (+); education (+); environmental awareness (+)	Slovenia
Amador et al., 2013	Discrete choice experiment	RES	WTP for RES	Income (+); education (+); green behaviour (+); environmental awareness (+)	Canary Islands
Kaenzig et al., 2013	Discrete choice experiment	RES; wind; sun; hydro	WTP for selected primary sources	-	Germany
Yoo and Ready, 2014	Discrete choice experiment	RES	WTP for RES	Energy literacy (+); pro-environmental attitude (+); environmental awareness (+)	USA
Bauwens, 2016	Correlation analysis	RES; wind; sun; hydro	Participation in green energy communities	Pro-environmental attitude (+); social norms (+); preference for local investment/producer (+)	Belgium
Conte and Jacobsen, 2016	Regression	RES	Participation in green energy programmes	Education (+); consumption (n.s.)	USA
Ma et al., 2016	Discrete choice experiment	RES	WTP for RES	Age (n.s.); male (-); education (n.s.)	Australia
Kim et al., 2018	Discrete choice experiment	RES; nuclear	WTP for selected primary sources	Income (n.s.); age (n.s.); male (-); education (+); electricity bill (n.s.); altruism/warm glow (n.s.)	South Korea
Koto and Yiridoe, 2019	Contingent valuation	Wind	WTP for wind energy	Income (+); age (-); male (n.s.); education (+); house owner (-); married (-); environmental awareness (+)	Canada
Dong and Sigrin, 2019	Parametrization and calibration	Sun	WTP for PV panels	-	USA
Petrovich et al., 2019	Discrete choice experiment	Sun	Investment in PV panels	Income (n.s.); age (n.s.); male (+); house owner (n.s.); personal savings (+); energy literacy (n.s.); pro-environmental attitude (n.s.); social norms (+); opinion on PV aesthetics (+); technical affinity (+)	Switzerl.

* Impact of individual drivers on the independent variable: + positive, - negative, n.s. included but not statistically significant

Table 2.2 – Studies concerning consumer preferences toward renewable energy sources

Estimated WTP and participation rates

Most studies detect a positive reaction of households toward a renewable-based supply.

In one of the first studies concerning the purchase of renewable-based electricity contracts, Goett et al., 2000 estimate a positive WTP among residential consumers in the USA, and detect a preference for a mix of renewables or hydro over wind energy. Menges et al., 2005 detect a positive WTP among German households; however, they point out that WTP values might be decreasing for higher shares of renewables in the electricity supply contract. Burkhalter et al., 2009 and Plum et al., 2019 focus on Swiss households: the former detect a significant interest toward a hydro-based supply, or a supply mix including a large share of hydro plus a non-negligible share of solar, wind, and biomass energy; the latter find that solar and wind are the preferred sources to replace nuclear energy. According to both, Swiss households regard the generation mix as the most important characteristic of their supply, followed by the cost and the geographical origin of the electricity. Inland or local productions are preferred over electricity imported from abroad. Kaenzig et al., 2013 find similar results for German households: they prefer wind or a combination of wind and other renewables over any generation mix that includes fossil fuels, favour locally generated electricity and small and medium-sized electricity producers, and signal a strong interest toward labels that certify the lower environmental impact of the chosen mix. Groesche and Schroeder, 2011 also find a preference for a renewable-based supply over a nuclear-based supply among German households. By including random parameters (RPs) in their regressions, moreover, they also detect a sizeable and unexplained heterogeneity in consumer preferences.

Drivers of consumer preferences: demographic variables

Going beyond the bare measurement of WTP values or enrolment rates into green energy programmes, interesting hints emerge when researchers dig into the demographic, behavioural, and attitudinal determinants of consumer preferences with respect to renewables (Table 2.2).

First, the surveyed literature does not provide univocal evidence regarding the role of demographic factors. Household income and a higher educational achievement are often, but not always, positively correlated to WTP. Older age and male gender tend to be negatively correlated to WTP, although some analyses report null or positive correlation. Other drivers, such as the magnitude of electricity consumption, the amount of the electricity bill, and the presence of children in the household are also mentioned, but there is no clear evidence on the direction of their impact.

Behavioural and attitudinal drivers

The investigation of behavioural and attitudinal drivers provides more stable results. The study of these drivers builds upon different streams of literature, in which economics and psychology often touch.

A first group of studies, inspired by the so-called “theory of planned behaviour” (Ajzen, 1991), connects individual actions to behavioural intentions, that are in turn determined by psychological attitudes, subjective norms, and perceived behavioural control. The link between individual attitudes and consumer preferences is confirmed by several researchers. A pro-environmental attitude, for example, is often correlated with a higher WTP for renewables or an increased acceptance of sustainable supply options, as found in Borchers et al., 2007, Oliver et al., 2011, Cicia et al., 2012, Yoo and Ready, 2014, and Bauwens, 2016. The same holds for a positive attitude towards renewable energy sources in general, as found in Nomura and Akai, 2004, Hansla et al., 2008, and Litvine and Wüstenhagen, 2011.

A neighbouring stream of literature focusses instead on the link between habits, behaviours, and consumer preferences. The typical example is the connection between “green behaviours”, such as waste recycling, commuting by public transport, reducing energy consumption, etc., and the decision to purchase a renewable-based supply. Amador et al., 2013 find a correlation between a higher WTP for a renewable-based supply and the regular adoption of energy saving measures. Oliver et al., 2011 measure a higher WTP for green electricity among South African households who commit to waste recycling. Whitmarsh and O’Neill, 2010 argue that the regular adoption of green behaviours is the visible manifestation of a “green identity”; they find that a pro-environmental self-identity is a predictor of purchases of carbon off-sets among UK residents, but point out that other determinants play a stronger role.

Energy and investment literacy, together with environmental and energy awareness, may also drive individual decisions concerning green energy supply options. The empirical evidence is however controversial. Zoric and Hrovatin, 2012 find that Slovenian households are both more likely to engage in a green energy programme, and more willing to pay for green energy if they are more aware of environmental issues. Hansla et al., 2008 also detect a significant positive correlation between the WTP for green energy and the awareness of the possible consequences of environmental problems. Whitmarsch and O’Neill, 2010 find instead that the link between self-reported knowledge about climate change and pro-environmental behaviour is not significant. Similarly, Petrovich et al., 2019 in a study on Swiss households find that a sounder knowledge of the photovoltaic technology is not necessarily associated to a higher probability of investing in it.

Finally, another stream of literature depicts the purchase of renewable-based electricity as a voluntary contribution to a public good: consumer preferences are described as driven by generosity, altruism, the “warm glow” of giving, or self-transcendence. Menges et al., 2005, for example, in their experiment conducted among German households find evidence of the so-called “impure altruism”, i.e. the fact that participants gain a positive utility not only from their consumption of private and public goods, but also from personally contributing to the public good.

Weaknesses of the surveyed literature

Although most studies elicit a positive WTP for renewable-based electricity supplies, Zoric and Hrovatin, 2012 point out that the estimates are rarely expressed with easily comparable measures, and exhibit a substantial variability. Two meta-analyses investigate whether the causes of this variability lie in the characteristics of the studies. Both Ma et al., 2015 and Sundt and Rehdanz, 2015 find that the kind of renewable energy source considered in the analysis affects the WTP. Sundt and Rehdanz, 2015 also highlight an effect of the primary energy source that is going to be replaced by renewables on the magnitude of the WTP. Ma et al., 2015 find moreover that some demographic variables, such as age, gender, income, electricity consumption, and education level influence the WTP estimate, but the direction of their effect is not clear-cut. Both meta-analyses highlight that the design of the study impacts the magnitude of the estimated WTP; more specifically, Sundt and Rehdanz, 2015 find that DC experiments tend to produce higher WTP values than contingent valuation studies.

The link between study design and study results deserves some additional attention. The use of stated preferences analyses, largely dominant in this field, has allowed the researchers to analyse hypothetical scenarios sometimes radically departing from the status quo. This advantage has come at a price: hypothetical bias is often mentioned as a possible problem in stated preferences analyses (Foster and Burrows, 2017; McFadden, 2017), especially as the choice of an environmentally sustainable option might be subject to a social desirability bias. Zoric and Hrovatin, 2012 point out that the actual participation rates in green energy programmes are, indeed, lower than some of the estimates available in the literature. Litvine and Wüstenhagen, 2011 argue however that lower participation rates in the real world might be due to the lack of effective information campaigns by energy suppliers, while Menges et al., 2005 suggest that they might be due to consumers’ inertia, i.e. a tendency to stay with the status quo contract.

Overcoming the limitations of stated preferences

A few studies have sought to overcome the limitations of stated preferences by considering revealed preferences or other real market data. Roe et al., 2001 compare their results concerning the stated WTP of US consumers for a greener electricity supply to the price premium charged by electricity providers for their green options. Interestingly, they find that the average WTP for an additional 1% of renewable-based supply is only slightly lower than the price premium required in the green energy programmes under scrutiny. Kotchen and Moore, 2007 base their analysis of voluntary contributions to public goods on survey data from US residential electricity consumers, some of which are already enrolled in the green energy programmes. Their finding that the enrolment probability increases with altruism, environmental awareness, and household income is consistent with those of comparable studies based only on stated preferences. Litvine and Wüstenhagen, 2011 develop their investigation using survey data, but complement it with a follow-up analysis of the new subscriptions to a green energy programme among the electricity consumers who participated in the study. They find that providing consumers with selected information increases both the stated intention to purchase green energy, and the probability that the respondents actually subscribe to a green energy programme within four months. Bauwens, 2016 relies on a survey conducted among Belgian households participating in two community energy projects in order to investigate the motives behind the enrolment decision. He detects two - often substitute – kinds of drivers: pro-environmental orientation and identification with the local community on the one hand, financial motives on the other hand. Finally, Conte and Jacobsen, 2016 shift away from survey data, and evaluate the participation into the green energy programmes in the United States using supplier and county level data. In line with some stated preference studies, they find a positive correlation between enrolment into green energy programmes and both income and education. In sum, even if the estimated parameters are not easily comparable across studies, it seems reasonable to say that there is no glaring systematic difference between stated preferences analyses and studies based on revealed preferences or real market data.

2.2.2 Preferences toward nuclear generation

Objectives of the surveyed studies

The preferences of citizens and households towards nuclear generation have also been investigated in the past. A nuclear option is sometimes included in the analyses of consumer preferences with respect to a renewable-based supply, especially where nuclear generation is used on a large scale, or where it is a

viable alternative to renewables in order to reduce emissions (Table 2.2). Other studies focus instead on the WTP for nuclear generation per se (Contu et al. 2016, Contu and Mourato, 2016) or on the acceptance of nuclear generation and its drivers (Visschers et al., 2011, Stoutenborough et al., 2013, Visschers and Siegrist, 2013, Visschers and Wallquist, 2013).

Estimated WTP for a nuclear-based supply

A review of the recent studies that examine the WTP of residential consumers for a nuclear-based supply shows that in most cases consumers dislike nuclear generation, and rather choose renewables or, in some cases, gas-fired plants. Menges et al., 2005 find that the WTP of German households for an increased share of renewables is significantly lower if the supply contract also includes a contribution from nuclear. Kaenzig et al., 2013 estimate that German consumers would require a significant reduction in electricity prices in order to accept a 25% share of nuclear in their supply, and would prefer an equivalent contribution from gas-fired plants. Groesche and Schroeder, 2011 measure a substantial decrease in German consumers' WTP if their electricity supply contract includes a higher share of nuclear. Interestingly, however, they also detect a significant heterogeneity in consumer preferences: a small, but not negligible share of respondents shows a positive WTP for nuclear generation. Kim et al., 2018 conduct a similar analysis for South-Korean households, and find that they prefer renewables over fossil fuels, and fossil fuels over nuclear. Nonetheless, the preferences towards nuclear show a sizeable heterogeneity: the authors estimate that 14.3% of respondents chose nuclear energy in the experiment, whereas only 3.3% chose fossil fuels. Looking at a country that has phased out nuclear since the late 1980s, Cicia et al., 2012 find that Italian households do not welcome nuclear energy, especially those who are more sensitive to climate change and environmental issues, and care about conducting a healthy life. There are, however, studies that detect a less negative attitude of residential consumers toward nuclear generation. According to Burkhalter et al., 2009 Swiss households prefer nuclear over fossil fuels, although they still regard both sources as less desirable than renewables. Roe et al., 2001 find that US citizens express a positive WTP for a reduction in the greenhouse gas emissions associated to electricity production, with slightly lower, but still positive values if the reduction is achieved through nuclear generation instead of renewables. Contu et al., 2016 and Contu and Mourato, 2020 use DC models with latent classes to explore households' preferences with respect to fourth generation nuclear energy projects in Italy and the UK. In both cases, they find that more than 40% of the respondents are open to this technology; respondents evaluate positively both reductions in greenhouse gas emissions and nuclear waste, and compensatory measures such as land recovery, construction of new hospitals, and electricity bill discounts.

Acceptance of nuclear generation and its drivers

The studies that investigate the acceptance of nuclear generation per se shed instead a light on the role of demographic, cognitive, and emotional drivers, as well as the impact that nuclear accidents may have on acceptance.

Looking at demographic drivers, Mah et al., 2014 and Chung and Kim, 2018 find that men have a better perception of nuclear than women. Sun and Zhu, 2014 and Chung and Kim, 2018 also find that older respondents are less reluctant to accept nuclear generation.

Psychological drivers are considered with increasing attention. The general attitude towards nuclear generation can be influenced by the perceived risks (harmful consequences of accidents or irregular nuclear waste disposal), the perceived benefits (security of electricity supply, lower greenhouse gas emissions, reduced need of fuel imports, lower electricity bills), trust in the government or institutions in charge of overseeing nuclear generation, energy literacy especially in the field of nuclear generation, and finally environmental concerns. According to some researchers, political views may also play a role. These drivers are often intertwined: energy literacy, for example, is often connected to risk perception. More in detail, Visschers et al., 2011, Stoutenborough et al., 2013, and Visschers and Siegrist, 2013 find that a lower perception of the risks associated to nuclear generation, a higher perception of its benefits, and a stronger trust in the institutions in charge of overseeing nuclear plants are positively correlated to a higher acceptance of this technology. Visschers and Siegrist, 2013 report on the results of a longitudinal survey conducted in Switzerland before and after the Fukushima accident. Despite measuring a lower public support for nuclear generation after the accident, they argue that the relationships between risk and benefit perceptions and trust on the one hand, and acceptance of nuclear on the other hand, have not been affected by the accident. Contu et al., 2016 confirm that the acceptance of nuclear energy is negatively correlated to the perceived risks, and positively correlated to perceived benefits and confidence in the achievement of the fourth generation reactors' goals. Moreover, they highlight that risk perception is positively correlated to egoistic values, and benefit perception to altruistic ones. Contu et al., 2016 and Countu and Mourato, 2020 also exploit psychological drivers within their DC models and find that a higher confidence in fourth generation reactors, a lower perception of the associated risks and a higher perception of the associated benefits are correlated to a higher likelihood of belonging to the latent class of moderate nuclear supporters.

The individual literacy about nuclear generation and energy issues in general also impacts the acceptance of this technology. Jun et al., 2010 find that South-Korean survey participants who received accurate

information about nuclear generation expressed a higher WTP for a nuclear-based supply. Stoutenborough et al., 2013 detect a positive, although limited impact of a better knowledge of energy and nuclear issues on the US citizens' support for nuclear energy. Stoutenborough and Vedlitz, 2016 point out that self-reported knowledge often differs from actual knowledge; a higher self-reported knowledge of nuclear generation is often associated to a higher risk perception, whereas the reverse holds for actual knowledge. Thus, they recommend a cautious approach when deciding about the way in which knowledge about nuclear energy is included in the analysis. Finally, Contu et al., 2016 find that individuals who have heard about fourth generation reactors are more likely to be moderate nuclear supporters, and Contu and Mourato, 2020 detect a positive correlation between having heard of fourth generation reactors and the WTP for research programmes concerning this technology.

2.2.3 Our contribution to the literature

Our analysis investigates the preferences of Swiss households with respect to selected renewable energy sources, nuclear generation, and a variable share of renewable energy from unspecified sources within a "grey mix" contract. In line with comparable studies (Table 2.2), we evaluate households' preferences for each primary energy source, and assess the impact of demographic, behavioural, and attitudinal drivers on households' choices.

The use of a DC model allows us to study the different dimensions of the electricity supply contract that may matter to the consumer: price, primary energy source used, and supply reliability. This approach has already been adopted in previous studies evaluating households' preferences for different characteristics of the own electricity contract (Goett et al., 2000; Burkhalter et al., 2009; Amador et al., 2013; Kim et al., 2018). The structure of our DC model allows us to investigate whether households' preferences for different energy sources also depend on their reliability, and shed light on a topic that has rarely been considered in the vast literature concerning the acceptance of specific primary energy sources and generation technologies (among the exceptions: Amador et al., 2013; Cohen et al., 2016; Kim et al., 2018; Merk et al., 2019; Siyaranamual et al., 2020).

In line with several studies mentioned in Table 2.2 and paragraph 2.2, we investigate and quantify the possible impact of demographic and behavioural variables on consumer preferences for specific energy sources. Moreover, by including LVs representing attitudes directly into the HDCM, we also study the possible role of psychological traits, such as environmental awareness, trust in the traditional generation technologies, and other latent drivers that have been considered in the existing literature (Table 2.2). The

structural equations describing each LV in our HDCM allow us to connect each attitude to a set of relevant demographic and behavioural variables, and thus provide a more nuanced representation of individual behaviour as compared to the studies where psychometric indicators are directly included in the DC model (Borchers et al., 2007; Petrovich et al., 2019). By accounting for attitudinal traits, we are able to improve the efficiency of our estimates and provide a better understanding of the drivers of consumer behaviour. Our results may provide useful insights to policy makers involved in the energy transition and electricity retailers facing the challenges of decarbonisation and possible market opening.

2.3 Methodology

As already mentioned, the method we chose is a HDCM.

DC analysis assumes that a decision maker, when facing a set of mutually exclusive and collectively exhaustive alternatives, selects the one that provides him/her with the highest indirect utility. The utility the decision maker extracts from each alternative depends on the alternative's characteristics, the so-called "attributes", and may be influenced by the decision maker's demographic characteristics and attitudinal traits (Ben-Akiva and Lerman, 1985).

We expand the basic multinomial logit (MNL) specification of DC models by explicitly including attitudes as LVs in the observable component of the utility functions (Walker, 2001; Bolduc and Daziano, 2010, Abou-Zeid and Ben-Akiva, 2014). We estimate each LV simultaneously within the HDCM, and exploit as indicators the psychometric data, visible manifestations of the underlying latent attitude. Thus, we avoid the measurement error implicit in any fitted attitudinal variable developed ex ante using selected psychometric indicators (Train et al., 1987).

The econometric specification of a HDCM with LVs consists of the following equations (Walker, 2001; Abou-Zeid and Ben-Akiva, 2014)³:

$$[A.1] \quad U_{ijt} = V_{ij}(Z_j, X_i, X_i^*; \beta) + \varepsilon_{ijt}, \text{ with } \varepsilon_{ijt} \text{ i.i.d. } \sim EV(0, \mu_\varepsilon)$$

$$[A.2] \quad y_{ijt} = 1 \text{ if } U_{ijt} = \max_k \{U_{ikt}\}, \quad y_{ijt} = 0 \text{ otherwise}$$

$$[A.3] \quad X_i^* = h(X_i; \lambda) + \omega_i, \quad \omega_i \sim N(0, \Sigma_\omega)$$

$$[A.4] \quad I_i = m(X_i, X_i^*; \alpha) + v_i, \quad v_i \sim N(0, \Sigma_v)$$

³ Further details on the functioning of HDCMs with LVs are provided in Appendix A.

Where:

- U_{ijt} is the utility that respondent i extracts from choosing alternative j in choice task t ,
- Z_j is a vector of attributes of alternative j ,
- X_i is a vector of respondent i 's demographic variables,
- X_i^* is a vector of respondent i 's unobservable LVs,
- I_i is a vector corresponding to respondent i 's answers in selected psychometric statements,
- β , λ , and α are vectors of parameters to be estimated.

The HDCM is estimated via simulated maximum likelihood. The likelihood function corresponds to the integral of the DC model over the distribution of the LVs, as measured through the selected indicators:

$$[A.5] \quad L = \int P(y_{ijt}|Z_{jt}, X_i^*, X_i; \beta, \Sigma_\varepsilon) * g(I_i|X_i, X_i^*; \alpha, \Sigma_v) * f(X_i^*|X_i; \lambda, \Sigma_\omega) dX_i^*$$

This mathematical framework allows the researchers to explore the systematic, but otherwise unobservable drivers of heterogeneity in consumer behaviour, and quantify the magnitude of their impact on consumer choices (Vij and Walker, 2016). As the estimation process is rather complex (Abou-Zeid and Ben-Akiva, 2014), some researchers (Mariel and Meyerhoff, 2016) have raised concerns regarding the performance of these models with respect to RP DC models that exploit simpler estimation procedures to measure heterogeneity without investigating its drivers. Mariel and Meyerhoff, 2016 argue however that while the predictive power of the two types of models is comparable, HDCM with LVs provide insights into the “black box” of the choice process that cannot be obtained through an ex post analysis of the distributions of RPs. Moreover, HDCM with LVs outperform RP models when the assessment of the magnitude and direction of the impact of psychological drivers on consumer choices is relevant to policy making (Mariel and Meyerhoff, 2016, Vij and Walker, 2016). Finally, Vij and Walker, 2016 argue that HDCM with LVs improve on specifications neglecting latent constructs whenever the researchers need to test more sophisticated hypotheses on consumer behaviour, and help identifying observable variables that impact choices through latent constructs, thus reducing the risk of incurring into omitted variable bias.

Some researchers (Abou-Zeid and Ben-Akiva, 2014; Chorus and Kroesen 2014) have discussed the limitations of HDCMs with LVs from a practical perspective, questioning the possibility of drawing policy suggestions based on this kind of models. They argue that latent attitudes may be endogenous to individual choices, particularly in revealed preference analyses, and that policy recommendations should not target LVs, as these are usually collected at one point in time, and thus their impact on choices can only be evaluated through between-person comparisons. Within our setting, however, these concerns should not hinder the development of sound policy implications. First, the possible endogeneity of the LVs

is less problematic, as our DC analysis is based on stated preferences and thus a reverse effect from choices to LVs is less likely to happen (Abou-Zeid and Ben-Akiva, 2014; Chorus and Kroesen 2014; Vij and Walker 2016). Secondly, the fact that we describe LVs through structural equations exploiting observable demographic and behavioural variables implies that we are able to provide a better representation of the channels through which these observable variables influence consumer preferences, and to evaluate what consequences may derive from policies or exogenous changes impacting specific observable variables rather than LVs per se (Vij and Walker 2016). On the other hand, our insight into the attitudinal drivers of household choices may serve as a basis to evaluate scenarios in which these drivers should change for exogenous reasons. Finally, a detailed understanding of the way individuals decide may support the design of communication or information strategies eliciting the desired reactions among citizens (Vij and Walker 2016).

2.4 Data

We conducted the DC experiment by means of an on-line survey, that was translated in French and German and distributed in January and February 2015 through an independent market research company. We collected 1006 valid responses, including a pre-test on a sub-sample of approximately 100 respondents. The sample was stratified in order to ensure a reasonable representativeness of the Swiss population. Descriptive statistics are available in Appendix 2.B.

4.1 Structure of the survey

The survey included:

- A short introduction explaining the purpose of the analysis,
- 30 psychometric questions: the respondents were asked to state on a 7-points Likert scale their agreement or disagreement with statements concerning electricity production and consumption and environmental problems. The statements were developed drawing from the surveyed literature,
- Questions regarding the respondent's habits and behaviour in the fields of energy consumption and environmental sustainability,
- Questions regarding the typical demographic variables,

- The DC experiment, consisting in seven choice tasks: in each of them, the respondents had to choose one out of five alternative electricity supply contracts for their own dwelling (Table 2.3). A short introductory text described the contributions of each primary energy source, the average electricity price, and the average blackout frequency and duration observed in Switzerland during the previous year.

Please select the electricity supply contract you would be ready to sign for your own flat or house. You can choose only one contract.

	Nuclear	Mix - of which 60% from renewables	Hydro	Solar	Wind
Price (centCHF/kWh)	18	27.5	21	24	50
Nr of 5 minutes blackouts	0	1 per year	1 per year	4 per year	1 per year
Nr of 4 hours blackouts	4 per year	4 per year	0	0	0
Your choice:					

Table 2.3 – Example of a choice task

4.2 Structure of the DC experiment

The alternative contracts included in each choice task were described through the following attributes:

- Kind of primary energy source used, also used as a label to identify the alternatives. In order to reduce complexity for the layman, the DC experiment did not mention specific generation technologies,
- Price of electricity in centCHF/kWh,
- Frequency of short (5 minutes) blackouts,
- Frequency of long (4 hours) blackouts,
- Share of renewable-based generation from unspecified energy sources in the “mix” alternative.

Table 2.4 provides an overview of the attributes and corresponding levels. Some price levels were not available for all alternatives, and the attribute “share of electricity from renewable energy sources” was only available for the mix alternative. The attribute levels were defined based on the current and

prospective structure of the electricity generation and retailing activities in Switzerland, and drawing from the experiences of other European countries.

Attributes	Levels
Primary energy source used for generation (This attribute is used as a label for the alternatives included in each choice task)	nuclear; mix; hydro; sun; wind
Price (cent CHF/kWh)	14.5 (not available for hydro, sun, wind); 18 (not available for sun); 21; 24; 27.5; 50
Nr of 5 minutes blackouts	0; 1 every four years; 1 per year; 4 per year
Nr of 4 hours blackouts	0; 1 every four years; 1 per year; 4 per year
% of electricity from renewable sources (This attribute is defined only for the mix alternative)	40; 60; 80; 100

Table 2.4 – DC experiment: alternatives, attributes, and attribute levels

The blackout attributes were described to the respondents as most likely frequencies of a short or long interruption over the upcoming years. When opting for a specific contract, the respondent did not commit to an interruptible service, but rather accepted a given outage risk.

4.3 Design of the DC experiment

The choice tasks were developed using the software NGene through an efficient design with blocking.

The priors for the attributes' parameters were defined based on the surveyed literature: we assumed a slight preference for renewables over the nuclear and mix alternatives, a modest dislike for price increases, and a stronger aversion for short and long blackouts. We also expected a sizeable heterogeneity in consumer preferences with respect to nuclear generation, and a non-zero covariance in the error terms of the nuclear and hydro alternatives, building the backbone of the Swiss electric system, and in those of the 100% renewable based alternatives, namely hydro, sun, and wind. Thus, we defined the optimal choice task structure by averaging a RP and an error component specification.

The final design consisted in eight blocks containing seven choice tasks each: each respondent was randomly assigned to one of the eight blocks. Thus, we collected 7042 choices.

2.5 Results

2.5.1 Overview

Using the software PythonBiogeme (Bierlaire, 2016) we estimated a series of DC models with increasing complexity. Considering the model fit (McFadden adjusted R-squared), significance of the results, and coherence with comparable studies, we chose a HDCM with two LVs as our preferred specification.

Figure 2.1 provides a visual description of our HDCM according to the standard format described in Walker, 2001 and Abou-Zeid and Ben-Akiva, 2014. Consumer preferences are directly influenced by the alternatives' attributes (Z_j), a set of observable demographic and behavioural characteristics of the respondents (X_i), and two attitudes characterizing the same respondents, the LVs "informed optimism" and "environmental concern" (X_i^*). Each LV is identified through the responses provided to three psychometric indicators (I_i), and is in turn correlated to a set of observable demographic and behavioural variables. Rectangles represent observable variables, ovals latent constructs; solid arrows correspond to structural equations, dotted arrows to measurement equations.

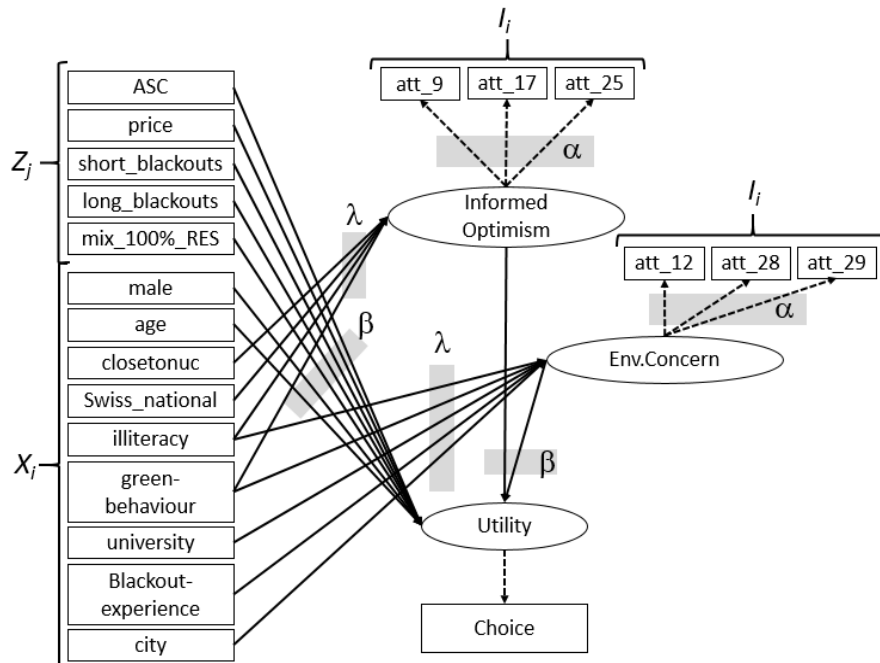


Figure 2.1 – Scheme of the HDCM with two LVs

The two LVs representing attitudinal traits of the respondents were identified starting from a principal component analysis of the responses collected in the attitudinal statements' section of the survey. Table 2.5 provides an overview of the two main components that were tested and exploited to build the LVs.

	Average	Standard Deviation	Loading	% of variance	Cronbach Alpha
The statements are evaluated on a Likert scale from 1 to 7, where 1 means "Completely disagree", 7 means "Completely agree"					
Component 1: "Environmental concern"					
att_29: I am worried about climate change	5.52	1.50	0.30	20.8%	0.76
att_12: I am worried about pollution	5.84	1.30	0.30		
att_28: It is important to generate electricity using renewable energy sources	6.36	1.04	0.29		
Component 2: "Informed optimism"					
att_9: I think the risk of a nuclear accident in Switzerland is very low	4.22	1.84	0.32	6.7%	0.69
att_25: It is dangerous to live close to a nuclear generation plant	4.60	1.92	-0.40		
att_17: It is dangerous to live close to a gas-fired generation plant	3.88	1.60	-0.42		

Table 2.5 – Results of a principal component analysis of the responses provided to the attitudinal statements

Components 1 and 2 are related to the kind of energy source used for generating electricity, and show reasonably good properties in terms of explained variance and internal consistency, as measured by the Cronbach Alpha. Component 1 measures a positive attitude towards environmental issues: hence, we named the corresponding LV “environmental concern”. Component 2 measures instead a confident attitude towards the risk of accidents involving nuclear generation and gas-fuelled plants; we defined the corresponding LV as “informed optimism”.

Table 2.6 collects the detailed results of our estimations: the HDCM with two LVs depicted in Figure 2.1 is identified as model [4]. As a term of comparison, Table 2.6 also collects the results of two MNL specifications, models [1] and [2], and a RP specification, model [3].

	[1] MNL	[2] MNL with demographic variables	[3] RP with demographic variables	[4] HDCM with LVs
Nr of estimated parameters	22	31	33	54
McFadden adj. R squared	0.22	0.23	0.23	0.36
Nr. of Halton draws	-	-	500	500
Nr. of individuals	1006	1006	1006	1006
Parameters: discrete choice model				
ASC_hydro	0.106	0.572*	0.581**	0.273
ASC_nuclear	-1.01***	-0.0683	-1.01*	-0.283
ASC_nuclear_std_dev			2.42***	
ASC_sun	-0.0769	0.672**	0.696***	0.379
ASC_wind	0.683***	1.24***	1.25***	0.941***
Beta_price_hydro	-0.0571***	-0.0573***	-0.058***	-0.0573***
Beta_price_mix	-0.0615***	-0.062***	-0.067***	-0.062***
Beta_price_nuc	-0.0884***	-0.0927***	-0.112***	-0.0916***
Beta_price_sun	-0.0477***	-0.0481***	-0.049***	-0.0481***
Beta_price_wind	-0.0801***	-0.0801***	-0.0805***	-0.0802***
Beta_mix_100%_RES	0.556***	0.559***	0.538***	-0.0681
Beta_mix_100%_RES_std_dev			1.26***	
Beta_mix_40%_RES	-0.0266	-0.0249	0.0211	-0.0235
Beta_mix_80%_RES	0.0818	0.0836	0.107	0.081
Beta_short_blackout_hydro	-0.128***	-0.128***	-0.131***	-0.129***
Beta_short_blackout_mix	-0.0642***	-0.0665***	-0.0676***	-0.0664***
Beta_short_blackout_nuc	-0.138***	-0.145***	-0.176***	-0.145***
Beta_short_blackout_sun	-0.137***	-0.139***	-0.145***	-0.139***
Beta_short_blackout_wind	-0.215***	-0.216***	-0.222***	-0.215***
Beta_long_blackout_hydro	-0.445***	-0.448***	-0.456***	-0.447***
Beta_long_blackout_mix	-0.283***	-0.285***	-0.304***	-0.286***
Beta_long_blackout_nuc	-0.269***	-0.284***	-0.359***	-0.281***
Beta_long_blackout_sun	-0.432***	-0.436***	-0.444***	-0.436***
Beta_long_blackout_wind	-0.564***	-0.566***	-0.579***	-0.566***
Beta_age_mix		0.0147***	0.0172***	0.0149***
Beta_male_hydro		0.249*	0.252**	0.25*
Beta_male_nuc		0.756***	1.2***	0.731***
Beta_male_sun		-0.33**	-0.336***	-0.33**
Beta_male_wind		0.065	0.0673	0.067
Beta_green-behaviour_nuc		-0.445***	-0.769***	
Beta_blackout-experience_nuc		0.289***	0.418***	
Beta_illiteracy_nuc		-0.0603	-0.0541	
Beta_Swiss_nuc		-0.00209***	-0.00394***	
Beta_LV_Env.Concern_RES				-0.273
Beta_LV_Env.Concern_mix_100%_RES				0.123***
Beta_LV_Env.Concern_mix				-0.333
Beta_LV_InformedOptimism_nuc				0.633*

(The table continues on the next page)

	[1] MNL	[2] MNL with demographic variables	[3] RP with demographic variables	[4] HDCM with LVs
Parameters: LV "Environmental concern"				
Lambda_LV_Env.Concern_city				0.633***
Lambda_LV_Env.Concern_green-behaviour (lights, heating, RES)				1.78***
Lambda_LV_Env.Concern_blackout-experience (at least 1)				0.286**
Lambda_LV_Env.Concern_illiteracy (insulating windows/walls, solar heating, PV, minergie, el. bill, other en. sav. eq., other RES eq.)				0.532***
Lambda_LV_Env.Concern_university				0.986***
Alpha_LV_Env.Concern_att12 (I am worried about pollution)				0.164***
Alpha_LV_Env.Concern_att28 (Generating electricity via RES is important)				0.0879***
Psychometric indicators: intercepts and sigmas				√
Parameters: LV "Informed optimism"				
Lambda_LV_InformedOptimism_Swiss_national				-0.00203***
Lambda_LV_InformedOptimism_closetonuc (resides in a district with nuclear or bordering a French/Swiss district with nuclear)				-0.469***
Lambda_LV_InformedOptimism_green-behaviour (lights, heating, RES)				-1.43***
Lambda_LV_InformedOptimism_illiteracy (insulating windows/walls, solar heating, PV, minergie, eletricity bill, other en. sav. eq., other RES eq.)				-0.48***
Alpha_LV_InformedOptimism_att25 (It is dangerous to live close to a nuclear generation plant)				-0.184***
Alpha_LV_InformedOptimism_att9 (I think the risk of a nuclear accident in Switzerland is very low)				0.181***
Psychometric indicators: intercepts and sigmas				√

* Significant at 5%; ** Significant at 1%, *** Significant at 0.1%

Table 2.6 – Estimated parameters

2.5.2 Main findings

The results collected in Table 2.6 allow us to draw three main messages concerning the preferences of Swiss households toward the energy sources considered in the analysis.

First, household preferences are expressed as different sensitivities toward variations in the price and reliability of the electricity supply depending on the source used, rather than as ceteris paribus preferences for each source per se. Table 2.6 shows indeed that the alternative-specific constants (*ASC_source*), that measure preferences for each primary energy source per se, are not statistically significant, with the exception of the wind-based contract. The price and blackout coefficients (*Beta_price_source*,

Beta_short_blackout_source, *Beta_long_blackout_source*) are instead negative, as expected, and show that price sensitivity hits its maximum for the nuclear contract, blackout sensitivity for the wind-based supply.

Secondly, among the typical demographic variables only gender and age are directly correlated to a higher propensity to choose a specific primary energy source. Men are more likely than women to choose the nuclear or hydroelectric options (*Beta_male_nuc*, *Beta_male_hydro*) and less likely to choose the solar one (*Beta_male_sun*); older respondents are more likely to go for the mix alternative (*Beta_age_mix*). Other demographic and behavioural variables influence consumer preferences only indirectly, through their correlation with the two LVs.

Finally, individual attitudes as measured by the two LVs do influence consumer choices. A higher value of the LV environmental concern is associated to a more positive evaluation of a 100% renewable-based supply in the mix alternative (*Beta_LV_Env.Concern_mix_100%_RES*). A higher value of the LV informed optimism is instead associated to a higher propensity to choose the nuclear option (*Beta_LV_InformedOptimism_nuc*). The structural equations connecting each LV to the relevant demographic and behavioural drivers reveal that environmental concern is positively correlated to the regular adoption of green behaviours (variable “green behaviour”), having a university degree, living in a city rather than in a town or in the countryside, being less informed about the own energy consumption pattern (“illiteracy”), and finally having experienced one or more blackouts in the past 12 months. The LV informed optimism is instead negatively correlated to green behaviour, illiteracy, residing in a district close to a nuclear generation plant, and finally being a Swiss national. The magnitude of the impact of the LVs is comparable to that of gender.

It is interesting to note that environmental concern does not influence consumer preferences towards the sun-, hydro-, or wind-based contracts (*Beta_LV_Env.Concern_RES*), nor towards the mix alternative per se (*Beta_LV_Env.Concern_mix*). Instead of choosing a specific energy source, the environmentally concerned respondents rather leave to their supplier the choice of the renewable energy mix. On the other hand, the dummy variable for a 100% renewable-based supply in the mix alternative (*Beta_mix_100%_RES*) does not produce a significant coefficient per se: the interest in a renewable-based supply is only kindled among the consumers that record a higher environmental sensitivity.

It is also interesting to remark that the estimates are stable across the four specifications, with just two exceptions. Indeed, *Beta_mix_100%_RES* is positive in models [1] and [2], positive, but with a sizeable standard deviation (*Beta_mix_100%_RES_stddev*) in model [3], and not significant in model [4]. This

suggests that the MNL specifications hide some substantial heterogeneity, and that the inclusion of the LV environmental concern (*Beta_LV_Env.Concern_mix_100%_RES*) is crucial to improve the assessment and understanding of consumer preferences toward renewables. Similarly, model [3] detects a sizeable heterogeneity in ceteris paribus attitudes towards the nuclear alternative (*ASC_nuclear_stddev*), which is explained in model [4] through the LV informed optimism (*Beta_LV_InformedOptimism_nuc*).

2.5.3 Attitudinal and behavioural drivers: discussion

The findings concerning the link between green behaviour and illiteracy on the one hand, and the environmental concern and informed optimism on the other hand, deserve some additional comment.

The variable green behaviour is an index ranging from 0 to 3; the respondent gets one point for having a renewable-based contract, one for always switching off lights when not needed, and one for lowering the heating at night. The structural model for environmental concern suggests that the strongest observable predictor of this latent construct is the regular adoption of environmental-friendly choices in everyday life. This finding is coherent with the suggestions of the literature concerning the link between the propensity to choose a renewable-based supply on the one hand, and green habits, behaviour, or identity on the other hand (Whitmarsh and O'Neill, 2010, Oliver et al., 2011, Amador et al., 2013).

The variable illiteracy is instead an index ranging from 0 to 7 and counting how many times the respondents answered “I don’t know” in a series of questions regarding the average electricity bill and the availability of green facilities at the own dwelling⁴. The structural model for environmental concern reveals that energy illiteracy is positively correlated to the pro-environmental attitude: this suggests that the environmentally concerned respondents might be attracted by the warm glow feeling sparked by the choice of a green option, rather than by the actual environmental impact of their chosen option. This finding is particularly interesting if we consider it against the literature concerning the role of green labels, such as the EU Energy Labels, in influencing consumer choices. Andor et al., 2020 show, for the neighbouring sector of energy efficiency of household appliances, that consumers use heuristic thinking and rely on energy efficiency labels for their choices rather than investigating the real energy (and economic) savings achieved by the chosen product or service. It is crucial, then, that energy labels are carefully designed and closely monitored, in order to ensure that they meet a given environmental

⁴ The facilities included in the list are: insulating windows, insulating wall panels, solar heating, photovoltaic panels, other Minergie equipment, other energy saving devices, other devices for exploiting renewable energy.

standard and fulfil the customers' expectation of a lower environmental impact. According to our estimates, this message also holds for the labels used for energy supply contracts.

The structural model for the LV informed optimism suggest instead that the respondents showing a more positive attitude towards nuclear generation and fossil fuels are, less likely to adopt green behaviours, but also better informed as regards their own energy consumption patterns. It is plausible to assume that a more accurate knowledge of the own consumption is a signal of a stronger interest in energy-related issues and, possibly, an increased awareness of the risks and benefits of the available generation technologies. If this is the case, our result confirms the findings of Jun et al., 2010, and Stoutenborough et al., 2013 as regards the role of knowledge and information in favouring the acceptance of the nuclear technology. It is also interesting to note that the respondents who show a high level of informed optimism - and are hence more likely to accept a nuclear-based supply - are less likely to live close to a nuclear plant. The demographic variable "close to nuclear" is a 0-1 dummy that takes value 1 if the respondent lives in a Swiss district that hosts a nuclear plant, or borders a district hosting a nuclear plant, or borders France in close proximity to a French nuclear plant.

2.6 Conclusion and policy implications

Decarbonizing the economy is one of the biggest challenges that modern economies face in this decade. Switzerland, as several other countries, has drafted a long-term strategy to achieve its decarbonisation target and phase out nuclear generation. The acceptance of citizens is a key ingredient for a smooth and efficient evolution of the energy systems, particularly where citizens are entitled to contribute to the definition of energy policies through referenda.

We build on the suggestions of the literature concerning household preferences for renewable energy sources and acceptance of nuclear energy, and develop an original contribution in which latent attitudinal drivers are explicitly considered among the determinants of individual behaviour towards each primary energy source. Our model sheds light on the multidimensional nature of consumer preferences by measuring households' reactions toward changes in the origin, price, and reliability of the own electricity supply, quantifies the influence of demographic, behavioural, and attitudinal drivers on household choices, and finally evaluates the relation between attitudes and demographic and behavioural variables.

We find that household preferences toward different primary energy sources translate into different sensitivities toward variations in the price and reliability of the own electricity supply. Our measures of the

trade-offs that consumer perceive among these attributes may help electricity retailers in defining the combinations of prices and energy sources that best meet their customers' expectations, and provide a basis for exploring the potential for demand response among residential consumers. Moreover, our assessment of the perceived trade-offs between the sustainability, affordability, and security of electricity supply may support the design of a transition path that elicits the least opposition among citizens.

Our analysis also points out that a few characteristics of the individuals, among which the attitudinal drivers environmental concern and informed optimism, directly influence consumer preferences. A higher environmental concern is associated to a stronger preference for a 100% renewable-based mix, whereas a higher informed optimism is associated to an increased likelihood of accepting a nuclear-based supply. While it is difficult to envisage policies specifically targeting the above-mentioned attitudinal drivers, our findings suggest that policy makers or other stakeholders might target instead individual behaviours that show a significant correlation with them. Information campaigns or policies promoting the regular adoption of environmental-friendly behaviours could foster environmental sensitivity, while initiatives aimed at spreading a higher awareness of the own energy consumption patterns could improve informed optimism. Moreover, policy makers or electricity companies might consider monitoring the evolution of the relevant attitudes through standing panels, repeated surveys⁵, or other research approaches.

Our results also show that a higher environmental concern – and hence a higher probability of choosing a 100% renewable-based supply from unspecified sources – tends to be associated to a lower energy literacy. As residential consumers may naively choose renewable-based supply options for altruistic reasons or environmental sensitivity, policy makers and energy regulators should carefully monitor the formal and informal labelling of electricity supply contracts by retailers, and ensure that options marketed as “green” actually meet the expectations of their subscribers.

This study is also subject to some limitations that can serve as a starting point for further research.

In the first place, our analysis is based on Swiss data. Hence, while our results concerning the increasing importance of attitudinal drivers in determining consumer preferences towards the energy transition are probably valid for most countries, the role of specific attitudes and the shape of consumer preferences could change depending on the context. Replicating the analysis in other countries with a different generation mix and different procedures for achieving or acknowledging citizens' consensus might yield interesting insights into the relationship between context, attitudes, and preferences.

⁵ An example in Switzerland is Cousse et al., 2020.

Secondly, we recognize that the role of specific attitudinal drivers might change along with the implementation of the energy transition. A careful evaluation of the evolution of consumers' attitudes and preferences could inform strategies to elicit or preserve consensus while progressing in the restructuring of the energy system.

Finally, we do not address consumer preferences with respect to the distributed generation technologies that provide an alternative to the purchase of a green contract from the traditional electricity suppliers. Several contributions have assessed consumer preferences toward specific features of the new small-scale generation technologies (Alvarez-Farizo and Hanley, 2002; Petrovich et al., 2019), explored the drivers of households' investment decisions (Petrovich et al., 2019), or evaluated the motives behind the decision of joining a local energy community (Bauwens, 2016). An investigation into the subjective and objective drivers that influence the choice between purchasing a green contract, investing in a private generation system, or joining an energy community might bridge the gap between these neighbouring streams of research.

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Appendix 2.A

This Appendix provides further details on the mathematical structure of a HDCM with LVs. We refer to Ben-Akiva and Lerman, 1985 for further details on the functioning of DC models, and Walker, 2001 and Abou-Zeid and Ben-Akiva, 2014 for an insight on the structure, advantages, and limitations of HDCM with LVs.

The basic structure of a DC model is the following:

$$[A.1] \quad U_{ijt} = V_{ij}(Z_j, X_i; \beta) + \varepsilon_{ijt}, \text{ with } \varepsilon_{ijt} \text{ i.i.d. } \sim EV(0, \mu_\varepsilon)$$

$$[A.2] \quad y_{ijt} = 1 \text{ if } U_{ijt} = \max_k \{U_{ikt}\}, y_{ijt} = 0 \text{ otherwise}$$

Where U_{ijt} is the utility that respondent i extracts from choosing alternative j in choice task t , Z_j is a vector of attributes of alternative j , X_i is a vector of respondent i 's demographic variables, β is a vector of parameters to be estimated, and y_{ijt} is a dichotomous variable that takes value 1 if respondent i chose alternative j in choice task t , and 0 otherwise. In other words, the DC model assumes that:

- In choice task t respondent i will choose alternative j within the choice set C_t if j is the alternative that provides him/her the highest utility: $P(y_{ijt}) = P(U_{ijt} \geq U_{ikt}, \forall j \in C_t)$
- The utility that i draws from each alternative j can be described as the sum of a deterministic and a random component. The former depends on the alternatives' characteristics Z_j and on i 's demographic variables X_i , the latter is modelled as an error term that, in the case of the MNL model, is assumed to be *i. i. d.* $\sim EV(0, \mu_\varepsilon)$.

The basic DC model thus consists of:

- A structural equation [A.1], connecting the inherently unobservable utility of respondent i to i 's observable characteristics and to the observable characteristics of each alternative $j \in C_t$,
- A measurement equation, [A.2], connecting i 's unobservable utility to an observable indicator choice indicator, y_{ijt} , i.e. respondent i 's choice in choice task t .

In the case of a HDCM with LVs, this basic framework is expanded to include in the deterministic component of the utility function one or more LVs X_i^* , each representing an attitudinal trait of the respondent that may influence his/her choices. Equation [A.1] thus becomes:

$$[A.3] \quad U_{ijt} = V_{ij}(Z_j, X_i, X_i^*; \beta) + \varepsilon_{ijt}, \text{ with } \varepsilon_{ijt} \text{ i.i.d. } \sim EV(0, \mu_\varepsilon)$$

The attitudinal traits of the respondent are included in the form of LVs because they cannot be directly observed as such, but are rather revealed by the respondent through his/her evaluations of a set of psychometric indicators. Thus, each LV X_i^* describing an attitudinal trait is modelled through a structural equation, [A.4], connecting the LV to the relevant observable demographic variables, and a few measurement equations [A.5], connecting the LV to a set of relevant psychometric indicators I_i :

$$[A.4] \quad X_i^* = h(X_i; \lambda) + \omega_i, \quad \omega_i \sim N(0, \Sigma_\omega)$$

$$[A.5] \quad I_i = m(X_i, X_i^*; \alpha) + v_i, \quad v_i \sim N(0, \Sigma_v)$$

Where λ and α are parameters to be estimated.

Assuming that the error terms ε , ω and v are independent, the joint probability that respondent i chooses alternative j in choice task t and provides a given evaluation for indicator I_i is:

$$[A.6] \quad P(y_{ijt}, I_i | Z_{jt}, X_i^*, X_i; \beta, \alpha, \lambda; \Sigma_\varepsilon, \Sigma_v, \Sigma_\omega) = \int P(y_{ijt} | Z_{jt}, X_i^*, X_i; \beta, \Sigma_\varepsilon) * g(I_i | X_i, X_i^*; \alpha, \Sigma_v) * f(X_i^* | X_i; \lambda, \Sigma_\omega) dX_i^*$$

That is, the probability that respondent i chooses alternative j in choice task t conditional on the distribution of each LV X_i^* , multiplied by the conditional density function of the indicators, integrated over the density function of the LV X_i^* .

Based on this framework, HDCMs with LVs can be estimated via simulated maximum likelihood, using an appropriate software as explained in paragraph 2.3.

Appendix 2.B

Gender	Sample	Population (2015)
Men	49.1%	49.5%
Women	50.9%	50.5%
Age group		
15-29	27.9%	27.3%
30-44	31.1%	32.0%
45-59	33.0%	33.9%
60-64	8.0%	6.8%
Language		
German	73.9%	74.0%
French	26.1%	26.0%
Lives in:		
Cities and agglomerations	79.1%	73.8%
Countryside	20.9%	26.2%
Nationality		
Swiss	80.4%	75.7%

Table 2.B.1 - Descriptive statistics for the sample and the Swiss population⁶

⁶ The descriptive statistics for the Swiss population are based on the census published by the Swiss Federal Office of Statistics.

Green equipment	Yes	I don't know
Insulating window panes	82%	4%
Insulating walls	62%	15%
Solar heating	11%	5%
Photovoltaic panels	7%	3%
Minergie standard	13%	13%
Other energy saving equipment	21%	26%
Other renewable energy equipment	8%	19%
Green behaviour		
Light off when not needed	91%	
Heating off at night	65%	
Renewable electricity contract	44%	38%
Electricity bill: awareness	Yes	No
In charge of paying electricity bill	81%	19%
Electricity bill per semester		
Below 200 CHF	25%	
201-400 CHF	38%	
401-800 CHF	13%	
Above 800 CHF	3%	
I don't know		21%
Blackout experience		
Short blackout at home	27%	
Short blackout at work	10%	
Long blackout at home	21%	
Long blackout at work	8%	

Table 2.B.2 – Sample description: consumption pattern, green behaviour, and previous blackout experience

Please evaluate each of these statements by stating how much you agree with it on a scale from 1 to 7. 1 means "Completely disagree", 7 means "Completely agree"	Average	Std. Dev.
Building new generation plants is essential to satisfy the increasing demand for electricity	4.74	1.70
Building new electricity generation plants from renewable energy sources is essential to satisfy the increasing demand for electricity	5.95	1.32
It is important to generate electricity using renewable energy sources	6.36	1.04
Most private buildings should be endowed with solar or photovoltaic panels	5.59	1.53
Wind turbines are noisy, which bothers the people who live near them	3.10	1.60
Wind turbines are dangerous for migrant birds and damage the fauna	3.32	1.55
Wind turbines spoil the scenery	2.86	1.69
I'm not worried about the risk of a nuclear accident in Switzerland	3.36	1.98
I think the risk of a nuclear accident in Switzerland is very low	4.22	1.84
It is a good idea to dismantle all nuclear plants in Switzerland	5.14	1.96
It is dangerous to live close to a nuclear generation plant	4.60	1.92
It is dangerous to live close to a coal-fired generation plant	4.27	1.65
It is dangerous to live close to a gas-fired generation plant	3.88	1.60
Electricity can be imported from foreign countries with no risk	3.16	1.58
It is safe to import electricity from abroad	3.40	1.49
I feel worried about depending on foreign countries for energy supplies	4.40	1.64
Depending on foreign countries for our energy supplies endangers our economy	4.51	1.57
Carbon dioxide from burning coal, oil, and natural gas is causing global warming	5.83	1.31
I find blackouts annoying	4.94	1.67
Blackouts can be very costly for private companies	5.28	1.47
Blackouts can be very costly for households	4.05	1.73
I feel in danger when a blackout occurs at my place	2.45	1.50
I am worried about the risk of future increases in electricity prices	4.36	1.75
If global warming does occur, it would be bad for people and the environment	5.98	1.29
I am worried about the consequences of pollution	5.84	1.30
I am worried about the consequences of climate change	5.52	1.50
Everyone should behave in an environmental friendly way	6.36	1.03
As a society, we should be using less oil, coal, and natural gas in order to reduce environmental impacts on land, water, and air quality	5.92	1.28
It is important to save energy in everyday consumption	6.21	1.12
It is my responsibility to behave in an environmental friendly way	5.96	1.25

Tab. 2.B.3 – Sample description: evaluation of statements concerning environmental or energy issues

	Nuclear	Mix	Wind	Hydro	Sun
Nr. of times this alternative was chosen	390 (5.5%)	2166 (30.8%)	1466 (20.8%)	1519 (21.6%)	1501 (21.3%)
Nr. of respondents who never chose this alternative	806 (80.1%)	222 (22.1%)	309 (30.7%)	304 (30.2%)	355 (35.2%)
Nr. of respondents who always chose this alternative	3 (0.3%)	42 (4.2%)	5 (0.5%)	6 (0.6%)	29 (2.9%)

Nr. of respondents: 1006; nr. of choice tasks completed: 7042.

Tab. 2.B.4 – Alternatives chosen in the DC experiment: general overview

	Alternative with the lowest price	Alternative with the lowest nr. of short blackouts	Alternative with the lowest nr. of long blackouts	Alternative with the lowest total nr. of long blackouts
Nr. of times this alternative was chosen	2015 (28.6%)	1333 (18.9%)	1772 (25.2%)	2115 (31.4%)
Nr. of respondents who always chose this alternative	6 (0.6%)	0 (0.0%)	0 (0.0%)	2 (0.2%)

Nr. of respondents: 1006; nr. of choice tasks completed: 7042.

Table 2.B.5 – Outcomes of the choice experiment: alternatives chosen by price and frequency of long and short blackouts

3. Security of supply and the energy transition: the households' perspective investigated through a discrete choice model with latent classes

Abstract

A consumer-centric, market-based approach to the security of electricity supply has been recognized as increasingly important in the context of the energy transition. Nonetheless, there is no clear-cut evidence regarding the drivers of consumer preferences toward security and the perceived trade-offs between security and sustainability. Using stated preference data, we develop a discrete choice model with latent classes to assess the willingness-to-accept (WTA) of Swiss households for variations in the frequency and duration of blackouts, while accounting for the primary energy sources used for generation. Our WTA estimates range from slightly negative values up to ten times the current electricity prices, depending on the characteristics of both blackouts, and respondents. More specifically, we identify three latent classes showing different preferences toward blackout frequency and length, but also different sensitivities toward blackouts associated to nuclear or solar generation, as well as toward prospective changes in the generation mix. Energy illiteracy, concern about the economic impact of blackouts, and concern about nuclear generation are the main determinants of class membership probability.

Keywords

Power outage; Security of supply; Energy transition; Willingness-to-accept; Hybrid discrete choice model; Latent classes

Abbreviations

DC: discrete choice; SOES: security of electricity supply; VOLL: value of lost load; WTA: willingness to accept; WTP: willingness to pay.

3.1 Introduction

The security of electricity supply (SOES), i.e. the ability of an electricity system to guarantee the supply of electricity to customers with a clearly established level of performance⁷, is a key determinant of economic growth and consumer welfare in modern economies. In the past decade, however, the energy transition started in several countries has created new threats to the SOES, among which the need to decommission carbon-intensive generation plants, counterbalance the volatility of intermittent renewables, integrate the contribution of distributed generation, and finally upgrade transmission and distribution grids pursuant to the new structure of the electricity system (Larsen, Osorio, Van Ackere, 2017).

Throughout the 2010s energy companies, policy makers, energy regulators, and academics have discussed and tested new tools to ensure the desired level of SOES during the transition towards an increasingly decentralized and low-carbon energy system. The initial steps to ensure security have mainly been based on a supply-side approach: several European countries have indeed introduced capacity remuneration schemes to support unprofitable programmable generation plants still needed for security (Olmos and Pérez-Arriaga, 2013; ACER/CEER, 2017). In the second half of the decade, however, the European Commission has started to express concern about the distortions possibly induced by these mechanisms (European Commission, 2015 (b); European Commission, 2016). The role of consumers in determining the desirable security level - and possibly even contributing to security itself - has gradually come into focus. The Commission has thus suggested that the wholesale market should be allowed to express scarcity signals through higher electricity prices along the different maturities: these prices should reflect both the adequacy level provided by the system, and the value of security to consumers (European Commission, 2015 (a)). The Clean Energy Package approved between 2018 and 2019 has further emphasized the need of a market-based, consumer-centric approach to SOES in order to replace uncoordinated and potentially distortive capacity mechanisms introduced on a national basis. Regulation (EU) 2019/943, among other things, provides for the removal of caps and floors on the prices in the wholesale markets for electricity, and states that the maximum and minimum clearing prices adopted for technical reasons should be determined taking into account the value of lost load (VOLL), defined as “the maximum electricity price that customers are willing to pay to avoid an outage”.

⁷ Art. 2, Regulation (EU) 2019/941.

A consumer-centric approach to the SOES has become increasingly popular also among electricity retailers. Thanks to the recent technological progress, these companies are often able to provide customized supply contracts which, among other features, may include higher security levels for selected customers, or ensure lower purchase costs for the consumers who are ready to participate in demand response programmes. The SOES, traditionally regarded as a public good (Abbott, 2001; Finon and Pignon, 2008), is gradually taking on some private good features, and markets for flexibility or higher security start to emerge.

Within this setting, a careful assessment of the value of SOES for the different categories of consumers is increasingly important from both a regulatory, and a marketing perspective. In the past few decades several researchers have undertaken this task using different methods, ranging from the production function approach to case studies, and from the analysis of stated preferences to the use of proxies or revealed preferences. However, even when focussing on the residential sector and considering relatively recent analyses of countries with comparable economic conditions and security levels, the estimates of the value of security span over a very wide interval. The evidence regarding the drivers of this variability is relatively limited and not always coherent across different studies. Moreover, even if the energy transition has brought in the foreground the link between electricity security on the one hand, and the replacement of carbon-intensive generation with low-carbon generation facilities on the other hand, very few studies consider consumer preferences towards both the SOES, and the different primary energy sources or electricity generation technologies.

Our analysis focusses on the case of Switzerland, a country with a very high level of security⁸ but committed to phasing out nuclear generation, contributing to approximately 40% of inland productions, and replacing it with new low-carbon generation plants⁹. The shift from nuclear to other low-carbon generation technologies, expected for the medium term, obviously entails a challenge to the SOES, that is further complicated by the developments observed in the energy markets, regulation, and infrastructures of the neighbouring European Union countries (Hettich et al., 2020). Since 2011, when the decision of phasing out nuclear generation was made, the Federal Government and Parliament have drafted and launched a long-term energy strategy which outlines an overarching restructuring of the Swiss energy

⁸ Switzerland ranks among the European countries with the lowest average duration of unplanned outages per year, according to Elcom (national regulatory authority in Switzerland), 2020: “Qualità dell'approvvigionamento elettrico 2019 - Rapporto della ElCom”.

⁹ Swiss Federal Office for Energy, 2018, “Chronologie der Energiestrategie 2050”; Swiss Federal Office for Energy, 2019, “Energiestrategie 2050 Monitoring-Bericht 2019, Kurzfassung”.

system and regulation, in order to address security next to the sustainability and affordability of the electricity supply¹⁰. The energy transition is gathering speed and the acceptance among citizens is increasing, as witnessed by the positive outcome of the referendum on the energy strategy held in 2017. Future decisions on the identification and sizing of new infrastructures will however benefit from a measurement of the value that consumers place on security, an assessment of consumers' views on the trade-offs between security, sustainability, and affordability of electricity supply, and finally an investigation into the demographic or behavioural traits that may exert any systematic influence on consumer preferences.

Our contribution to the debate concerning the optimal level of SOES and the design of an energy system matching the expectations of electricity consumers is twofold. On the one hand, we explore the preferences of Swiss residential consumers towards both the risk of supply outages, and a set of primary energy sources used for generation¹¹. On the other hand, we investigate the demographic and behavioural drivers of heterogeneity in household preferences towards security. Our analysis is based on stated preference data collected by means of a survey distributed in 2015. More specifically, we use a discrete choice (DC) experiment to measure the households' willingness to accept (WTA) for an increase in the frequency of long and short blackouts, and include the primary energy sources used for generation as one of the attributes of the available alternatives. The specification we choose is a hybrid DC model with latent classes: this model allows us to provide a nuanced explanation of the drivers that determine heterogeneity in consumer behaviour, and include the attitudinal motives that are not directly observable from the data. Our evaluation of the value of SOES to household consumers may support the definition of specific details of the wholesale electricity market design, and provide a basis for deciding about the desirable security level. Our assessment of the trade-offs that consumers perceive between the SOES and the use of specific generation technologies may instead support decisions concerning specific investments into new generation facilities, and facilitate the design of customized electricity supply contracts.

Our contribution develops as follows. Paragraph 3.2 collects the relevant suggestions from the economic literature. Paragraphs 3.3 and 3.4 describe our econometric method, survey, and data. Paragraph 3.5 presents our results, and finally paragraph 3.6 discusses the novelty of our findings and analytical approach, together with the resulting policy implications.

¹⁰ Swiss Federal Office for Energy, 2018, "Chronologie der Energiestrategie 2050".

¹¹ The residential segment accounts for approximately one third of the final electricity consumption in Switzerland (Bundesamt für Energie (BFE), 2020).

3.2 Literature review

Household preferences with respect to the SOES have been investigated by several researchers and with growing interest over the last few decades. While the SOES is, generally speaking, a multifaceted concept stretching to different time horizons and involving several actors along the electricity supply chain (Rodilla and Batlle, 2012), the analyses considering the consumers' perspective focus on its practical, short-term impact, i.e. an electricity outage or blackout¹² and its material and immaterial damage. More specifically, these studies measure the damage associated to each unit of unsupplied electricity, or the damage caused by a blackout with given characteristics, or finally a household's willingness to pay (WTP) to avoid a blackout or WTA to accept it (Table 3.1).

3.2.1 *Aims of the existing analyses*

Most of the studies on household preferences with respect to the SOES have been developed in order to support decisions regarding the optimal investment into system adequacy. By assessing the marginal value of security to households – and usually also to manufactories and service companies – these analyses provide a reference against which the marginal cost of preserving or improving the current level of SOES can be evaluated. The value of SOES to residential consumers has also been investigated in order to inform the design of incentive regulation schemes set up to encourage distribution system operators to reach a given quality standard (Bertazzi et al., 2005; Carlsson and Martinsson, 2008; Kjølle et al., 2008; Baarsma and Hop, 2009; Bliem, 2009). Other studies have instead contributed to the definition of specific details of the electricity market design, such as the price caps applied in the commodity markets (CEPA, 2018), the functioning of the rationing schemes in case of emergencies (de Nooij et al., 2009; Kim et al., 2015), or the structure of capacity and balancing markets (London Economics, 2013; Shivakumar et al., 2017). Finally, a relatively recent stream of literature has assessed the heterogeneity of consumer preferences toward the SOES and explored its drivers, with the aim of supporting the design of customized electricity supply contracts matching the expectations of consumers as regards the continuity and other qualitative features of the electricity supply (Abdullah and Mariel, 2010; Pepermans, 2011; Amador et al., 2013).

¹² The two terms are used here as synonyms.

3.2.2 *Methods used*

Most of the analyses concerning the value of SOES for residential consumers rely either on the production function method, or on the analysis of stated preferences (Table 3.1). A few studies have analysed revealed preferences, evaluating the costs and characteristics of the back-up devices purchased by consumers, or investigated specific case studies, collecting quantitative or qualitative evidence as regards consumers' reactions when a blackout happens.

The production function method equates the value of security to that of the goods produced using electricity: every kWh not served is worth as much as the goods that electricity consumers would have produced through it. In the case of households, this approach assumes that they use electricity to produce leisure, and the worth of each hour of leisure is equal to the net hourly wage, or half of it for persons who are unemployed or not in the workforce (Munasinghe, 1980). The production function approach is thus based on easily accessible macroeconomic data: average or median hourly wage, rate of employment, use-of-time statistics, yearly electricity consumption of the average household, and finally, if relevant and known to the researcher, the hourly consumption profile and the rate of dependence on electricity for leisure production. The production function approach is relatively straightforward to implement and produces estimates which are usually easily comparable across countries, but is a relatively simplistic representation of how the residential segment is impacted by blackouts. First, the estimated blackout damage is deterministically computed based on the above mentioned variables, among which hourly wage and electricity consumption of households play a major role. Secondly, several analyses assume that the value of leisure is constant in time, space, and across the population, and neglect the hassle or material damage that households may suffer on top of the loss of leisure. Moreover, several researchers neglect the impact of advance blackout notice, as well as blackout duration and timing. Finally, the production function approach assumes that consumer preferences as regards security are symmetric, i.e. that the benefit gained from a unit improvement in SOES is equal in magnitude to the damage caused from a unit deterioration. This assumption, besides neglecting the suggestions of prospect theory (Kahneman and Tversky, 1979), is controverted by several empirical findings, as discussed in Woo et al., 2014, Abrate et al., 2016, Longo et al., 2018, Amoah et al., 2019, and more generally in Brown and Gregory, 1999.

The analyses based on stated preferences, usually exploiting contingent valuation or DC experiment data collected by means of surveys, help overcome some of the limitations of the production function approach. The use of survey data has, indeed, several advantages. First, surveys allow the researcher to investigate household preferences towards different blackout scenarios: duration, frequency, timing, and

any other feature of the blackout that may matter to the analysis can vary in the survey questions. Secondly, they can be used to collect information on the respondent's demographic, behavioural, and attitudinal characteristics. The researcher can thus evaluate the relationship between the respondent's individual characteristics and his/her preferences toward the SOES. Finally, surveys allow the researcher to go beyond the measurement of the simple value of leisure lost. Indeed, the responses provided in contingent valuation studies or DC experiments implicitly account not only for the forgone leisure, but also for any material or immaterial damage perceived by the respondent, as well as for the actual substitutability of electricity as an input for the household's activities and leisure production. There are, however, also some important drawbacks in the use of survey data. As with any analysis relying on stated preferences, indeed, hypothetical bias and strategic behaviour often threaten the external validity of the results (Foster and Burrows, 2017; McFadden, 2017). Some researchers further argue that the respondents have very limited experience in answering questions concerning the value of SOES, and rather tend to feel entitled to a reliable and uninterrupted electricity supply. Moreover, the results obtained through different contingent valuation analyses or DC experiments are not always easy to compare, due to the diversity of the blackout scenarios under scrutiny and the variety of parameters that affect consumer preferences. Finally, the data collection process usually requires more time and resources as compared to the production function approach.

It is interesting to note that in recent years a few policy-driven analyses have tried to integrate the production function and stated preferences approaches, with the aim of producing easily comparable estimates, while accounting for different blackout scenarios (duration, timing, advance notification, ...) and the dimensions of the blackout damage that are only known to the consumers (substitutability of electricity as an input, material and immaterial damage caused by a blackout, ...). CEPA, 2018, for example, reports a computation of the VOLL for all EU Member States based on macroeconomic data, but complemented with survey data concerning the substitutability of electricity as an input for leisure production, the impact of advance blackout notice, and finally the impact of blackout duration. The ENTSO-E Proposal (ENTSO-E, 2020) for a common methodology for computing the VOLL pursuant to the requirements of Regulation (EU) 2019/943, in consultation at the time of writing, recommends as well that the VOLL should be computed based on a triangulation of methods. More in detail, the VOLL for the residential segment should be computed based on survey data, comparing the results obtained from contingent valuation and direct worth questions, whereas the VOLL for the industrial segment should be computed cross-checking survey data with the production function method.

3.2.3 Estimates and drivers of the value of SOES

A closer look at the existing estimates of the value of SOES provides interesting suggestions as concerns its magnitude, the strengths and weaknesses of the various methods, and finally the directions for further research.

Table 3.1 collects the estimates of the value of SOES for residential consumers provided by 31 analyses carried out since 2000 in countries showing comparable economic conditions and security of supply levels. For the sake of comparability, the estimates of each individual study have been converted into 2015 USD; when multiple blackout scenarios were evaluated within the same study, we selected the results concerning the scenario closer to the reference of a one hour long blackout without advance notice.

The estimated values of SOES show, indeed, a large variability. Stated preferences studies usually consider a variety of scenarios and produce results expressed in different measures. The main regularity for this kind of studies is the fact that, in line with the literature concerning the WTP/WTa discrepancy (Brown and Gregory, 1999), WTa values are two to four times higher than WTP values for the same country and scenario. The analyses based on the production function approach are instead easy to compare, and tend to yield, by construction, SOES values that are positively correlated to the average wages, and negatively correlated to the average electricity consumption in the residential segment.

Reference	Method*	Region	Year	Value of security for residential consumers (in 2015 USD)**
Bertazzi et al., 2005	CV	Italy	2003	WTP: 4.2, WTA: 19.4; VOLL: 28.81
Carlsson & Martinson, 2007	CV	Sweden	2004	WTP: announced blackout: 1.07; unannounced blackout: 1.62
Baarsma & Hop, 2009	CV	Netherlands	2003-2004	WTA: 5
Carlsson et al., 2011	CV	Sweden	2004; 2005	WTP for announced blackouts lasting 1 hour: before storm Gudrun 1.08, after storm with no cheap talk script: 0.49, after storm with cheap talk script: 1.68; WTP for unannounced blackouts lasting 1 hour: before storm 1.61, after storm with no cheap talk script: 0.79, after storm with cheap talk script: 2.34
Ozbaflı & Jenkins, 2015	CV	North Cyprus	2008	WTP: 28.39 USD/month for having zero blackouts
Woo et al., 2014	CV	Hong-Kong	2013	Outage cost: 45.67
Kim et al., 2015	CV	South Korea	2014	WTP: unannounced 2 hour blackout: 2.8; announced 2 hour blackout: 2.2
Kjølle et al., 2008	CV, direct worth	Norway	2009	WTP: 0.93; direct worth: 2.16
London Economics, 2013	CV, DCE	United Kingdom	2013	VOLL based on WTA: 11.04-18.76 USD/kWh; VOLL based on WTP: 0-4.39 USD/kWh
CEPA, 2018	CV, PF	EU-28 (Malta not covered in the survey)	2018	VOLL: unannounced blackout: 1.66-25.45; blackout with 24-hrs advance notice: 0.92-14.12
Carlsson & Martinson, 2008	DCE	Sweden	2004	WTP for a 4 hour blackout: weekday, winter: 1.27; weekday, summer: 1.84; weekend, winter: 5.06; weekend, summer: 3.44;
Pepermans, 2011	DCE	Belgium	2004-2005	WTA: 45.7-76.3
Bliem, 2009	DCE	Austria	2007	WTA: 3 minute blackout: 1.49% of the electricity bill; 4 hour blackout: 16.05% of the electricity bill
Ozbaflı & Jenkins, 2016	DCE	North Cyprus	2008	Compensating variation: 6.27 USD/month for having zero blackouts in summer, 24.33 USD/month for having zero blackouts in winter
Amador et al., 2013	DCE	Canary Islands	2010	WTP: 2.85 USD/month for having one unannounced blackout less per year; 1.43 USD/month for reducing blackout duration by 5 minutes
Reichl et al., 2013	DCE	Austria	2011	WTP: 2.07

(The table continues on the next page)

Reference	Method*	Region	Year	Value of security for residential consumers (in 2015 USD)**
Cohen et al., 2016	DCE	RO, BG, GR, HU, PL, FI, ES, EE, FR, SE, DK, IE, NL, DE	2012-2013	WTP: 0.49-5.36
Longo et al., 2018	DCE	Estonia, Netherlands, Portugal	2018	VOLL - Planned outages: based on WTP: EE 0.38, NL 0.68, PT 0.65; based on WTA: EE 21.32, NL 27.81, PT 29.00. VOLL - Unplanned outages: based on WTP: EE 0.73, NL 1.15, PT 1.08; based on WTA: EE 19.94, NL 27.29, PT 18.8.
Merk et al., 2019	DCE (vignette study)	Germany, UK, Ireland	2013	Germany: WTP for electricity supply is 0.08 USDcent/kWh lower for any additional minute of blackout during one year; UK: WTP is 0.04 USDcent/kWh lower for any additional minute of blackout during one year
Abrate et al., 2016	DCE	Italy	2015	VOLL: 28.14
Morrissey et al., 2018	DCE	England	2015	WTP: 0.61; separate estimates for blackout timing
de Nooij et al., 2007	PF	Netherlands	2001	VOLL: 24.53
de Nooij et al., 2009	PF	Netherlands	2001	VOLL: 22.87
Leahy & Tol, 2011	PF	Ireland	2007	VOLL: 0-134.5 in Northern Ireland, 1.31-55.7 in the Republic of Ireland
Bliem, 2005	PF	Austria	2007	VOLL: 20
Linares & Rey, 2013	PF	Spain	2008	VOLL: 9.2-13.2
Zachariadis & Poullikkas, 2012	PF	Cyprus	2009	VOLL: 14
Castro et al., 2016	PF	Portugal	2010	VOLL: 10.62
Praktiknjo et al., 2011	PF	Germany	2011	VOLL: 23.19
Shivakumar et al., 2017	PF	EU	2013	VOLL: 11.72

* CV: Contingent Valuation; PF: Production Function; DCE: Discrete Choice Experiment

** Unless otherwise specified: direct cost, WTP and WTA are measured in 2015 USD per 1 hour blackout, VOLL is measured in 2015 USD/kWh

Table 3.1 – Value of SOES for residential consumers in comparable countries since year 2000

The surveyed literature suggests the value of SOES to household consumers may depend on several drivers. Figure 3.1 provides an overview of the characteristics of blackouts (left half of the histogram) and individual households (right half) that are mentioned in at least one of the analyses under scrutiny. Beyond the studies explicitly mentioned in Table 3.1, Figure 3.1 includes other analyses developed before year

2000 and in countries whose economies and energy systems are very different from the Swiss ones (Munasinghe, 1980; Abdullah and Mariel, 2010; Woo et al., 2014; Kim et al., 2015; Nkosi and Dikgang, 2018; Amoah et al. 2019; Siyaranaumal et al., 2020).

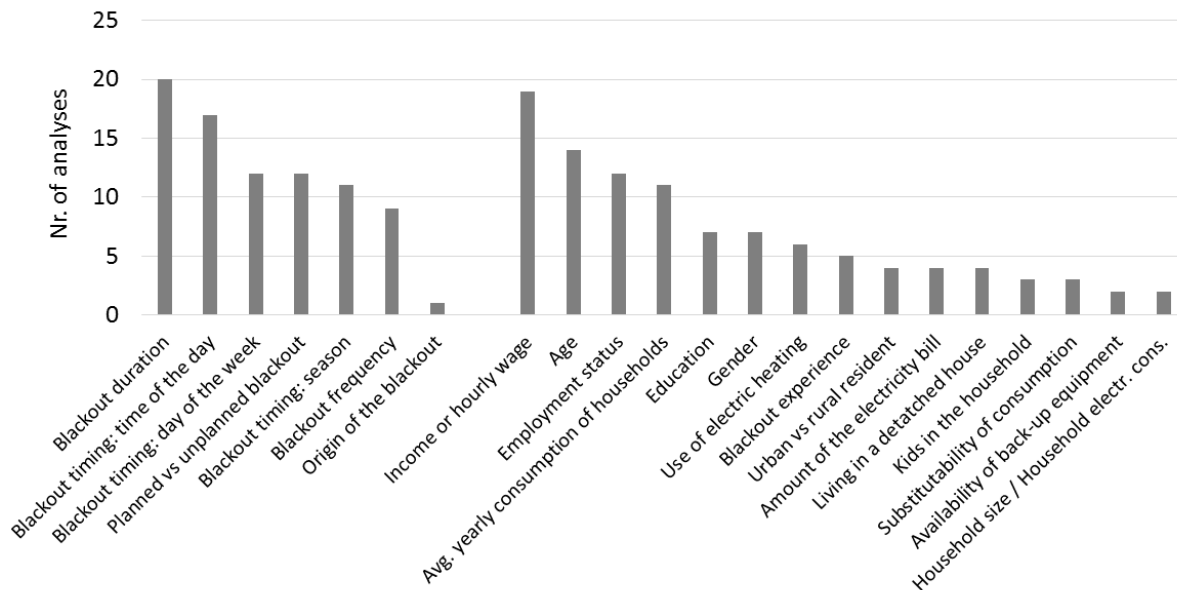


Figure 3.1 – Drivers of the value of SOES in 41 studies considering residential consumers. Source: author's review

Higher blackout duration and higher blackout frequency, where considered, are generally associated to a higher WTP or WTA; most studies report however that the marginal increase in WTP or WTA values from an additional minute of blackout is positive, but decreasing with blackout duration. Unannounced blackouts generally harm more than planned ones. When blackout timing is considered, researchers usually find that the VOLL, WTP, or WTA values are lower during the night; there is instead no univocal evidence as regards the difference between working days and weekends, nor between Winter and Summer, although in colder countries Winter blackouts tend to harm more than Summer ones (Carlsson and Martinsson, 2008; Pepermans, 2011; Reichl et al., 2013; Abrate et al., 2016; CEPA, 2018; Morrissey et al., 2018; Nkosi and Dikgang, 2018; Amoah et al, 2019). The evidence concerning the role of demographic variables is not clear-cut across the studies included in the analysis: only higher income and longer education, where considered, are usually associated to higher VOLL, WTP, or WTA values.

The conflicting evidence as regards the role of some demographic variables, together with the scattered estimates of the value of SOES even for similar countries and consumption segments, suggest that a

sizeable share of heterogeneity in consumer behaviour is still unexplained. Indeed, several researchers using random parameters for the WTP or WTA values in contingent valuation studies (Carlsson and Martinsson, 2007; Longo et al., 2018; Nkosi and Dikgang, 2018; Niroomand and Jenkins, 2020) or DC experiments (Carlsson and Martinsson, 2008; Bliem, 2009; Abdullah and Mariel, 2010; Pepermans, 2011; Morrissey et al., 2018, Siyaranamual et al., 2020) detect a significant heterogeneity across consumers. Morrissey et al., 2018 explicitly recognize that household preferences toward the SOES are often only partially explained, and call for a deeper investigation of possible drivers.

In the last few years some researchers have taken up this challenge and tried to dig into the psychological determinants of heterogeneity. Pepermans, 2011, for example, incorporates in his study the respondents' attitudes toward the possibility of regularly paying a higher bill in order to reduce outage probability (so-called "WTP attitude"), as well as toward the possibility of accepting a higher outage probability in exchange for a lower electricity bill ("WTA attitude"). His results suggest that the perceived blackout damage is positively correlated to a positive WTP attitude, and negatively correlated to a positive WTA attitude. Furthermore, he finds that the WTP to reduce outage frequency is higher among households who expect a higher outage frequency in the future. Longo et al., 2018 report instead a positive correlation between self-reported environmental sensitivity and a higher WTP for scenarios with less frequent blackouts. They also find that personal values such as egoism or hedonism tend to be associated to a lower WTP to reduce outage frequency with respect to the status quo. A few studies have explored the possible trade-offs or complementarities between the choice of a renewable-based electricity supply versus the choice of a supply ensuring lower blackout frequency or duration. Amador et al., 2013, for example, develop a DC experiment including the risk of blackouts, the availability of an energy auditing service, and finally the renewable content of the electricity supply. They are thus able to disentangle consumer preferences toward the risk of blackouts on the one hand, and consumer preferences for other features of the electricity supply related to environmental sustainability on the other hand. Merk et al., 2019 develop a similar vignette study including both outage duration and frequency, and the renewable content of the electricity supply. Beyond measuring a sizeable heterogeneity in consumer responses, they point out that consumers are ready to pay for renewable-based generation only as long as the continuity of supply is safeguarded. Siyaranamual et al., 2020 develop a DC experiment in which respondents located in Indonesia evaluate at the same time blackout duration, share of hydroelectricity and coal in the supply mix, and finally the increase in the electrification rate in rural areas. They use a random parameter and a latent class specification to detect and explain heterogeneity in the respondents' WTP, and find that the

WTP for reducing outage duration is positive in most latent classes, but generally lower than the WTP for increasing the electrification rate and the share of hydroelectric generation. Finally, Sagebiel and Rommel, 2014 develop a DC experiment in Hyderabad, India, to evaluate households' preferences toward blackout frequency, share of renewables in the generation mix, and type of company providing the service. Interestingly, they find that part of the heterogeneity observed in the WTP to improve continuity is connected to the heuristics of the decision process; more specifically, 32.7% of the respondents systematically chose the cheapest options, and neglected the other attributes.

3.2.4 Our contribution to the literature

Our contribution to the debate concerning the value of the SOES in the context of the energy transition is twofold.

First, we analyse the preferences of Swiss households toward variations in the frequency and duration of blackouts on the one hand, and the primary energy sources used for generation on the other hand. We are thus able to evaluate the trade-offs that households perceive between the two dimensions of security and sustainability of electricity supply, and identify whether consumers expect different security levels from specific primary energy sources.

Secondly, we develop a DC model with latent classes: this strategy allows us to include in the analysis not only the observable demographic variables, but also the otherwise unobservable attitudinal drivers that may influence the value that households place on security. Latent classes allow us to identify distinct consumer segments showing heterogeneous preference patterns. The use of class membership functions allows us to further investigate the determinants of the class membership probability, and hence to provide a better description of the demographic, behavioural, and attitudinal characteristics of each market segment. Latent classes significantly improve the model fit and, most importantly, the understanding of consumer behaviour, thus responding to the call emerging from the surveyed literature.

3.3 Method

As already mentioned, our analysis is based on stated preferences, more specifically on a DC experiment with latent classes and class membership functions.

The backbone of DC analysis is the assumption that a decision maker, when facing a set of mutually exclusive and collectively exhaustive alternatives showing different characteristics – the so-called

“attributes” – will select the one providing him/her the highest indirect utility. Individual preferences may be influenced by the alternatives’ attributes, but also by the consumer’s demographic, behavioural, and attitudinal traits.

The basic specification of DC models, the multinomial logit, assumes that consumer preferences are homogeneous across the sample, after accounting for the relevant demographic variables. The latent class specification assumes instead that market segments showing different preferences can be identified endogenously within the model (Bhat, 1997); thus, it allows the researcher to account for systematic, but otherwise unobserved heterogeneity in consumer behaviour (Bhat, 1997; Gopinath, 1995). Instead of estimating a simple class membership probability for each individual, we model latent classes by means of class membership functions embedded in the DC model and connecting the probability of belonging to each of the latent classes to the relevant demographic, behavioural, or attitudinal drivers. Latent classes, particularly when including a model for class membership instead of a simple probability, provide a better behavioural interpretation of the observed heterogeneity as compared to a random parameter specification, whose very flexible structure is instead mainly useful to quantify the observed heterogeneity under given assumptions as regards the distribution of the parameters (Greene and Hensher, 2003; Hurtubia et al., 2014).

The econometric specification of a DC model with latent classes and class membership functions consists of the following equations (Bhat, 1997):

$$[1] \quad U_{ijt}^s = V_{ijt}^s(Z_j, X_i; \beta^s) + \varepsilon_{ijt}, \text{ with } \varepsilon_{ijt} \text{ i.i.d. } \sim EV(0, \mu_\varepsilon)$$

$$[2] \quad y_{ijt} = 1 \text{ if } U_{ijt}^s = \max_k \{U_{ikt}^s\}, y_{ijt} = 0 \text{ otherwise}$$

$$[3] \quad F_t^s = f(X_i; \gamma^s) + \omega_t^s, \omega_t^s \text{ i.i.d. } \sim EV(0, 1)$$

Where:

- U_{ijt}^s is the utility that respondent i , belonging to class $s \in S$, extracts from choosing alternative j from choice set C in choice task t ,
- Z_j is a vector of attributes of alternative j ,
- X_i is a vector of respondent i 's demographic variables,
- y_{ijt} is a dummy variable taking variable 1 if respondent i chooses alternative j in choice task t , and value 0 if i chooses a different alternative,

- F_i^s is the class membership function, connecting the characteristics of respondent i to the probability that i belongs to class s ,
- β^s and γ^s are class-specific parameters to be estimated.

Thanks to the assumptions made on the distribution of the error terms, the choice probability for each alternative and the class membership probability can be written as follows:

$$[4] \quad P_{it}(j|s) = \frac{e^{V^s(Z_i, X_j; \beta^s)}}{\sum_{k \in C^s} e^{V^s(Z_i, X_k; \beta^s)}}$$

$$[5] \quad P_i(s) = \frac{e^{f(Z_i; \gamma^s)}}{\sum_{r \in S} e^{f(Z_i; \gamma^r)}}$$

Where:

- $P_i(j|s)$ is the probability that respondent i chooses alternative j in choice task t , given that he belongs to class s ,
- $P_i(s)$ is the probability that respondent i belongs to class s . If the class membership function F_i^s is omitted, $P_i(s)$ is estimated as such.

The model is estimated via simulated maximum likelihood: the log-likelihood function takes the following form:

$$[6] \quad L = \sum_i \log\{\sum_s [P_i(s) * \prod_t \prod_{i \in C^s} P_{it}(j|s)^{y_{ijt}}]\}$$

To the best of our knowledge, the latent class approach has rarely been used in the analysis of the value of SOES to end consumers: two exceptions are Sagebiel and Rommel, 2014 and Siyaranamual et al., 2020. Their analyses are similar to ours, as both use a latent class DC model to evaluate household preferences toward the risk of blackouts and the use of renewable-based electricity or a hydroelectric supply. However, the contexts in which their studies are conducted (Indian megacities for Sagebiel and Rommel, 2014, Indonesia for Siyaranamual et al., 2020) are very different as compared to Switzerland in terms of outage frequency, structure and problems of the electricity sector, and demographic conditions of households. Moreover, although they both describe specific behavioural patterns corresponding to each latent class, their DC models only estimate a class membership probability; hence, they do not investigate the demographic or attitudinal determinants of heterogeneity directly within the DC model. Drawing from the methodological suggestions of Gopinath, 1995, and Hurtubia et al., 2014, we use instead the available psychometric indicators in the class membership functions together with the relevant demographic

variables, and thus evaluate the role of attitudinal drivers in determining consumer preferences directly within the DC model.

3.4 Data

The DC experiment was administered by means of an on-line survey, translated in French and German and distributed through an independent market research company in January and February 2015. The survey was tested on 100 respondents with satisfactory results; the final sample - including the sub-sample used for the test - consisted of 1006 respondents, stratified according to the main demographic variables in order to ensure representativeness of the population living in the French- and German-speaking regions of Switzerland. A detailed description of the sample is available in Appendix A.

The survey included:

- A short introductory text describing the purpose of the analysis,
- 30 psychometric questions, in which the respondents declared on a 7-points Likert scale their agreement or disagreement with statements concerning renewable energy, nuclear, coal- and gas-fired generation, the local impacts of wind generation, electricity imports, blackouts, increases in electricity prices, climate change, and environmental pollution,
- Questions regarding the respondent's habits and behaviour in the fields of energy consumption and environmental sustainability: environmental friendly facilities adopted in the household, average electricity bill, subscription to a green energy plan, energy-related habits in daily life, experience of a long or short blackout at home or in the workplace in the past 12 months,
- Questions regarding the typical demographic variables: gender, age, nationality, education, region of residence, working status, monthly household income, type of dwelling, number and age of the people living in the household,
- The DC experiment: each respondent was asked to complete seven choice tasks, in which he/she had to select one out of five electricity supply contracts for his/her own dwelling. Table 3.2 provides an example of a choice task. The DC experiment was introduced by a short text describing the electricity generation mix observed in Switzerland, the average price of electricity in centCHF/kWh, and the average frequency and duration of blackouts in 2013.

Please select the electricity supply contract you would be ready to sign for your own flat or house. You can choose only one contract.

	Nuclear	Mix - of which 60% from renewables	Hydro	Solar	Wind
Price (centCHF/kWh)	18	27.5	21	24	50
Nr of 5 minutes blackouts	0	1 per year	1 per year	4 per year	1 per year
Nr of 4 hours blackouts	4 per year	4 per year	0	0	0
Your choice:					

Table 3.2 – Example of a choice task

The DC experiment included five alternatives, each described by four or five attributes. The first attribute, that was used as a label, described the primary energy source used for generation; the available options were nuclear energy, hydroelectric energy, wind, sun, and a “grey mix” from unspecified sources. The remaining attributes were the price of electricity in centCHF/kWh, the number of short (5 minutes) blackouts per year, the number of long (4 hours) blackouts per year, and finally the share of renewable-based generation from unspecified energy sources in the grey mix alternative. The levels of the attributes were defined based on the current and prospective structure of the electricity generation and retailing activities in Switzerland, and drawing from the experiences of other European countries (Table 3.3).

Attributes	Units of measure	Levels	Average levels in 2013
Primary energy source (attribute used as a label in the DC experiment)	Kind of primary energy source used for generation	Nuclear, hydro, wind, sun, "grey mix"	"grey mix"
Share of renewables from unspecified sources (attribute only available for the "grey mix" alternative)	% of supply	40%; 60%; 80%; 100%	60%
Frequency of 5 minute blackouts	Nr. of 5 minute blackouts per year	0; 0.25; 1; 4	0.25
Frequency of 4 hour blackouts	Nr. of 4 hour blackouts per year	0; 0.25; 1; 4	0.25
Price of electricity	Final price of electricity in centCHF/kWh	14.5, 18, 21, 24, 27.5, 50 (14.5 not available for hydro, sun, wind; 18 not available for sun)	21

Table 3.3 – DC experiment: alternatives, attributes, and attribute levels

The attributes concerning the number of short and long blackouts were described in terms of expected frequency of each kind of blackout during the upcoming year. The respondents were thus asked to select a contract with a given reliability level, rather than to engage in a demand response programme. By expressing the expected blackout frequency in terms of number of blackouts in the upcoming year, we tried to rule out the possible bias connected to the season in which the survey was distributed. Indeed, as reported in paragraph 3.2, some stated preference analyses explicitly mention the season among the blackout attributes, and find that in Northern-European or alpine countries Winter blackouts tend to harm more than Summer ones; to the best of our knowledge, however, no study evaluates the possible consequences of administering a survey in Winter rather than in Summer. By bringing the respondent's attention on a yearly scenario both in the introductory text, and in the description of the blackout attributes, we tried to mitigate the possible bias connected to the fact that our survey was administered in Winter.

The choice tasks were defined using the software NGene through an efficient design with blocking, averaging a random parameter and an error component specification. The final design consisted in eight blocks with seven choice tasks each: each respondent was randomly assigned to one out of the eight blocks.

The fact that each respondent had to complete seven choice tasks with five alternatives each might raise some concern related to respondent's fatigue, attribute non-attendance (Hensher and Greene, 2010) or the use of heuristic decision rules deviating from the standard assumption of random utility maximization underlying discrete choice modelling (Hess et al., 2010). Overall, the survey completion time was around 12 minutes, a reasonable value for respondents participating in a standing panel and receiving a small compensation for filling in the survey. The inspection of the results suggests moreover that the responses were rather balanced across alternatives and attributes (Tables 2.B.4 and 2.B.5 in Appendix 2.B). As our preliminary estimations did not reveal glaring deviations from the expected random utility maximization, we concluded that this assumption was satisfied, and proceeded with the analysis as explained in the next paragraph.

3.5 Results

Using the software PythonBiogeme (Bierlaire, 2016) we estimated a series of DC models with increasing complexity. We started with a multinomial logit specification including the relevant demographic

variables, then tested several latent class specifications with class-specific parameters for the sensitivity to the frequency of short and long blackouts and class membership estimated as a simple probability. Finally, we tested several latent class models with class-specific parameters for blackout sensitivity but including appropriate class membership functions instead of class membership probabilities. This allowed us to investigate the demographic and behavioural characteristics of the respondents belonging to each class. Our preferred specification is a latent class model with three latent classes and class membership functions. We decided to retain this specification as the McFadden adjusted R^2 , the BIC, and the AIC indicators showed a continuous improvement along with the inclusion of the second and third latent class and the class membership functions, whereas our attempts to estimate a model with four latent classes resulted in the fourth class repeatedly collapsing into the third one. The estimated parameters are mostly stable across the various specifications: the structure of the model is reasonably robust, and provides sensible insights into households' behaviour. The rest of this paragraph comments on our preferred specification; detailed information concerning the estimated models is collected within Table 3.A.1 in Appendix A.

3.5.1 Estimation results: overview

Figure 3.2 provides a visual description of our preferred specification: the image depicts the statistically significant relationships connecting the relevant alternatives' attributes and respondents' characteristics to the respondents' utility, and thereby to the respondents' choices. Following Walker, 2001 we use rectangles for observable variables, ovals for latent constructs, solid arrows for structural equations, and dotted arrows for measurement equations.

Figure 3.2 shows that the respondent's utility – and hence his/her choices – depends on the attributes of each alternative electricity supply contract, on a few demographic and behavioural variables characterizing the respondent, and finally on the probability that he/she belongs to one of the three latent classes. The latter is in turn correlated to selected demographic, behavioural, and attitudinal variables, as measured by the class membership functions.

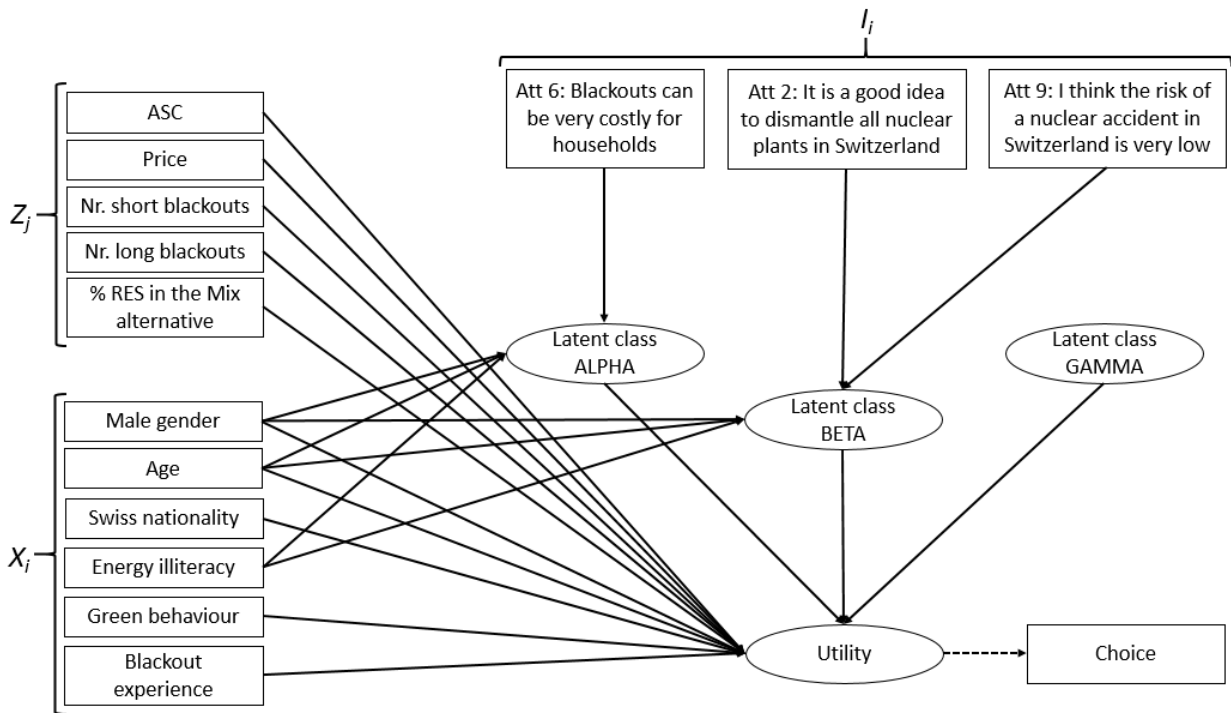


Figure 3.2 – Scheme of the DC model with three latent classes

Table 3.4 collects the detailed results of our estimates: our preferred specification, a latent class model with three latent classes and class membership functions, is compared to a simple multinomial logit to evaluate the robustness of the model structure and the improvements achieved by including latent classes.

	M1	M2
	Multinomial logit	Three latent classes with class membership functions
Nr of observations	1006	1006
Nr of estimated parameters	31	61
Model fit		
Final log-likelihood	-8725.2	-8042.7
McFadden adjusted R2	0.227	0.3
AIC	17512.4	16207.4
BIC	17664.7	16507.2
Estimated parameters		
Alternative-specific constants		
Hydro	0.572**	0.169
Nuclear	-0.0683	-0.0531***
Sun	0.672***	0.589**
Wind	1.24***	1.25**
Price		
Hydro	-0.0573***	-0.0568***
Mix	-0.062***	-0.0715***
Nuclear	-0.0927***	-0.0873***
Sun	-0.0481***	-0.0629***
Wind	-0.0801***	-0.0932***
Share of renewable electricity in the mix alternative		
40% RES	-0.0249	-0.438***
80% RES	0.0836	0.145
100% RES	0.559***	0.646**
Demographic variables		
Age_mix	0.0147***	0.0129**
Green_behaviour_nuclear (1)	-0.445***	-0.439***
Blackout_experience_nuclear (2)	0.289***	0.241**
Illiteracy_nuclear (3)	-0.0603	-0.0752***
Swiss_nuclear	-0.00209***	-0.00147***
Male_hydro	0.249**	0.231**
Male_nuclear	0.756***	0.797**
Male_sun	-0.33***	-0.157***
Male_wind	0.065	0.00524

(The table continues on the next page)

	M1 Multinomial logit	M2 Three latent classes with class membership functions		
Long blackouts		Class Alpha	Class Beta	Class Gamma
Hydro	-0.448***	-0.336***	-0.669***	-0.669***
Mix	-0.285***	-0.138***	-0.745***	-0.534***
Nuclear	-0.284***	-0.188***	-10.3***	-22.2***
Sun	-0.436***	-0.571***	-0.765***	0.444**
Wind	-0.566***	-0.61***	-0.664***	-3.26***
Short blackouts		Class Alpha	Class Beta	Class Gamma
Hydro	-0.128***	-0.198***	-0.0554***	-1.17***
Mix	-0.0665***	0.109**	-0.43***	-0.589***
Nuclear	-0.145***	-0.0541***	-2.28***	-8.52***
Sun	-0.139***	-0.505***	-0.0531***	0.621**
Wind	-0.216***	-0.508***	-0.159***	-0.672***
Parameters of the class membership functions		Class Alpha	Class Beta	Class Gamma
Green_behaviour		0.0659		
Age		0.0179**	-0.0019***	
Illiteracy		0.461**	0.398**	
Male		1.99**	2.22**	
Att6 - Blackouts can be very costly for households		0.0774*		
Att2 - It is a good idea to dismantle all nuclear plants in Switzerland			0.341**	
Att9 - I think the risk of a nuclear accident in Switzerland is very low			-0.123***	
Estimated size of each class^		46.70%	47.10%	6.10%

* p-value ≤ 0.1 , ** p-value ≤ 0.05 , *** p-value ≤ 0.01 ; ^ class size computed from the estimated parameters

(1) “Green behaviour” is an index ranging from 0 to 3 and counting whether the respondent switches lights off when not needed, lowers the heating at night, and has a renewable-based electricity contract for his/her own dwelling.

(2) “Blackout experience” is a dummy variable equal to 1 if the respondent has experienced at least one blackout at home or in the workplace in the past 12 months, and 0 otherwise.

(3) “Illiteracy”: the energy illiteracy index, ranging from 0 to 8, counts how many times a respondent answers “I don’t know” to questions concerning his/her own electricity bill and the energy saving or renewable-based facilities installed in his/her dwelling.

Table 3.4 – Results

3.5.2 *Perceived impact of blackouts*

Table 3.4 suggests that blackout frequency and duration play a substantial role in influencing utility and hence consumer choices: both models show, indeed, that households have a marked sensitivity toward the risk of blackouts. The parameters for an increase in the frequency of short and long blackouts are generally negative and significant: as expected, a higher blackout frequency decreases utility. Long blackouts harm more than short ones: on average, we find that a blackout lasting 4 hours harms almost 300% than one lasting 5 minutes, with sizeable differences across latent classes and energy sources.

Households have, indeed, a different sensitivity to blackout frequency and duration depending on the primary energy source used for generation. The results suggest that they do perceive a connection between the impact of a blackout and the way electricity is generated: the direction in which preferences run depends very much on the attitudinal traits, included in the model through latent classes.

In fact, the latent class model identifies three latent classes, Alpha, Beta, and Gamma, showing very specific preference patterns. Class Alpha collects approximately 47% of the sample; the probability of belonging to it increases with male gender, older age, a higher score in the energy illiteracy index, and finally a stronger agreement with an attitudinal statement concerning the risk that blackouts can cause high costs to households. The attitudinal indicator included in the definition of class Alpha, as those picked for class Beta, was selected based on a principal component analysis of the available indicators, which identified three main dimensions, namely environmental concern, risk aversion, and optimism as concerns nuclear generation. Looking at the preferences toward security, Alpha respondents show relatively stable coefficients for blackout frequency, with a moderately higher aversion to blackouts associated to sun- and wind-based supplies, and a small, but positive coefficient for short blackouts associated to the grey mix. Long blackouts harm from 1.2 to 3.5 times more than short blackouts; the biggest difference is observed for the grey mix and the nuclear-based supply.

Class Beta collects another 47% of the sample; the probability of belonging to it is positively correlated to male gender, a higher score in the energy illiteracy index, a younger age, and finally a negative attitude toward nuclear generation. Indeed, Beta respondents tend to agree with the nuclear phase-out in Switzerland, and disagree with the idea that the risk of a nuclear accident in the country is low. Their preferences with respect to blackouts and primary energy sources signal a strong dislike for blackouts associated to a nuclear-based supply: the blackout coefficients are in this case 13 to 14 times larger than the averages for the remaining energy sources, depending on blackout length. The aversion to blackouts associated to a sun-, wind-, or hydro-based supply is instead particularly low in the case of short blackouts,

and in line with that observed for the grey mix in the case of long blackouts. The damage perceived from longer blackouts is 1.7 times higher than that associated to short blackouts for the grey mix, around 4 times higher for wind-based and nuclear generation, 12 times higher for the hydroelectric option, and 14 times higher for sun-based generation.

Class Gamma collects the remaining 6% of the sample. This class is described as the residual group with respect to classes Alpha and Beta: thus, its members are more likely to be energy literate, women, younger than the members of class Alpha, and slightly older than those of class Beta. Class Gamma respondents show very radical preferences with respect to blackouts coming from specific primary energy sources. They record, indeed, a deep aversion to interruptions in a nuclear-based supply: the coefficients are negative and more than double in magnitude than the already large ones expressed by Beta respondents. On the other hand, Gamma respondents express small, but positive coefficients for short and long blackouts associated to a sun-based supply. The blackouts associated to the remaining alternatives record negative, but more stable coefficients, several times smaller than those associated to the interruptions in the nuclear-based option. The perceived difference between long and short blackouts is less extreme as compared to class Beta. Indeed, the coefficients for longer blackouts are around the same size as those for short ones in the case of sun-based supplies and the grey mix, slightly more than double for hydro- and nuclear-based contracts, and around 4.8 times larger for the wind-based option.

The fact that two groups of respondents express small, but positive coefficients for an increased blackout frequency if the electricity supply comes from specific supply options deserves more attention. There are, indeed, a few studies exploiting random parameter techniques (Nkosi and Dikgang, 2018; Niroomand and Jenkins, 2020) that find a counterintuitive, positive impact of blackouts on utility for a small subset of the respondents, although in a very different setting. In our case the positive blackout coefficients, rather than signalling a low interest in the SOES, might suggest that some respondents are so attached to a specific energy source, or to the current structure of the electricity system, that they choose it even if it is, or becomes, less reliable. Class Gamma respondents, for example, might think that solar generation is inherently unpredictable and hence more subject to blackouts, or that its lower emission levels make it more desirable than other generation technologies even if it is less reliable. Alternatively, they might consider that a blackout in a sun-based supply, even if caused by an accident in the generation facilities, is not necessarily dangerous for the local residents, as it could be the case for nuclear generation or other large-scale generation technologies. The fact that class Alpha respondents are instead ready to accept a higher frequency of short blackouts in the grey mix alternative might suggest that they might be willing to

bear a slightly lower security level if this means that the electricity system will not undergo the deep transformation implied by the energy transition. In this case, the weaker opposition to blackouts could stem from a preference for the current structure of the electricity system, characterized by a top-down functioning, featuring a passive role for consumers, and largely based on large-scale generation plants that are often less visible in everyday life.

The comparison of the blackout coefficients across the three classes suggest another interesting remark: besides measuring class-specific preferences toward blackouts associated to each primary energy source, the results also reflect a class-specific attitude toward change in the electricity system in general. Class Alpha respondents seem indeed reluctant to accept a sizeable increase in the contribution of the new renewable-based generation technologies unless they ensure a high level of security. Beta respondents welcome a nuclear phase-out, but they are ready to accept a somewhat higher risk of blackouts connected to the use of renewables only if the expected blackouts are short. Finally, Gamma respondents are the strongest advocates of a nuclear phase-out and require a near-zero risk of blackout if they have to accept nuclear generation, but at the same time ready to opt for solar generation even if it is associated to a higher risk of blackout.

Lastly, it is interesting to note that blackouts enter the models in linear form: this means that an increase in the frequency of blackouts has a constant impact on consumer utility, irrespective of the initial blackout frequency. The linear specification was retained after testing several alternative models, including a quadratic specification, one where each frequency level entered as a dummy variable, and one considering increases and declines with respect to the average blackout frequency recorded in Switzerland in 2013, that was mentioned in the short text introducing the DC experiment. Our results suggest, indeed, that even the possibility of experiencing one short blackout every four years elicited a negative response: coherently with the comments collected during the design of the survey, the perceived blackout frequency among Swiss households is very close to zero.

3.5.3 *WTA for blackouts*

Together with the impact of blackouts, our model estimates the effect on consumer utility of price increases in the different alternatives. The results suggest that the respondents' preferences with respect to each primary energy source also translate into different sensitivities to price increases depending on the primary source used for generation. Table 3.4 shows that price increases have, as expected, a negative

effect on utility; the strongest negative impact is recorded for the wind- and nuclear-based contracts, the weakest for solar and hydroelectric generation.

The different sensitivity to price increases depending on the primary energy source used has interesting implications for the assessment of the value of security. Indeed, by estimating price and blackout sensitivities within the same DC model, we are able to compute the WTA of households for an additional short or long blackout throughout a year as a ratio between the appropriate blackout and price coefficients. Table 3.5 collects the WTA values based on the results obtained through our latent class specification; as a term of comparison, the average price of electricity for the household segment in 2013 was around 21 centCHF/kWh.

Class Alpha, WTA in cent CHF/kWh		Class Beta, WTA in cent CHF/kWh		Class Gamma, WTA in cent CHF/kWh	
Short blackouts		Short blackouts		Short blackouts	
Hydro	3.49***	Hydro	0.98*	Hydro	20.6**
Mix	-1.52***	Mix	6.01***	Mix	8.24***
Nuclear	0.62	Nuclear	26.12***	Nuclear	97.59***
Sun	8.03***	Sun	0.84*	Sun	-9.87***
Wind	5.45***	Wind	1.71***	Wind	7.21**
Long blackouts		Long blackouts		Long blackouts	
Hydro	5.92***	Hydro	11.78***	Hydro	46.13***
Mix	1.93***	Mix	10.42***	Mix	7.47***
Nuclear	2.15***	Nuclear	117.98***	Nuclear	254.3***
Sun	9.08***	Sun	12.16***	Sun	-7.06***
Wind	6.55***	Wind	7.12***	Wind	34.98***

* p-value ≤ 0.1 , ** p-value ≤ 0.05 , *** p-value ≤ 0.01 . Confidence intervals computed via Delta method.

Table 3.5 – Estimated WTA for accepting a blackout of the selected type

The WTA estimates suggest that consumers place, on average, a very high value on the SOES. The figures span however on a wide interval, ranging from close to zero or even negative values to more than 10 times the average price of electricity, depending on the blackout length, primary energy source used, and market segment.

The extreme WTA values observed for the nuclear-based supply in latent classes Beta and Gamma suggest that these respondents feel deeply entitled to an uninterrupted electricity supply if their electricity comes from this technology. Beta respondents also express low WTA values for short blackouts associated to renewable-based contracts, ranging between 4% and 8% if current electricity prices; when it comes to long

blackouts, however, the WTA values associated to renewable-based supplies and the grey mix are comparable and range between 33% and 55% of current prices. These results suggest that Beta respondents might be ready to trade a few short blackouts for an environmental friendly and cheaper supply, but are far less ready to accept an increase in the frequency of long blackouts irrespective of the primary energy source used. Gamma respondents express instead a very high WTA for blackouts associated to a hydroelectric supply, and a negative WTA for blackouts associated to a solar supply. These reactions suggest that Gamma respondents could be very reluctant or even virtually unavailable to accept any worsening of the SOES if their country or supplier do not engage in the energy transition, and might be ready to engage with demand response schemes or a private backup solution in order to support the growth of solar generation. At the opposite side of the spectrum, the respondents belonging to class Alpha express a relatively low opposition to short and long blackouts from the traditional generation technologies, such as nuclear, the grey mix, and hydroelectricity, and request instead a better performance from the new sources whose contribution is projected to grow in the next few years. Despite adopting a more demanding perspective when considering solar and wind generation, however, class Alpha respondents express reasonable WTA values, always well below 50% of the current electricity prices and, on average, around 15% of current electricity prices for short blackouts and 25% for long blackouts.

The WTA estimates collected in Table 3.5 are net of the impact of several possible confounding factors. Indeed, as reported in Table 3.4, a variation in the share of renewables included in the grey mix with respect to the current average level of 60% impacts consumer choices (coefficients “40% RES”, “80% RES”, and “100% RES”). Moreover, a few demographic and behavioural variables, i.e. gender, age, Swiss nationality, previous blackout experience, energy illiteracy, and regular engagement in environmental friendly behaviour further contribute to shaping consumer preferences with respect to each primary energy source. These variables were selected based on the suggestions of the economic literature and retained, after testing several interactions, as they proved significant; in a few cases, they were retained despite not being significant as it was interesting to check that they weren’t. Although the literature regarding the drivers of households’ preferences with respect to selected primary energy sources does not provide univocal evidence as regards the role of demographic variables, the sign of the estimated coefficients is broadly consistent with some comparable studies. While a detailed comment of the drivers of consumer preferences with respect to each primary energy source per se is outside the focus of this analysis, it is useful to remind that by including these variables into our model, we are able to disentangle

consumer preferences with respect to blackouts from other factors influencing individual choices among the available options.

Generally speaking, the fact that our estimates for the value of SOES span over such a wide interval might also suggest that the large variability observed in the literature (Table 3.1) could be determined not only by the different structure of the electricity sector and consumption habits observed in the various countries, but also by the inherent heterogeneity of consumer reactions in the different contexts, as well as by a structural taste variability. The studies exploiting random parameters measure the magnitude of taste heterogeneity, but do not investigate the existence of specific preference patterns; our approach exploiting latent classes with class membership functions provides instead an assessment of the otherwise unobservable trends in consumer behaviour and an evaluation of the demographic and behavioural drivers that may determine them.

3.6 Conclusions

An assessment of the value of SOES to electricity consumers is increasingly important in the context of the energy transition, where policy makers, energy regulators, and energy companies will need to decide on large-scale investments, structure and functioning of the energy markets, and strategies to involve consumers and elicit citizens' consensus.

Our contribution sheds light on the value of the SOES for residential consumers in Switzerland. By means of a DC model with latent classes applied to stated preference data, we evaluate the WTA of Swiss households for accepting an increase in the frequency of short and long blackouts. Our analysis improves on the existing literature in two directions. First, by accounting for consumer preferences toward alternative primary energy sources used for producing electricity, we are able to explore the connections or trade-offs that consumers may perceive between security and sustainability, or between the risk of (and from) blackouts and the use of specific primary energy sources. Secondly, the use of a DC model with latent classes and class membership functions allows us to investigate the demographic, behavioural, and attitudinal drivers of consumer preferences, and identify three market segments showing different preference patterns.

We find that the WTA of Swiss households for an increased blackout frequency spans over a very wide interval, ranging from slightly negative values up to more than 10 times the actual electricity prices, depending on the characteristics of the blackout, the primary energy sources used for generation, and the

individual characteristics of the residential consumers. According to our estimates, the kind of energy source used is the main driver of consumer WTA; different market segments have radically diverging preferences in this respect.

More in detail, we identify three latent classes showing the following preference patterns:

- Class Alpha, corresponding to around 47% of the respondents, collects individuals showing a mild aversion toward blackouts and a comparably lower availability to accept them if they come from the new generation technologies;
- Class Beta, about the same size as class Alpha, collects environmentally concerned consumers who place a high value on security, are in favour of the nuclear decommissioning, and are more ready to accept blackouts if they are short and associated to sun-, hydro-, or wind-based generation;
- Class Gamma, consisting of the remaining 6% of the sample, gathers respondents who express a strong aversion to the risk of blackouts, but with source-specific WTA values stretching over a very wide range of values. Indeed, Gamma respondents show a negative WTA for blackouts associated to a sun-based supply, and a WTA above 10 times the current electricity prices for long blackouts from a nuclear-based supply. Generally speaking, Gamma respondents might be seen as radical supporters of the nuclear phase-out and of an uptake of solar energy in Switzerland.

Overall, the latent class profiles also suggest that preferences for change or stability of the electricity system are another important driver of heterogeneity in the responses of residential consumers to the risk of blackouts.

Several researchers (Longo et al., 2018; Morrissey et al., 2018; Niroomand and Jenkins, 2020; Siyaranamual et al., 2020) have recently measured a significant heterogeneity in households' preferences with respect to the SOES, and highlighted the need of a deeper investigation of the drivers of household behaviour. Merk et al., 2019 have pointed out that German and British households perceive a trade-off between an expansion in the share of renewables and the SOES, and prioritize the security over the sustainability of their electricity supply. Our findings contribute to a better understanding of the drivers of consumer preferences, and shed further light on households' attitudes toward the primary energy sources involved in the energy transition. Besides filling a gap in the literature concerning the value of security and its determinants, our results may support the evaluation of investments in new generation capacity and in the upgrading of the transmission and distribution grids, and serve as a basis for the design of customized electricity supply contracts matching the expectations of different market segments as regards the SOES and the future of the electric system. Furthermore, despite being focussed on the Swiss households and

electric system, our results may be of use for any industrialized country facing the challenge of decarbonizing the energy system and reducing at the same time the contribution of existing nuclear generation plants.

There are, of course, some limitations that may constrain the practical use of our results. First, as already mentioned in paragraph 3.2, the external validity of stated preferences analyses is often questioned, particularly when the respondents face a choice that they rarely or never make in real life. Furthermore, some researchers argue that WTA assessments tend to overestimate the real value of security for electricity consumers. Finally, the fact that our DC experiment did not include an attribute for the advance notice somehow limits the possibility of exploiting these results as an input to design demand response schemes targeting specific household segments. As the contributions from the new generation technologies increase and new technological solutions allow for the introduction of smart contractual arrangements, a new experiment to investigate household choices among real, customized supply contracts could validate our results and further expand our understanding of household preferences and their drivers.

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Appendix 3.A

	Multinomial logit	Two latent classes	Two latent classes with class membership functions	Three latent classes	Three latent classes with class membership functions
Nr of observations	1006	1006	1006	1006	1006
Nr of estimated parameters	31	42	46	53	61
Final log-likelihood	-8725.2	-8326.6	-8279.1	-8085.8	-8042.7
McFadden adjusted R2	0.227	0.262	0.265	0.282	0.285
AIC	17512.4	16737.2	16650.3	16277.7	16207.4
BIC	17664.7	16943.6	16876.3	16538.1	16507.2
Parameters of the utility functions					
Alternative-specific constants (ASC)					
ASC_hydro	0.572**	0.0474	0.142	0.108	0.169
ASC_nuclear	-0.0683	-0.576	-0.0475	-0.619	-0.0531***
ASC_sun	0.672***	0.445	0.548**	0.479*	0.589**
ASC_wind	1.24***	0.976***	1.02***	1.16***	1.25**
Price					
Price_hydro	-0.0573***	-0.0564***	-0.0561***	-0.0577***	-0.0568***
Price_mix	-0.062***	-0.0727***	-0.0715***	-0.0726***	-0.0715***
Price_nuclear	-0.0927***	-0.0827***	-0.0861***	-0.084***	-0.0873***
Price_sun	-0.0481***	-0.0542***	-0.0546***	-0.0621***	-0.0629***
Price_wind	-0.0801***	-0.0858***	-0.0848***	-0.0927***	-0.0932***
Share of renewable electricity in the mix alternative					
Mix_40%_RES	-0.0249	-0.449	-0.374	-0.597**	-0.438***
Mix_80%_RES	0.0836	0.133	0.122	0.102	0.145
Mix_100%_RES	0.559***	0.682***	0.671***	0.621***	0.646**
Demographic variables					
Age_mix	0.0147***	0.0126***	0.0132***	0.0131***	0.0129**
Green_behaviour_nuclear	-0.445***	-0.477***	-0.441***	-0.469***	-0.439***
Blackout_experience_nuclear	0.289***	0.271***	0.224***	0.281***	0.241**
Illiteracy_nuclear	-0.0603	-0.0674	-0.0779	-0.0676	-0.0752***
Swiss_nuclear	-0.00209***	-0.0023***	-0.00147***	-0.0024***	-0.00147***
Male_hydro	0.249**	0.254**	0.269**	0.219*	0.231**
Male_nuclear	0.756***	0.802***	0.799***	0.785***	0.797**
Male_sun	-0.33***	-0.38***	-0.357***	-0.165	-0.157***
Male_wind	0.065	0.0349	0.06	-0.000818	0.00524

(The table continues on the next page)

	Multinomial logit	Two latent classes	Two latent classes with class membership functions	Three latent classes	Three latent classes with class membership functions
Long blackouts					
Long_blackout_hydro	-0.448***				
Alpha_Long_blackout_hydro		-0.292***	-0.343***	-0.313***	-0.336***
Beta_Long_blackout_hydro		-0.623***	-0.602***	-0.632***	-0.669***
Gamma_Long_blackout_hydro				-19.9***	-2.62***
Long_blackout_mix	-0.285***				
Alpha_Long_blackout_mix		-0.123***	-0.149***	-0.106***	-0.138***
Beta_Long_blackout_mix		-0.722***	-0.646***	-0.746***	-0.745***
Gamma_Long_blackout_mix				-0.513**	-0.534***
Long_blackout_nuclear	-0.284***				
Alpha_Long_blackout_nuclear		-0.0714	-0.195***	-0.0279	-0.188***
Beta_Long_blackout_nuclear		-1.43***	-9.42***	-1.21***	-10.3***
Gamma_Long_blackout_nuclear				-17.6***	-22.2***
Long_blackout_sun	-0.436***				
Alpha_Long_blackout_sun		-0.626***	-0.685***	-0.513***	-0.571***
Beta_Long_blackout_sun		-0.493***	-0.478***	-0.753***	-0.765***
Gamma_Long_blackout_sun				0.516**	0.444**
Long_blackout_wind	-0.566***				
Alpha_Long_blackout_wind		-0.549***	-0.592***	-0.553***	-0.61***
Beta_Long_blackout_wind		-0.647***	-0.638***	-0.659***	-0.664***
Gamma_Long_blackout_wind				-3.32***	-3.26***
Short blackouts					
Short_blackout_hydro	-0.128***				
Alpha_Short_blackout_hydro		-0.203*	-0.197***	-0.257***	-0.198***
Beta_Short_blackout_hydro		-0.066	-0.0662**	-0.0452	-0.0554***
Gamma_Short_blackout_hydro				-1.74	-1.17***
Short_blackout_mix	-0.0665***				
Alpha_Short_blackout_mix		0.109*	0.105***	0.143***	0.109**
Beta_Short_blackout_mix		-0.38***	-0.387***	-0.391***	-0.43***
Gamma_Short_blackout_mix				-0.584***	-0.589***
Short_blackout_nuclear	-0.145***				
Alpha_Short_blackout_nuclear		-0.0344	-0.057	-0.0202	-0.0541***
Beta_Short_blackout_nuclear		-0.409***	-2.12***	-0.381***	-2.28***
Gamma_Short_blackout_nuclear				-7.65***	-8.52***
Short_blackout_sun	-0.139***				
Alpha_Short_blackout_sun		-0.575***	-0.574***	-0.538***	-0.505***
Beta_Short_blackout_sun		-0.0179	-0.0104	-0.0723***	-0.0531***
Gamma_Short_blackout_sun				0.638***	0.621**
Short_blackout_wind	-0.216***				
Alpha_Short_blackout_wind		-0.651***	-0.495***	-0.66***	-0.508***
Beta_Short_blackout_wind		-0.128***	-0.128***	-0.17***	-0.159***
Gamma_Short_blackout_wind				-1.71	-0.672***

(The table continues on the next page)

	Multinomial logit	Two latent classes	Two latent classes with class membership functions	Three latent classes	Three latent classes with class membership functions
Parameters of the class membership functions					
Alpha_Blackout_experience			0.173*		
Alpha_Green_behaviour					0.0659
Alpha_Age					0.0179**
Alpha_Illiteracy					0.461**
Alpha_Male					1.99**
Alpha_att2 - It is a good idea to dismantle all nuclear plants in Switzerland			-0.373***		
Alpha_att22 - I feel worried about depending on foreign countries for energy supplies			0.095**		
Alpha_att28 - It is important to generate electricity using renewable energy sources (wind, water, sun)			0.108*		
Alpha_att6 - Blackouts can be very costly for households			0.127***		0.0774*
Beta_Age					-0.00191***
Beta_Illiteracy					0.398**
Beta_male					2.22**
Beta_att2 - It is a good idea to dismantle all nuclear plants in Switzerland					0.341**
Beta_att9 - I think the risk of a nuclear accident in Switzerland is very low					-0.123***
Class membership probability or estimated size of each class					
P_Alpha / Size class Alpha		0.436***	0.461^	0.389***	0.467^
P_Beta / Size Class Beta		0.564^	0.539^	0.565***	0.471^
P_Gamma / Size class Gamma				0.046^	0.061^

* p-value ≤ 0.1, ** p-value ≤ 0.05, *** p-value ≤ 0.01; ^ class size or class membership probability computed from the estimated parameters

Table 3.A.1 – Estimation results: details

4. Electricity blackouts for business consumers: perceived impacts, heterogeneous responses, and the role of cognitive drivers

Abstract

The reliability of the electricity supply is essential for most production activities, yet ensuring the security of supply is increasingly a challenge for several countries engaged in the energy transition. The existing literature provides very scattered estimates of the value of security for the segment of business electricity consumers. Through a survey conducted on a sample of 543 business consumers located in Canton Ticino, Switzerland, we study the kind and magnitude of damage that blackouts may cause to this consumption segment, and the spreading of back-up devices and specific insurance contracts. By including a discrete choice experiment in the survey, we measure the preferences of these consumers toward blackout duration, advance notice, and damage compensation. We find that an unannounced blackout lasting one hour causes a damage up to 20% of the yearly electricity bill. We detect a sizeable heterogeneity in the reactions toward advance notice and damage compensation: while a substantial share of this variability remains unexplained, part of it can be traced back to previous blackout experiences and the availability of back-up devices. Heuristic decision making in the form of lexicographic preferences may seriously bias the estimation results, unless carefully addressed in the model.

Keywords

Power outage; Security of supply; Discrete choice model; Choice heuristics

Abbreviations

VOLL: value of lost load; WTA: willingness to accept; WTP: willingness to pay.

4.1 Introduction

The security of electricity supply, obviously a key problem for the countries with energy access problems or low reliability levels (Oseni and Pollitt, 2015; Ghosh et al., 2017), has become an increasingly important topic also for the countries engaged in the energy transition (Reichl et al., 2013; Wolf and Wenzel, 2016). The growing contribution of intermittent and often small-scale renewables observed in the 2010s is already changing the functioning of distribution and transmission grids, as well as the business model of

programmable power plants. In the next few decades, the electrification of substantial parts of the transport and heating systems will require a careful planning of the evolution of the electricity system as a whole, in order to ensure that the electricity demand is met with an efficient level of security, affordability, and sustainability. Measuring the value of security is thus particularly important in order to support the definition of the future of the electricity systems and the appropriate investment plans (Linares and Rey, 2013), and eventually in order to meet the needs of the various consumption segments. The business segment is particularly interesting in this respect, as it includes very heterogeneous consumption profiles, ranging from small firms belonging to the service sector to large energy-intensive manufactories. An assessment of the value of blackout damage and its drivers and an evaluation of the variety of strategies and perceptions that business consumers express with respect to blackouts can be very useful for both policy makers involved in drafting energy policies, and energy suppliers interested in providing customized solutions.

The last twenty years have witnessed, indeed, a growing interest in measuring the value of security of electricity supply to end consumers. Several studies have assessed the value of security for specific countries or regions, for the economy in general or for specific consumption segments. The business segment, including both manufactories and service companies, has been considered within wider studies aimed at measuring the value of lost load (VOLL) for a given region (de Nooij et al., 2007; de Nooij et al., 2009; Leahy and Tol, 2011; Zachariadis and Poullikkas, 2011; Linares and Rey, 2013M; Reichl et al., 2013; Growitsch et al., 2014; Castro et al., 2016; Wolf and Wenzel, 2016; CEPA, 2018), within studies investigating the productivity gains connected to a reduction in the frequency of blackouts (Allcott et al., 2016; Abdisa, 2018) or the value of the damage that blackouts may cause to different economic activities (Kjølle et al., 2008; Diboma and TamoTatietse, 2013; Küfeoğlu and Lehtonen, 2015), and finally within analyses evaluating the willingness-to-pay (WTP) or willingness-to-accept (WTA) of business consumers for blackouts with different characteristics (Caves et al., 1992; Matsukawa and Fujii, 1994; Willis and Garrod, 1997; Kjølle et al. 2008; Bliem, 2009; London Economics, 2013; Ghosh et al., 2017; Kim and Cho, 2017; Carlsson et al., 2020; Niroomand and Jenkins, 2020), and the measures that business consumers may undertake to prevent blackout damages (Matsukawa and Fujii, 1994). As new technologies enabling self-generation, electricity storage, and demand response are spreading fast, a deeper understanding of the nature and drivers of blackout damage for business consumers may provide useful information to evaluate both infrastructural investments, and the demand response potential or the attractiveness of customized solutions meeting specific customers' needs.

We build on these contributions, and study the value of electricity security for business consumers in Canton Ticino, Switzerland. Based on an original survey distributed in December 2018 and January 2019 to a sample of 543 firms, we explore the magnitude and kind of damage that firms of different dimensions and economic sectors suffer in the event of a blackout, the precautionary measures that they adopt, and the impact of a different blackout timing or the availability of blackout notice. Finally, by including a discrete choice model in the survey we are able to measure the willingness-to-accept (WTA) of the respondents for blackouts of different durations and their willingness-to-pay (WTP) for receiving advance blackout notice, and to explore the demographic and cognitive determinants of the respondents' reactions. We follow Carlsson 2020 and set up our discrete choice model as a profit maximisation problem: more specifically, we assume that the firm's profit is exogenous, and the blackout creates a damage that the firm will try to minimize. Moreover, as the inspection of the responses suggests that 38.8% of the respondents systematically choose the alternative with the shortest blackout duration, we discuss and evaluate the presence of heuristic decision making in our discrete choice experiment, and disentangle the heterogeneity stemming from taste variability from that connected to the use of different decision rules. The analysis develops as follows. Paragraph 4.2 collects the main suggestions coming from the economic literature concerning the cost of blackouts for business electricity consumers. Paragraph 4.3 describes our survey and the structure of the sample, and discusses our econometric approach and the main challenges that arise when facing heuristic decision making, more in detail in the form of lexicographic preferences. Paragraph 4.4 presents the descriptive statistics concerning the impact of blackouts on the activity of business consumers, and the results of our discrete choice model. Paragraph 4.5 discusses our findings and the resulting policy implications.

4.2 Literature review

The literature addressing the economic impact of blackouts for business electricity consumers provides interesting hints as regards the kind and magnitude of the damage that blackouts may cause, the available coping strategies, and the impact of different blackout characteristics, such as duration, advance notice, and timing. The evidence collected in the available analyses is relatively wide, but very fragmented in terms of approaches, findings, and comparability of the results. Table 4.1 summarizes the main findings of the surveyed analyses, and provides an overview of the main suggestions that can be drawn from them.

Reference	Geo	Year	Method	Target group	Magnitude of the blackout damage*	Kind of damage	Characteristics of the blackout	Characteristics of the consumer
Willis and Garrod, 1997	UK	1996	Contingent ranking	Manufactories	WTA as a % of current yearly bill: for 1 additional blackout per year: 6.7%; for 1 additional minute of blackout per year: 0.04%, for a shorter notice: 6.4%		Duration (+), frequency (+), timing (n.s.), reduction in notice period (+)	Back-up equipment (+), electricity consumption (+), employees (n.s.), previous blackout experience (+)
Niroomand and Jenkins, 2020	Nepal	2016-2017	Contingent valuation	All economic sectors	WTP for a 50% reduction: 22.5%-37.2% of el. bill; 100% reduction: 49.5%-88.5% of el. bill			
Ghosh et al., 2017	India	2010	Contingent valuation (stated preferences)	Micro, small, medium enterprises	0.024-0.027 USD/kWh for reducing outages from current level to zero (20% of el. price)		Advance notice (+)	Back-up equipment (+)
Bliem, 2009	Austria	2007	DCE	All economic sectors	WTA: 9.92% of current bill for accepting a 4 hour blackout instead of a 30 mins one		Duration (+), frequency (+), daytime (+), working day (+)	Sector; interaction: back-up equipment * blackout duration (+)
Carlsson et al., 2020	Ethiopia	2018	DCE	Micro, small, medium enterprises	1 blackout less per month: 0.005 USD/kWh (24% of el. price); 1 hour shorter blackouts: 0.01 USD/kWh (47% of el. price); zero blackouts: 131.7-179.4 USD per month (700% of monthly bill)		Duration (+), frequency (+)	Sector, employees
London Economics, 2013	UK	2013	DCE (households and SMEs); VOLL (industrial and service sector)	All economic sectors	SMEs: 53.0-70.0 USD/kWh; industrial and commercial: 2.7 USD/kWh			
Matsukawa and Fujii, 1994	Japan	1988	DCE (probability and cost of owning back-up equipment)	Manufactories and service companies using large computers	Compensating variation: finance and communications: 269-387 USD/kWh; other sectors: 131-154 USD/kWh			Sector (finance and communications: +); electricity consumption (+)
Küfeoğlu and Lehtonen, 2015	Finland	2013	Direct worth + VOLL	Service sector	1 hour blackout, unplanned: 0.01-6.60 USD/kWh; 1 hour blackout, planned: 0.01-5.28 USD/kWh	Equipment loss, turnover, cost of labour, loss of inputs		
Diboma and TamoTatietse, 2013	Cameroon	2009	Direct worth, compensatory estimation method (cost of a back-up device)	All economic sectors	1 hour blackout, planned: 5.6 USD/kWh; 1 hour blackout, unplanned: 8.4 USD/kWh	Equipment loss, cost of labour, cost of back-up equipment, loss of inputs	Duration (+), advance notice (+)	Sector, back-up equipment, electricity consumption (for normalization)
Kjølle et al., 2008	Norway	2001-2003	Direct worth, WTP	Industry; commercial; large industry; public sector, agriculture (and residential)	2.0-16.5 USD/kWh		Duration (+), season, daytime (+), working day (+)	Sector; electricity consumption (for normalization)
Allcott et al., 2016	India	2016	Loss of productivity	Manufactories and service companies	1% increase in blackouts decreases revenues by 1.09%			

(The table continues on the next page)

Reference	Geo	Year	Method	Target group	Magnitude of the blackout damage*	Kind of damage	Characteristics of the blackout	Characteristics of the consumer
Abdisa, 2018	Ethiopia	2018	Loss of productivity	All economic sectors	Total cost of power outages over a year: 23.5% of firms' aggregate costs			
Cole et al., 2018	Sub-Saharan Africa	2006-2014	Loss of sales	All economic sectors	Firms without generator located in Sub-Saharan Africa: +85.1% yearly sales if outage hours drop to 118 hours/year			
Kim and Cho, 2017	South Korea	2014-2015	Survey + VOLL	All economic sectors	Average outage cost suffered by one business for a 1 hour blackout: 117'700 USD	Equipment loss, production loss, cost of back-up equipment, loss of inputs	Duration (+), advance notice (-)	Size of the back-up equipment (+), electricity consumption (+), employees (+)
CEPA, 2018	EU-28	2018	Survey + VOLL	All economic sectors	1.7-25.5 USD/kWh		Advance notice (-)	Sector, substitutability of electricity as an input (-)
de Nooij et al., 2007	Netherlands	2001	VOLL	All economic sectors	4.7-40.0 USD/kWh			Sector; electricity consumption (for normalization)
Leahy and Tol, 2011	Republic of Ireland; Northern Ireland	2007	VOLL	All economic sectors	Industrial sector: 5.5-6.3 USD/kWh; Services: 8.0-20.6 USD/kWh		Daytime (+), working day (+)	Sector
Zachariadis and Poullikkas, 2011	Cyprus	2009	VOLL	All economic sectors	0.3-182.3 USD/kWh		Winter (-), daytime (+), working day (+)	Sector
Linares and Rey, 2013	Spain	2008	VOLL	All economic sectors	2.2-54.4 USD/kWh (neglecting substitutability of electricity as an input)		Daytime (+)	Sector, substitutability of electricity as an input (-)
Growitsch et al., 2014	Germany	2007	VOLL	All economic sectors	Manufactories: 3.46 USD/kWh; Construction: 162.9; Services: 17.4			
Castro et al., 2016	Portugal	2010	VOLL	All economic sectors	Manufactories: 1.8-22.2 USD/kWh; services: 9.5 USD/kWh		Winter (+), daytime (+), working day (+)	Sector
Wolf and Wenzel, 2016	Germany	2010	VOLL	All economic sectors	Manfactories: 0.65-17.9 USD/kWh; agriculture: 2.8 USD/kWh; construction: 168.9 USD/kWh; services: 14.6 USD/kWh			
Reichl et al., 2013	Austria	2011	VOLL (industrial consumers); CV (households)	All economic sectors	1.1-58.9 USD/kWh		Duration (+), daytime (+), winter (n.s.)	

* Monetary values have been transformed in 2015 USD for the sake of comparability

Table 4.1 – Blackout damage and its drivers for the business segment in the surveyed literature

4.2.1 *Methods used*

The surveyed literature exploits three main approaches to the estimation of the value of security or, equivalently, the cost of a blackout.

The first approach implies the use of survey data, for example in direct worth analyses, contingent valuation studies, or discrete choice experiments. These contributions evaluate stated damage values, or exploit stated preferences to measure either the magnitude of the blackout damage, or the WTP or WTA for blackouts with different duration, timing, or advance notice (Matsukawa and Fujii, 1994; Willis and Garrod, 1997; Bliem, 2009; Diboma and TamoTatietse, 2013; London Economics, 2013; Küfeoğlu, S., Lehtonen, M., 2015; Ghosh et al., 2017; Carlsson et al., 2020; Niroomand and Jenkins, 2020). In a few cases (Matsukawa and Fujii, 1994; Diboma and TamoTatietse, 2013) the researchers also exploit information on the availability of a back-up device and the costs for purchasing and operating it as a proxy for the value that the business consumers place on security. The use of surveys allows a detailed investigation of the relationship between the magnitude of blackout damage on the one hand, and specific characteristics of blackouts (duration, timing, advance notice, ...) and firms (sector, availability of a back-up generator, electricity consumption, ...) on the other hand. The disadvantages of this approach lie in the cost of collecting survey data, particularly among business consumers, and in the possible low external validity of the results due to the risk of hypothetical bias.

The second approach involves the use of macroeconomic data: these analyses compute the VOLL for individual sectors and for specific regions as a ratio between the gross value added and the electricity consumption (de Nooij et al., 2007; Leahy and Tol, 2011; Zachariadis and Poullikkas, 2011; Linares and Rey, 2013; Reichl et al., 2013; Growitsch et al., 2014; Castro et al., 2016; Wolf and Wenzel, 2016). This method is widely used as it resorts to national accounts and sectorial electricity consumption data that are usually available free of charge, and yields easily comparable estimates. On the other hand, however, the quality of the estimates and the comparability across studies may be hindered by the availability of detailed consumption data for each economic sector, as well as by the decision to use, where available, real or synthetic load profiles for each economic sector or region and thus to compute hourly values rather than yearly averages. Similarly, the use of different assumptions underlying the computation of the VOLL may prevent a straightforward comparison: this happens, for example, with sector- or region-specific hypotheses as regards the substitutability of electricity as an input, or the effect of providing advance blackout notice.

A third approach to the assessment of the value of security is based on the use of panel or cross-section data concerning the economic performance of individual firms and the frequency and duration of blackouts in the regions where the firms are located. These contributions usually focus on countries with a low security level, and exploit specific econometric techniques, typically instrumental variables, to compute the decrease in the firms' productivity or turnover determined by the observed blackout frequency and length (Allcott et al., 2016; Abdisa, 2018).

Finally, it is interesting to note that a hybrid approach to the assessment of the value of security is emerging. A few recent studies (Kim and Cho, 2017; CEPA, 2018) rely indeed on the use of a combination of macroeconomic and survey data; more precisely, these analyses estimate the VOLL based on macroeconomic data, and exploit survey data to refine this assessment, for example by taking into account the declared substitutability of electricity as an input of the production process for each economic sector, or the respondents' estimations as regards the impact of providing advance blackout notice.

4.2.2 Main findings

The estimates concerning the magnitude of the damage caused by blackouts span over a very wide interval, frequently even within the same study, depending on the country, sector, and method used (Table 4.1). Moreover, the results are often difficult to compare across studies, as they are expressed in different units, and data availability or specific underlying assumptions may preclude any normalization attempt.

The surveyed literature provides instead mostly coherent suggestions as regards the relationship between specific characteristics of blackouts and business consumers on the one hand, and the magnitude of blackout damage on the other hand (Table 4.1). As could be expected, longer blackouts harm more than shorter ones, although the negative impact of an additional minute of blackout is decreasing. When considering blackout timing, the researchers usually find that blackouts harm more in Winter, on working days, and during daytime, i. e. when most firms perform their production processes. Advance notice helps reducing blackout damage, as does reducing blackout frequency. The availability of a back-up device is sometimes associated to a higher blackout cost: this counterintuitive result is usually due to the fact that firms owning back-up devices are more likely to be heavily dependent on electricity. The economic impact of blackouts varies substantially across economic sectors. The analyses using a macroeconomic approach often find that economic activities that use less electricity have, by construction, a counterintuitively higher VOLL: the typical example is the construction sector (CEPA, 2018), that is thus often excluded from

the computation of average values. It is also interesting to note that already in the 1980s Matsukawa and Fujii, 1994 found that Japanese firms using large computers were most heavily damaged by blackouts. Only three analyses explicitly investigate the kind of damage that blackout cause to business consumers. Diboma and TamoTatietse, 2013, Küfeoğlu and Lehtonen, 2015, and Kim and Cho, 2017 report indeed that the heaviest impacts consist in damaged equipment, damaged inputs, lost turnover or production, cost of operating a back-up device, and finally cost of labour, considering both the workers who remain idle during the blackout, and those who need to devote some working time to restarting the technical devices.

4.2.3 Our contribution to the literature

Our study fits in the stream of literature exploiting survey data to shed light on the impact of blackouts on business electricity consumers. We investigate the case of business consumers located in Canton Ticino, Switzerland, and shed light on several aspects connected to the impact of blackouts, the strategies adopted in order to prevent or minimize their damage, and the preferences of business consumers with respect to the security of the electricity supply.

We provide descriptive evidence on the adoption of back-up technologies and the subscription of insurance contracts for specific kinds of blackout damage. Moreover, we investigate the kind of damage that a blackout may cause, the share of the production activity that can continue during a blackout, the timing in which a blackout causes the highest damage, and finally the magnitude of the damage that an announced or unannounced blackout lasting one hour may cause. Finally, we exploit a discrete choice experiment to measure the WTA of business consumers for blackouts with different durations, and their WTP for receiving an advance notice. Besides accounting for the possible impact of specific characteristics of the business consumers on their own preferences, our discrete choice model explicitly measures the residual taste heterogeneity with respect to blackout duration, advance notice, and availability of a compensation for blackout damage, and disentangles the share of heterogeneity connected to the use of heuristic decision rules from that connected to actual variations in the respondents' tastes. This information complements the direct assessment of the magnitude of blackout damage, providing interesting hints on the priorities and decision making of this consumption segment.

4.3 Methodology

4.3.1 *Survey design*

Our investigation of the value of electricity security for business consumers located in Canton Ticino, Switzerland, was conducted by means of an on-line survey. The survey included:

- Questions concerning the respondent's location, number of employees, turnover, electricity bill, electricity consumption pattern, previous blackout experience, and evaluation concerning the reliability of the own supplier;
- Questions concerning the availability of an insurance for the damages caused by blackouts, as well as the availability of back-up devices (generator, UPS, and back-up connection to the distribution grid);
- Questions concerning the season, day of the week, and time of the day in which a blackout would cause the highest damage;
- Questions concerning the perceived economic impact of a blackout with and without advance notice, and the respondent's evaluation of the percentage of the production activities that could be carried out during a blackout with or without notice;
- A list of possible damages caused by a blackout, that each respondent was asked to evaluate on a five points severity scale in the two hypotheses of a one-hour long blackout with and without advance notice;
- And finally a discrete choice experiment in which each respondent was asked to choose one out of two blackout scenarios, differing in blackout length, advance notice, and possible compensation for the damage caused by a blackout. Figure 4.1 reports the short text that introduced the discrete choice experiment, and an example of a choice task.

These are the last six questions. In each question you will see two hypothetical scenarios in which your company is hit by a blackout.

Please imagine that the blackout hits your company in the season, day of the week, and time of the day in which it causes the highest damage.

The blackout scenarios that you will see differ in terms of:

- Duration of the blackout
- Availability of advance blackout notice
- Compensation that your electricity supplier may pay to your company for the inconvenience and damage caused by the blackout.

Please consider the consequences that your company may suffer in each scenario, and select the most acceptable scenario among the two.

Scenario 1	Scenario 2
Blackout lasting 4 hours	Blackout lasting 1 hour
24-hour advance notice	No advance notice
Compensation: 5% of your monthly electricity bill	Compensation: 25% of your monthly electricity bill

Your
choice:

☐☐

Figure 4.1 – Discrete choice experiment: introductory text and example of a choice task

Table 4.2 reports the attributes and corresponding levels that were used in the discrete choice experiment. The attributes and levels were defined based on the surveyed literature and on the security levels observed in Switzerland and in other comparable countries. The choice tasks were defined with an efficient design with blocking using the software Ngene: the result was six blocks with six choice tasks each, and two unlabelled alternatives per choice task. As a consequence, each respondent was randomly assigned to one of the six blocks, and had to complete six choice tasks.

Blackout attribute	Value	Corresponding description
Blackout duration (minutes)	0	No blackout
	5	Blackout lasting 5 minutes
	60	Blackout lasting 1 hour
	240	Blackout lasting 4 hours
	720	Blackout lasting 12 hours
Compensation (% of the monthly electricity bill)	0	No compensation
	5	Compensation: 5% of the monthly electricity bill
	10	Compensation: 10% of the monthly electricity bill
	15	Compensation: 15% of the monthly electricity bill
	20	Compensation: 20% of the monthly electricity bill
	25	Compensation: 25% of the monthly electricity bill
Advance notice (no / yes)	0	No advance notice
	1	24-hour advance notice

Table 4.2 – Attributes of the discrete choice experiment and corresponding levels

4.3.2 Data

The on-line survey was distributed between December 2018 and January 2019 to a sample of 543 firms. The invitation to complete the survey was sent per e-mail to a panel of approximately 3'000 firms active in the Canton. Most of these firms have already been in touch with our Institute in the past years for similar studies, and are thus somewhat used to participating in research and monitoring studies. The e-mail asked the recipient to forward the invitation to the person in charge of deciding about the company's electricity supplies.

The final sample ensures a reasonable representativeness of the business electricity consumers in Canton Ticino in terms of economic sector (Table 4.3), number of employees, and electricity consumption (Table 4.4). In line with the economic structure of the region, most of the firms are rather small in terms of employees and electricity yearly electricity consumption; however, the sample also includes a good share of larger firms and energy intensive activities. All in all, 65.9% of the respondents state they are always personally paying the company's electricity bill, and an additional 6.3% state they are personally paying the electricity bills at least occasionally; the remaining 27.2% state they are not in charge of this task. Considering that 88.0% of the respondents are employed in micro or small companies with up to 50 employees (Table 4.4), we can reasonably assume that the people who filled in our survey are aware of their company's electricity consumption profile, and able to gauge the consequences of a blackout on their company's production activity.

Economic sector	% respondents	% population (2015)
Constructions	17.3%	9.2%
Real estate; scientific, technical and administrative services	14.4%	25.0%
Manufacturing	10.3%	5.4%
Retailing; car and motorbike services	22.1%	16.4%
Health services	2.9%	8.3%
Financial services	7.7%	3.5%
Arts and entertainment	2.9%	11.5%
Accommodation and catering	7.2%	5.8%
Information and communication	5.7%	3.1%
Transport and storage	4.8%	2.5%
Insurance services	1.1%	3.5%
Education	1.5%	2.0%
Agriculture and fishery	0.6%	3.4%
Mining and extraction	0.2%	0.1%
Energy and water supply; waste disposal	0.9%	0.3%
Family services	0.4%	0.0%

Table 4.3 – Composition of the sample by economic sector, compared to the population in 2015

Number of employees	% respondents
1-10 employees	64.1%
11-50 employees	23.9%
51-250 employees	10.3%
More than 150 employees	1.7%

Yearly electricity bill	% respondents
0-2'500 CHF	41.4%
2'501-5'000 CHF	20.1%
5'001-10'000 CHF	11.0%
10'001-20'000 CHF	9.6%
20'001-50'000 CHF	8.8%
50'001-100'000 CHF	3.7%
100'001-250'000 CHF	2.4%
250'001-500'000 CHF	1.5%
500'001-1'000'000 CHF	0.7%
More than 1'000'000 CHF	0.7%

Table 4.4 – Composition of the sample by number of employees and amount of the yearly electricity bill

Despite the high level of security of supply recorded in Switzerland (Elcom 2019, Elcom 2020), 70.5% of the respondents declare that their company has experienced at least one unannounced blackout in the previous six months. Indeed, during the second half of 2018 some of the electricity retailers active in Canton Ticino recorded four local blackouts lasting between 30 and 90 minutes and due to unexpected technical failures along the distribution grids. Nonetheless, 76% of the respondents express a positive evaluation as regards the quality of the electricity supply, and 80% of them describe their company's electricity supplier as very reliable.

4.3.3 Econometric model

The analysis of the survey data is carried out in two steps. In the first step we analyse with the usual descriptive statistics the responses collected in the first part of the survey, namely the questions concerning the strategies to cope with blackouts or reduce their impact, as well as the actual damage suffered by the business consumers in the event of a blackout. This analysis provides a detailed picture of the perceptions and reactions of the business consumers located in Ticino with respect to blackouts, and serves as a basis for the second step, in which we analyse with the appropriate modelling tools the second part of the survey, devoted to the discrete choice experiment. This paragraph describes in detail the econometric approach adopted for the discrete choice model.

Our strategy starts from the basic assumptions of discrete choice modelling: individuals considering a set of mutually exclusive and collectively exhaustive goods or services will select the alternative providing them the highest indirect utility; according to the random utility theory, the researcher may analyse their choices decomposing the utility associated to each alternative into an observable and an unobservable component (Ben-Akiva and Lerman, 1985).

Following Carlsson et al., 2020, we adapt this framework to a firm's setting, and set up the model as a profit maximization problem: each firm i is expected to choose in each choice task t the blackout scenario j that causes the lowest damage, and thus allows the maximization of an otherwise exogenous profit π_i . The firm's profit is modelled as a function of blackout's characteristics, firm's characteristics, and an error term accounting for unobserved heterogeneity and measurement error. Thus, the model structure is the following:

$$[1] \quad \pi_{ijt} = X'_{jt}\beta + Z'_i\gamma + \varepsilon_{ijt}, \text{ with } \varepsilon_{ijt} \text{ i.i.d. } \sim EV(0, \mu_\varepsilon)$$

$$[2] \quad y_{ijt} = 1 \text{ if } \pi_{ijt} = \max_k \{\pi_{ikt}\}, \quad y_{ijt} = 0 \text{ otherwise}$$

Where:

- π_{ijt} is the profit that firm i gains when choosing the blackout scenario j in choice task t ,
- X_j is a vector of attributes of the blackout scenario j ,
- Z_i is a vector of firm i 's demographic variables,
- ε_{ijt} is an error term which is assumed to follow an extreme value distribution
- β and γ are vectors of parameters to be estimated.

We start from a multinomial logit specification, in which the elements of vectors β and γ are constant across all the respondents, and expand this basic structure to account for heterogeneous preferences across individual firms. More in detail, we develop a random parameter specification in which we assume that the elements of vector β follow a normal distribution, and estimate both their means μ_β , and their standard deviations σ_β . This allows us to include and measure the heterogeneity existing in the respondents' tastes.

Under the above-mentioned assumptions concerning the error term ε_{ijt} , in the random parameter specification the choice probability corresponds to the integral of the discrete choice model over the probability density functions $f(\beta | \mu_\beta, \sigma_\beta)$ of the random parameters belonging to vector β :

$$[3] \quad P_{ijt} = \int \frac{e^{x'_{jt}\beta + z'_i\gamma}}{\sum_k e^{x'_{kt}\beta + z'_i\gamma}} * f(\beta | \mu_\beta, \sigma_\beta) d\beta$$

The discrete choice model is then estimated via simulated maximum likelihood.

Within this framework, we devote some further attention to the analysis of the heterogeneity that the respondents show in the process of choosing, next to the heterogeneity observed in the respondents' tastes. A preliminary analysis of the responses collected in the discrete choice experiment shows indeed that 38.8% of the respondents systematically choose the blackout scenario with the shortest blackout duration (Table 4.5); the percentages of respondents who always choose the alternatives with advance blackout notice or with the highest monetary compensation are instead much lower.

	% of the respondents who always choose this alternative
Shortest blackout duration	38.8%
With advance blackout notice	13.1%
Highest compensation	2.4%

Table 4.5 – Preferred alternatives in the discrete choice experiment

The behaviour of the respondents who always choose their preferred option based on a subset of attributes is described in terms of lexicographic preferences in the literature concerning the choice heuristics, i. e. the rules that individuals apply when processing information in discrete choice experiments (Hensher and Greene, 2010; Hess et al., 2010). Lexicographic preferences, as other forms of heuristic decision making, may either witness the extremely high importance that some respondents place on

avoiding lengthy blackouts, or rather be due to boredom, fatigue, disengagement, or simply the desire of reducing the cognitive effort required for completing each choice task (Hess et al., 2010; Hess et al., 2012). In the past twenty years a growing body of literature has been focussing on detecting and understanding the heterogeneity in the process of choosing, next to the heterogeneity in the observed preferences. From a methodological point of view, the challenge lies in developing the most appropriate strategies to detect possible violations to the random utility assumptions, e.g. cases in which the respondents do not use all information or are not willing to trade among attributes, identifying the kind of heuristic rule that was used by the decision maker, and finally dealing with this kind of responses in the estimation of the parameters of interest (Louviere et al., 2000; Hensher and Greene, 2010; Hess et al., 2010; Hess et al., 2012). In the case of lexicographic preferences, Hess et al, 2012 develop a latent class model to deterministically assign the lexicographic respondents to a separate class, and estimate the parameters of interest only for the subset of respondents who are willing to trade among all attributes. In a somewhat similar fashion, Carlsson et al. 2020, while assessing the WTP for electricity security among Ethiopian business consumers, detect attribute non-attendance by explicitly asking the respondents whether they considered all attributes while completing the discrete choice experiment, and set equal to zero the relevant coefficients for the respondents who declared they didn't consider one or more of the attributes. The idea behind both strategies is that the true value that the respondents place on each attribute can only be inferred from the respondents who stick to the random utility maximization process and are willing to trade among all attributes; as a consequence, including the respondents who neglected one or more of the attributes would lead to biased estimates.

In our case, we exploit a simple probit regression in order to investigate whether the probability of showing lexicographic preferences is more or less frequent within specific groups of business consumers. The results (Table 4.6) suggest that lexicographic preferences with respect to blackout duration are less frequent among the respondents who have experienced at least one blackout in the previous six months and, to a lesser extent, among those who would suffer higher damage to machinery in the event of an unannounced blackout. On the other hand, lexicographic preferences are more common among the respondents who own at least one back-up device, and who would suffer higher costs for the workers who could remain idle during the blackout.

Probit model: Y = 1 if the respondent always chooses the alternative with the shortest blackout duration	
Nr. of observations	543
Nr. of estimated parameters	5
Model fit	
Pseudo R2	0.061
Estimated parameters	
Blackout experience	-0.487***
Back-up device	0.276**
Inactive labour force	0.191***
Damage to machinery	-0.185***
Constant	-0.311*

* $p\text{-value} \leq 0.1$, ** $p\text{-value} \leq 0.05$, *** $p\text{-value} \leq 0.01$

Table 4.6 – Probit regression for the probability of showing lexicographic preferences with respect to blackout duration

While no significant correlation is found with the typical demographic variables describing business electricity consumers, such as yearly bill, sector, or number of employees, the correlations linking lexicographic preferences on the one hand, and previous blackout experience, availability of back-up devices, and perceived blackout damage on the other hand, further highlight the need of investigating carefully the origin of the observed heterogeneity, and assessing what share of it is due to heuristic decision making rather than to taste variations. Thus, based on the suggestions of the literature, we estimate the same multinomial logit and random parameter specifications on the whole sample, as well as on a subsample excluding the lexicographic respondents, i. e. those who always chose the alternative with the shortest blackout duration. In the former case, the model accounts for the lexicographic preferences a form of heterogeneity in the respondents' behaviour. In the latter case, the model accounts instead for lexicographic preferences as a form of heterogeneity in the decision process, that needs to be excluded from the estimation of the true value that the respondents place on security. The comparison of the two specifications sheds light on the kind of impact that choice heuristics can have on the estimates. As we will discuss in greater detail within the next paragraph, we retain the latter specification as our preferred one.

4.4 Results

4.4.1 *Business consumers and electricity blackouts: coping strategies and perceived damage*

The first part of the survey provides interesting information as regards the strategies adopted by business consumers to prevent blackout damage, the impact of blackouts on the production activities, and finally the magnitude of blackout damage.

When interviewed about the strategies to prevent blackouts or reduce blackout damage, 50.8% of the respondents declare they own at least one back-up device: more in detail, 46.6% own an UPS, and among these 5.7% also own a generator, 0.2% an additional supply line, and 0.6% both a generator, and an additional supply line; moreover, 3.9% only own a generator, and 0.4% only own an additional supply line. Specific insurance contracts covering the damages caused by blackouts are rather common: 37% of the respondents are insured against blackout damage to their machinery, 34% are insured against blackout damages to their information and communication technologies, including data availability and protection, 32% are insured against blackout damages to their furniture and devices, and finally 28% are insured against blackout damage to their buildings.

A blackout is very disruptive for the firms' activities: Figure 4.2 reports on the share of the production activities that according to the respondents can continue in the two scenarios of an announced and unannounced blackout lasting 60 minutes. On average only 38.8% of the production activities can be carried out in the event of a one-hour blackout without advance notice: this figure is higher than the 24.8% resulting from the recent estimates for the EU-28 reported in CEPA, 2018. The picture improves if the one-hour blackout is announced 24 hours in advance: the share of production activities that can be carried out in this case increases, on average, to 48.9%.

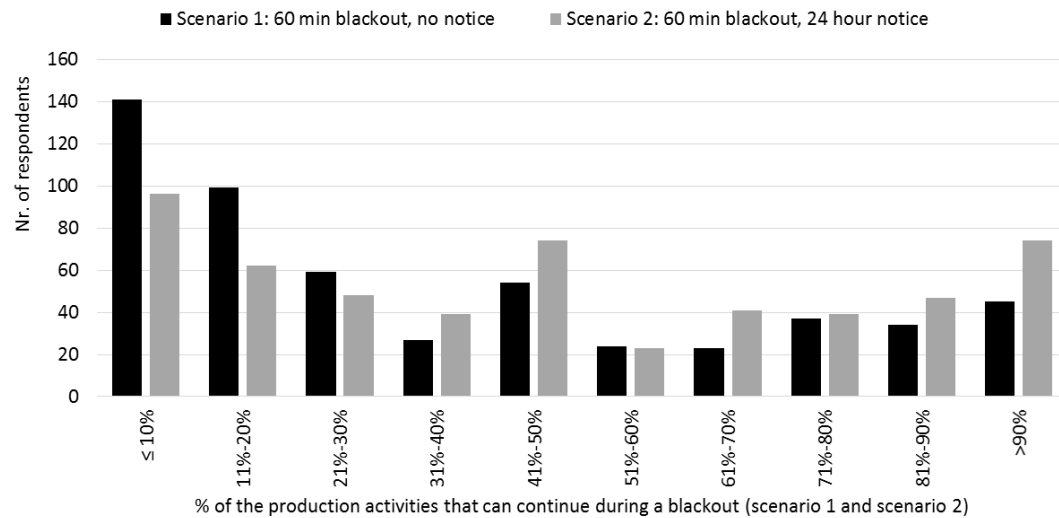


Figure 4.2 – Share of the production activities that can continue during a blackout lasting 60 minutes, with or without advance notice

When interviewed about the moment of the year, week, and day in which a blackout would cause the worst damage, 75% of the respondents state that there is no difference between Winter and Summer, 66.5% state that blackouts happening during working days would have heavier consequences than blackout happening on Saturdays or Sundays, and 54.5% state that the worst timing during the day is between 10:00 and 16:00.

In the survey the respondents were also asked to consider the specific consequences that a blackout may have for their business: Figure 4.3 collects their evaluations of the severity of each kind of damage in the event of a one hour long unannounced blackout. Cost of labour, damages to information and communication technologies, lost turnover, and damaged machinery rank as the heaviest consequences for most respondents.

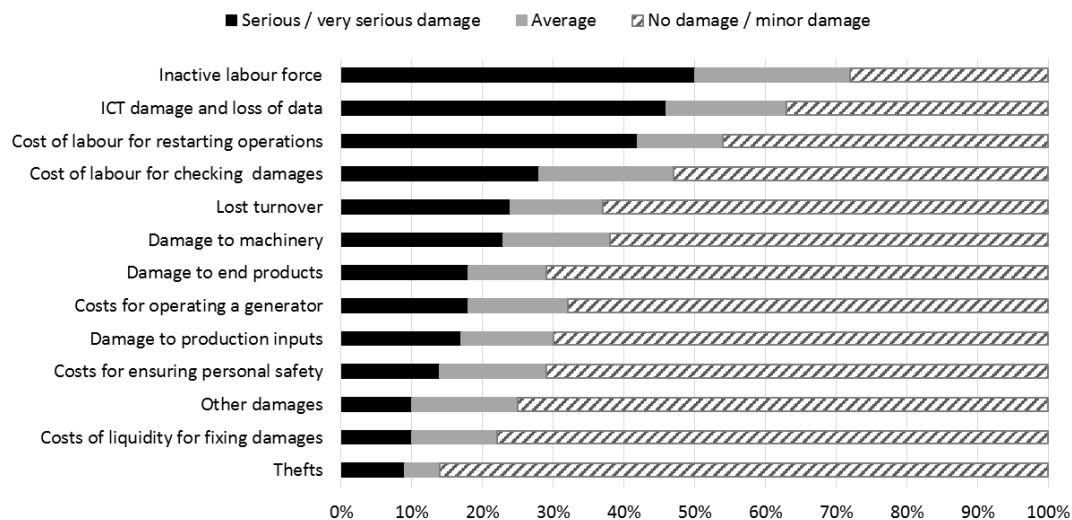


Figure 4.3 – Kind of damage that an unannounced blackout lasting 60 minutes may cause to a business consumer: respondents' evaluations

Finally, the survey also investigated the magnitude of the economic damage that a blackout may cause to business consumers and the impact of providing advance notice. The responses show that the median damage caused by a blackout lasting 60 minutes is in the range of 501-1000 CHF if the blackout is not announced, and in the range of 0-500 CHF if it is announced 24 hours in advance. These figures need to be considered in light of both the structure of the sample, largely composed of micro and small firms, and the amount of the yearly electricity bill. Figure 4.4 suggests indeed that the magnitude of the median blackout damage tends to increase with the yearly electricity consumption, and hovers between 10% and 20% of the yearly electricity bill for the consumers with yearly bills below 100'000 CHF, and well below 10% for those yearly bills above the 100'000 CHF threshold. The availability of advance notice helps reducing the value of blackout damage for all consumption classes.

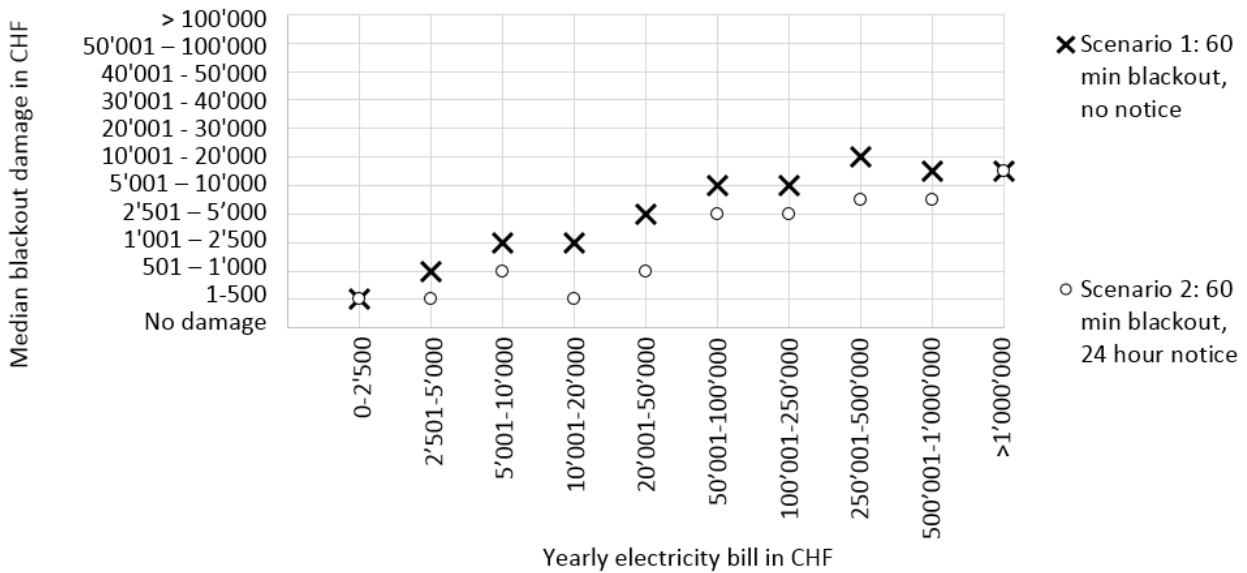


Figure 4.4 – Economic value of the damage from a blackout lasting 60 minutes, with and without advance notice: median values for each consumption class

4.4.2 The preferences of business consumers toward blackout length, advance notice, and compensations: results of the discrete choice model

The discrete choice experiment included in the survey allows us to analyse in greater detail the preferences of business consumers with respect to blackout duration, the availability of advance notice, and the possibility of receiving a compensation for blackout damage.

Table 4.7 collects the results of our estimations, obtained using the software PythonBiogeme (Bierlaire, 2016). The table includes our preferred multinomial logit and random parameter specifications: both models are estimated on the whole sample and on a subsample excluding the respondents who always choose the alternative with the shortest blackout duration, i.e. those showing lexicographic preferences with respect to blackout duration. Next to the specifications included Table 4.7, we tested several alternative specifications including different characteristics of the respondents, and found no significant coefficient next to the ones that are mentioned in the table. After considering the measures of goodness of fit and the coherence with our reasoning concerning the magnitude and origin of heterogeneity in the respondents' behaviour, we choose [4], the random parameter model estimated on the subsample of respondents who stick to the random utility maximization rule, as our preferred specification.

	[1] MNL	[2] MNL excluding lexicographic respondents	[3] RP	[4] RP excluding lexicographic respondents
Nr. of observations	543	332	543	332
Nr. of estimated parameters	7	7	10	10
Model fit				
Final log-likelihood	-1875.8	-1321.9	-1660.7	-1294.7
Mc Fadden adj. R squared	0.17	0.04	0.48	0.53
AIC	3765.5	2657.8	3341.4	2609.4
BIC	3795.6	2684.4	3384.4	2647.4
Estimated parameters				
Advance notice	0.372***	0.258***	0.399***	0.276***
Std. dev. advance notice			0.684***	0.382*
Compensation	-0.0189***	0.0186***	-0.0654***	0.0198**
Std. dev. Compensation			0.125***	0.0517***
Ln(duration)	-0.274***	-0.201***	-0.379***	-0.228***
Std. dev. Ln(duration)			0.202***	0.00787
Generator * Ln(duration)	-0.0412	-0.021	-0.0202	-0.00618
Back-up line * Ln(duration)	0.38***	0.245***	0.436***	0.291***
UPS * Ln(duration)	-0.111**	-0.052	-0.117**	-0.0591
Blackout experience * compensation	0.0375***	0.0171**	0.0672***	0.0212**

* $p\text{-value} \leq 0.1$, ** $p\text{-value} \leq 0.05$, *** $p\text{-value} \leq 0.01$

Table 4.7 – Discrete choice models: estimation results

The estimates resulting from model [4] as regards the respondents' evaluation of blackout duration and advance notice are coherent with the findings emerging from the literature. Blackout duration enters the model in logarithmic form: thus, a long blackout harms more than a short one, but the damage of an additional minute of blackout is decreasing with blackout length. The respondents who own a back-up connection to the electricity distribution grid are less affected by blackout duration as compared to those who have different back-up devices, or no back-up system at all. The respondents place, on average, a high value on receiving advance blackout notice. The random parameter specification detects however a sizeable heterogeneity in this respect, suggesting that the impact of information provision and the ability of firms to take advantage of advance notice vary substantially across the sample. Finally, the respondents' evaluation of the availability of a monetary compensation for the blackout damage is positive, but rather small in magnitude as compared to the parameters of the other attributes. Moreover, the random

parameter specification detects a substantial amount of heterogeneity in this respect, with 35% of the respondents expressing a negative compensation coefficient. The lukewarm appreciation of the monetary compensation for blackout damage might be due to the fact that the compensation is expressed as a percentage of the monthly electricity bill, and its maximum value is relatively small as compared to the assessment of blackout damage collected in the previous sections of the survey (Figure 4.4). Some of the respondents might also implicitly associate the provision of a compensation for blackout damage to a possible reduction in the reliability of their supply, and thus express a negative evaluation of this attribute. However, it is interesting to notice that the respondents who experienced at least one unannounced blackout in the previous six months express a more positive evaluation of the monetary compensation, as witnessed by the interaction between blackout experience and monetary compensation.

The estimated parameters can be used for computing the WTP of business consumers for receiving advance notice, as well as their WTA for accepting a longer blackout. The average WTP for advance blackout notice is around 13.9% of the monthly electricity bill. The WTA for a longer blackout ranges instead from 26.3% of the monthly electricity bill for a blackout lasting five minutes up to 53.9% for a blackout lasting one hour, 69.8% for a blackout lasting 4 hours, and finally 82.4% for a blackout lasting 12 hours. As WTP and WTA values are computed as ratios of normally distributed variables, these values should be considered carefully, as the hint of an average value subject to a considerable variability across the respondents.

A quick comparison between the random parameter estimates conducted on the whole sample (model [3]) and on the subsample of non lexicographic respondents (model [4]) shows, next to a modest improvement in model fit, some interesting changes in the estimated parameters. After excluding the lexicographic respondents, the heterogeneity in the respondents' tastes becomes significantly lower, as witnessed by the smaller estimated standard deviations for duration, advance notice, and compensation. This suggests that at least some of the extreme responses leading to counterintuitive results in the estimates conducted on the whole sample are probably due to the non-trading decision rule adopted by some of the respondents while completing the discrete choice experiment, rather than to actual preferences with respect to each of the attributes characterizing the blackout scenarios. Moreover, the sign of the compensation coefficient is negative in model [3] and positive, in line with our expectations, in model [4]; based on the estimated standard deviations, the share of respondents who express a negative evaluation of the compensation coefficients decreases from 70% in model [3] to the above mentioned 35% in model [4]. This suggests that the respondents who considered all attributes tend to evaluate more

positively the availability of a compensation. At the same time, the coefficient for the interaction between the value of the compensation and the respondent's previous blackout experience becomes smaller, probably because part of the effect of the latter variable has been washed out by excluding the lexicographic respondents. A series of t test comparing the parameters of models [3] and [4] leads to rejecting the hypotheses that the parameters of the two specifications are identical.

Following the reasoning of Hess et al., 2010, and Carlsson et al., 2020, we conclude that the inclusion of respondents adopting heuristic decision rules leads to distorted estimates, and that within our discrete choice experiment the true preferences of the business consumers can only be inferred by restricting the sample to the respondents who consider all attributes.

4.5 Conclusions

Our analysis contributes to the debate concerning the value of security of supply in electricity by providing an insight into the perceived impact of a blackout, the diffusion of coping strategies, and the preferences toward blackout duration, advance notice, and financial compensations for blackout damages among business electricity consumers in Canton Ticino, Switzerland.

The use of an on-line survey allows us to dig into the details of the impact of a blackout for the business consumption segment, explore several dimensions of the perceived impact of a blackout, and complement quantitative information concerning the cost of a blackout with given characteristics with qualitative information concerning the kind of consequences that it may induce for business consumers.

The main messages we can draw from our study are the following.

The occurrence of a blackout causes sizeable damages to industrial consumers, particularly if the blackout lasts for a longer time and if it is not announced. The magnitude of the damage caused by an unannounced blackout lasting one hour is in the range of 10% - 20% of the yearly electricity bill for business consumers with yearly bills below 100'000 CHF, and below 10% for those yearly bills above the 100'000 CHF threshold. The possibility of receiving a compensation from the electricity supplier elicits a lukewarm appreciation, particularly among the consumers who did not experience a blackout in the previous semester and among those who own a back-up device. The reactions of business consumers toward blackouts are very heterogeneous: although we are able to measure this heterogeneity and detect some of its demographic and cognitive drivers, a large share of it remains unexplained. The sizeable variability of individual

reactions toward blackouts might indeed mirror, to some extent, the scattered estimates of the value of security collected in the surveyed literature exploiting survey data.

The results of the discrete choice experiment included in our survey suggest however that a careful assessment of the use of heuristic decision making in answering stated preference questions is crucial to ensure that the heterogeneity stemming from taste variability is disentangled from that originated by cognitive processes that may arise when completing the survey.

Despite being focussed on a relatively small region, our study may provide an interesting term of comparison for other countries with a comparable economic structure. Moreover, our analysis highlights some hints of general interest as regards the sizeable heterogeneity of the preferences of business consumers with respect to blackouts, and the challenges in detecting its drivers.

Future studies might consider including other characteristics of the possible blackout scenarios, such as the blackout timing or the uncertainty concerning blackout duration, directly within the discrete choice model, in order to provide a more detailed analysis of the possible impact of a blackout. The researchers might also consider investigating the impact of the use of heuristic decision rules through follow-up questions included in the survey, and possibly compare the results obtained with this strategy to those obtained by using, as we did, the observed responses in the discrete choice experiment to identify the respondents using heuristic decision strategies. Finally, a similar survey and discrete choice experiment could also be used to evaluate the interest of business consumers for flexibility products or supply contracts offering customized security levels; these options will probably become increasingly appealing for both consumers, and suppliers along with the progress in the energy transition.

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5. Conclusions

The decarbonisation challenge is bringing about a deep restructuring of the structure and functioning of energy systems. In the context of rapidly evolving electricity markets, my work contributes to the debate concerning the preferences and attitudes of electricity consumers, which, according to the recent trends in the European energy policies, are increasingly at the heart of the energy transition. The three contributions building my PhD dissertation discuss indeed the preferences of Swiss residential and business consumers with respect to selected primary energy sources available for electricity generation and to the risk of blackouts.

Electricity is a homogeneous good, indispensable for daily life and production activities, and often absorbing a relatively small fraction of the monthly budget for households and firms. Nonetheless, my results suggest that consumers show a sizeable sensitivity to the differences existing across alternative supply options in the three dimensions of security, environmental sustainability, and affordability. Moreover, I find that consumer preferences are very heterogeneous, and heavily impacted by attitudinal, behavioural, and cognitive drivers characterizing each individual.

The first two contributions of my PhD dissertation, collected in chapters 2 and 3, focus on the residential segments. Their main findings can be summarized as follows:

- Individual preferences toward the electricity supply are multidimensional: households evaluate at the same time the environmental impact, the reliability, and the cost of their supply contract, and perceive strong trade-offs across these three dimensions;
- When deciding about their electricity supply contract, households are driven by attitudes such as environmental concern, fear of certain technologies, ability to rationally manage the perceived risks, and acceptance of the envisaged evolution of the electricity system;
- The multidimensional nature of household preferences is mirrored in the behavioural constructs that influence individual choices. Indeed, these psychological drivers often reflect at the same time environmental sensitivity and risk aversion, or acceptance of new generation technologies and dislike for an increased risk of blackouts;
- Finally, information has a crucial role in shaping individual choices. On the one hand, indeed, the attitudinal drivers are heavily influenced by the individual literacy as regards the own energy consumption pattern and the benefits and risks associated to selected generation technologies. On the other hand, as individuals showing a high environmental concern tend to choose driven by

their sensitivity rather than by a real awareness of the environmental impact of their choices, a careful monitoring of the correspondence between the environmental impact and the labelling of each electricity supply contract is crucial to ensure that the quality of the available supply options meets the expectations of the prospective buyers.

The third contribution, collected in chapter 4, focusses instead on the business segments, and finds that:

- Business consumers have very heterogeneous preferences with respect to blackouts; while a sizeable share of the variability in individual behaviour remains unexplained, another share is connected to the individual electricity consumption pattern and previous blackout experience, as well as to the cognitive processes that may interfere with the expected profit maximizing behaviour;
- The fact that a sizeable share of the respondents resort to heuristic decision making in the form of lexicographic preferences when evaluating alternative blackout scenarios may be connected to respondent's fatigue or disengagement while filling in the survey. However, this result might also reveal a sense of entitlement to an uninterrupted power supply, or an extremely high sensitivity to the occurrence of a blackout, irrespective of its duration or advance notice;
- The acknowledgement of the variability of individual responses toward the risk of blackouts suggests that the call for a consumer-centred approach to security is justified not only in light of the need to improve system planning, going beyond the straightforward but simplistic information contained in the value of lost load, but also in light of the opportunity to develop customized supply contracts, in a world where a market for security and flexibility is gradually emerging.

From a methodological point of view, my PhD dissertation exploits three different tools offered by discrete choice modelling to account for heterogeneity in individual behaviour: a hybrid discrete choice model with latent variables, a hybrid discrete choice model with latent classes, and finally a random parameter discrete choice model where the respondents adopting lexicographic preferences are deterministically excluded from the analysis, in order to disentangle taste heterogeneity from the heterogeneity stemming from the process of choosing.

The specifications exploiting latent variables and latent classes ensure that unobservable, but systematic drivers of consumer preferences are accounted for in the analysis and do not bias the estimates for the parameters of interest. Hybrid discrete choice models exploiting latent variables or latent classes allow the researcher to open the black box behind individual choices, and improve the quality of the estimates and the understanding of consumer behaviour. The resulting estimates may support the drafting of

policies addressing observable behaviours connected to individual choices either directly, or through attitudinal drivers, and may serve as a basis for defining supply products targeting specific consumption segments.

The random parameter specification accounts instead for the otherwise unexplained heterogeneity directly within the estimated parameters; thus, it reduces the risk of incurring into omitted variable bias when the causes of this heterogeneity cannot be detected from the available data. The decision to deterministically exclude from the random parameter estimation the respondents whose choices reveal lexicographic preferences is in line with the literature concerning the problem of choice heuristics, namely the study of both the different strategies that respondents may use to decide, and of the impact of the possible violations of the random utility maximization assumption on the estimated parameters. Within our setting, i. e. a survey targeting business consumers, the fact that several respondents resort to heuristic decision making highlights the importance of both focussing on survey design, and reaching the right person within each organization, in order to ensure a good match between the responses collected in the survey and the choices that would be observed in a similar real-world decision.

My analyses provide useful hints on the trends emerging in consumer behaviour with respect to the new contractual and technological options that are brought about by the decarbonisation challenge, and might serve as a basis to further explore consumer preferences with respect to the technologies enabling demand response or a customized level of security.

The three contributions are centred on the case of Switzerland; however, a similar study could be extended with the necessary adjustments to similar high income countries engaged in the energy transition, in order to measure the heterogeneity in consumer behaviour and investigate its demographic, attitudinal, and cognitive determinants. Behavioural and attitudinal drivers are typically specific to each setting: a careful monitoring of their evolution within the same country, along with the progress in the energy transition, and a comparison across different countries may indeed provide interesting hints as regards consumer preferences in the current fast changing environment. Even if attitudes per se can hardly be targeted by specific policies, a better understanding of their role and evolution over time is crucial to define the most effective channels to involve citizens and firms in the energy transition.

Future research concerning households could investigate their preferences toward innovative options, such as energy communities or demand response programmes. In both cases, indeed, drivers such as environmental awareness, risk aversion, and identification with a community of peers or neighbours might exert a strong influence on the decision to join the community or participate in the programme. Discrete

choice models exploiting stated or revealed preferences and integrating latent variables or latent classes could provide interesting hints as regards the role of the relevant attitudinal drivers or behavioural patterns. This information could be very useful to design projects, supply options, and contracts that elicit the broadest participation. Moreover, a comparison between the preferences and perceptions of households who are already involved in similar projects on the one hand, and households who rely on traditional supply contracts on the other hand, might provide interesting insights into the changes that might occur in consumer preferences, behaviour, and attitudes along with the spreading of these new technologies.

A similar extension could be conceived also for the segment of business consumers. The analysis of their stated or revealed preferences toward new technological options, such as energy communities or demand response programmes, could provide interesting hints for the design of projects and supply options able to attract different consumption profiles. In the case of business consumers, moreover, further research could also explore the strategies to incorporate the decision making processes adopted in different kinds of firms within the choice modelling framework. While the random utility maximization assumption can easily be formally translated into a profit maximization problem, it is indeed less clear to what extent the decision makers within a firm actually stick to this approach, both within a discrete choice experiment, and in their actual choices. Interesting hints could thus come from the study of the different choice heuristics that may arise when business consumers face decisions concerning their electricity supply, as well as from the study of the most suitable strategies to incorporate these different heuristic processes within a discrete choice model. Moreover, the investigation of real case studies could provide detailed insights into the different aspects of the decision making process adopted by business consumers involved into innovative energy projects, and feed or complement the analyses carried out through discrete choice models.